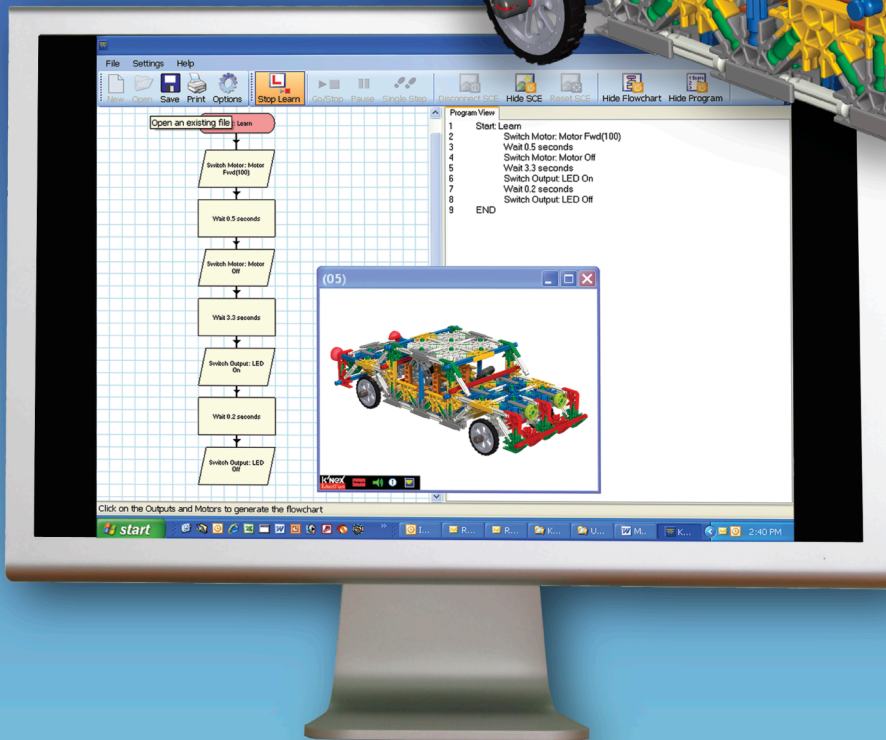
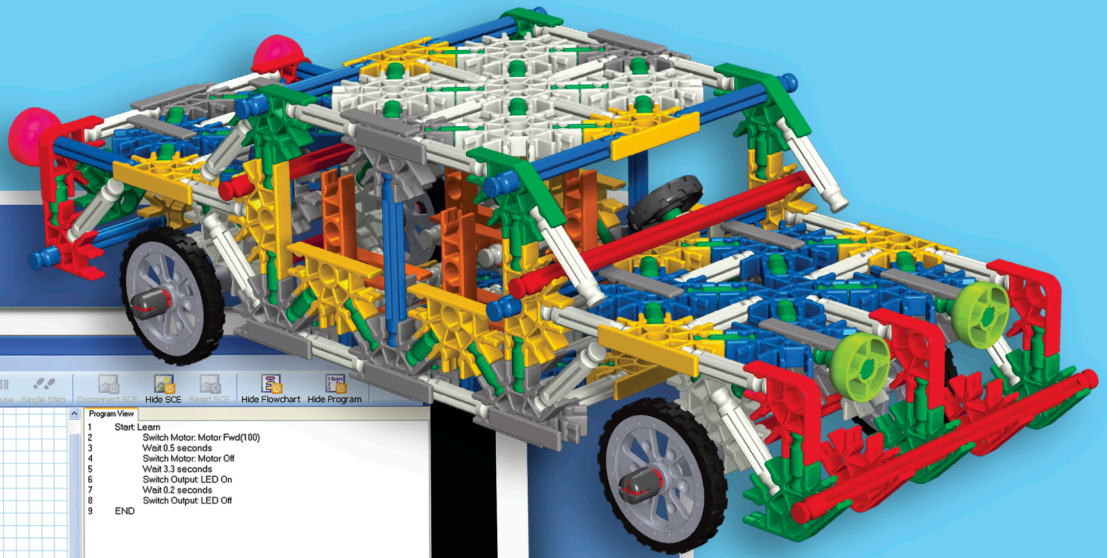




STEM EXPLORATIONS™

Teacher's Guide



79118

10+
AGE

**Author:**

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- Pennsylvania Certification in Industrial Arts/Technology Education, K-12
- Pennsylvania Keystones: Technology Integrator award recipient
- National Board Certification for Career and Technical Education, Early Adolescence through Young Adulthood

Concept List:

- Teamwork and Cooperation Through Hands-On Activities
- Unifying Concepts Using Systems & Models
- Exploratory and Discovery Learning
- Critical Thinking & Problem Solving
- Applied Mechanical Physics
- Design Process/Engineering Design Process
- Computer Control Technology and Logic
- Troubleshooting and Optimization
- Data Presentation and Analysis
- Evaluation and Redesign
- Real World Mathematics
- Invention and Innovation

Web links to standards used:

- Technology Standards www.iteea.org/TAA/Publications/TAA_Publications.html
- Science Standards www.nap.edu/openbook.php?record_id=4962
- NCTM Mathematics Standards www.nctm.org/conferences/default.aspx?id=52
- Common Core State Standards for Mathematics www.corestandards.org/assets/CCSSI_Math%20Standards.pdf



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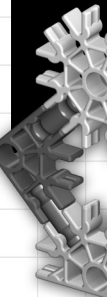
CHOKING HAZARD - Small Parts.
Not for children under 3 years.

A Note About Safety

Safety is of primary concern in science and technology classrooms. It is recommended that you develop a set of rules that governs the safe, proper use of K'NEX in your classroom. Caution students to keep, hands, face, hair and clothing away from all moving parts.

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Introduction:

Set Description

This K'NEX Education computer control set, *STEM Explorations*, and its accompanying ***Teacher's Guide***, have been designed for students to investigate a variety of concepts related to STEM (*Science, Technology, Engineering, and Mathematics*) at the middle school level (grades 5-9). The modules are hands-on, cooperative activities providing stimulating inquiry and problem solving through design. These concepts are fashioned around rigorous content and national standards in Science (NSES), Technology (ITEEA), and Mathematics (NCTM and Common Core State Standards for Mathematics and Education).

In this set, students are given the scenario revolving around a family, *STEM Exploration* road trip with activities planned around various experiences they encounter along the way. They will be constructing basic K'NEX models, developing computer control programs to control the models, and then revising the models and programs to solve more advanced tasks with room for personal creativity and research. There are nine stimulating lessons in this set:

- **Lesson #1: Is The Car Ready?** - Exposes the students to the K'NEX control software and examines basic motor control for speed and time testing.
- **Lesson #2: Cruise Control** - Takes the car model and uses sensors and programming to test the vehicle's self-driving features. Now that the car is ready, it is time for the road trip.
- **Lesson #3: Beginning the Journey** - Looks at leaving the garage and starting the trip. How does a garage door operate? This lesson uses sensors to limit motion for repetitive tasks.
- **Lesson #4: The Highway Ride** - Takes us to the toll booth to examine manual and automatic gate operation and system optimization.
- **Lesson #5: Over the Bridge** - Uses a swing bridge to enhance the programming experience with emphasis on gear ratios, timing and accuracy.
- **Lesson #6: Taking a Spin at the Park** - Puts the students on an amusement park ride where they look at linear and rotational forces.
- **Lesson #7: Pick It Up and Put It Down** - Brings the students past a large crane in their travels where they will accept a challenge to automate the crane for competition.
- **Lesson #8: A Safe Combination** - Brings the students to the concepts used for a digital combination lock. They will also examine boolean logic and logic gates.
- **Lesson #9: A Hockey Game at a Hockey Game** - Ends the series with the students at an arcade. Their challenge will be to make a functional game with timing, sounds and goals.

Computers are used to control many aspects in our everyday lives. From garage door openers to complex security systems, computer programs have been developed to take the place of human control with accuracy and reliability. With the K'NEX Computer Control software, the K'NEX Interface, various input/output devices, motors, and K'NEX Rods & Connectors, the students will experience problem solving in design and automation using programming, construction techniques, and devices to help them understand how to program and operate computer controlled devices.

The K'NEX Education STEM Explorations Set provides nine outstanding K'NEX Models for students to build, control, and explore. K'NEX Education's Computer Control software (included on CD) recreates the control experience for students; right on their computer screen. Computer simulations using images of the very same models the students work with in the classroom make learning easy, high tech, and exciting.

This Teacher's Guide outlines a series of 9 comprehensive lessons that introduce students to computer control technology, writing programs to operate models, and rigorous content in science, technology, engineering, and mathematics. The Teacher's Guide provides guidance to the teacher as you present a comprehensive STEM experience for their students with each and every lesson. After the completion of the instructional components of each lesson the teacher has the option to have students begin their exploration and programming on the computer screen using a Simulated Control Environment (SCE).

There are nine SCEs, one for each of the K'NEX models in the set. The SCEs allow students to control multiple input and output devices as well as motors on a simulation of the K'NEX model right on their computer screens. Just as students can use K'NEX Computer Control Software to operate inputs, outputs and motors on the real K'NEX model, they can click the same buttons on the computer simulation of the Computer Control Interface to make the on-screen devices and images operate. Or, they can click directly on the devices in the simulation to activate the on-screen K'NEX model.

Students will construct the models from full-color building instructions (provided on CD). Construction is not just matching colors with the instructions but an opportunity to watch a three-dimensional model come to life from a two-dimensional design on the computer screen. As students build they will be constructing many systems that will work together in the final model. The construction phase of the lessons also requires students to wire various electronic devices to their models and the K'NEX Interface. Following directions, troubleshooting, and attention to detail will enable students to produce models that will work the first time every time

What is STEM Education?

This K'NEX set is designed to integrate the four areas of STEM education into all learning activities to enhance student interest and comprehension. These four content areas of STEM are as follows:

- **SCIENCE:** Science deals with and seeks the understanding of the natural world. (*National Research Council - NRC*)
- **TECHNOLOGY:** Technology is the modification of the natural world to meet human wants and needs. (*International Technology and Engineering Educator's Association- ITEEA*)
- **ENGINEERING:** Engineering is "the profession in which a knowledge of mathematical and natural sciences gained by study, experience, and practice is applied with judgement to develop ways to utilize economically the materials and forces of nature for the benefit of mankind." (*Accreditation Board for Engineering and Technology- ABET*)
- **MATHEMATICS:** Mathematics is "the science of numbers and their operations, interrelations, combinations, generalizations, and abstractions and of space configurations and their structure, measurement, transformations, and generalizations". (*Webster's Dictionary*)


In order for STEM education to be most successful, all content areas should be taught in an integrated and cross-curricular manner and represent real-world applications. No area should dominate the other.

Reference:

<http://www.iteea.org/Resources/PressRoom/STEMDefinition.pdf>, William E. Dugger, Jr., Professor Emeritus at Virginia Tech and a Senior Fellow of the ITEEA.

Instructional Strategy

This guide follows the 5E instructional model. This teaching strategy begins with an **ENGAGEMENT** wherein the teacher creates interest and elicits responses from the students through interactive demonstrations and discussions. In the second phase, the **EXPLORATION**, students are encouraged to work together in building the K'NEX models and crafting responses to initial questions. Students then **EXPLAIN** the concepts and definitions in their own words. They are subsequently expected to apply the



concepts and skills during the **ELABORATION** segment while using formal labels, definitions and reflective explanations. Students may also be challenged to modify the model to perform a different or enhanced function. In the final phase of the 5E model, the **EVALUATION**, students are expected to further apply the new concepts as they address real life applications and Design Brief Challenges.

Process Skills:

As the students engage in the activities, as outlined in this guide, they will be learning, modeling, and applying integrated process skills. They will be following the basic process of scientific inquiry and engineering design. Students will be given a specific problem, ask questions and conduct research using fair and consistent testing procedures, chart and analyze their data, refine solutions through feedback from their designs, and communicate their results. While these process skills are general for all units, some other specific skills are addressed in individual units.

Keeping a Record of Learning:

The various models in the building instructions were designed to provide a themed approach to learning and to coincide with identical, functioning models on the computer screen. The SCEs for the models provide students with the opportunity to practice writing programs on their computers before they program the real K'NEX models. Upon completion of instructional presentations by the teacher, students will be directed to complete Vocabulary, Exploration, and Challenge Activities to guide their programming and learning as they become critical thinkers and problem solvers. The Teacher's Guide provides written forms for the students to use as they complete the activities or links to editable electronic versions of the Research & Design logs, Student Response Sheets, Design Briefs, Evaluation/Assessment forms and the Cost Per Piece chart can be accessed by the students from the Start Menu, or you can drag and drop the "Worksheets" folder from the software CD onto the desktop or a shared drive. These forms can be used as students work with the actual model, computer and interface or they can be used in conjunction with the SCEs on the computer.

Student Design Journals:

All research projects require accurate data collection and organization. Professionals have used journals throughout history to keep a visual and written record of the design process. The design journal is also a useful tool in helping the students make the connection between the models they create and real world applications. As students work through the units, they will be recording and interpreting their observations, thoughts, data and illustrations, using vocabulary related to the unit. Throughout this guide, you will see reference to a Design Journal. This should be a notebook or folder where students will keep all of their unit material together.

The Design Journal will include the following:

- Research and Design Logs
- Student Response Sheets
- Challenge Design Briefs
- Teamwork and Self-Evaluations
- Computer Program Flow Charts
- Self Reflection/Evaluation Rubrics
- Any additional drawings, sketches and notes created during the design and construction process.

If the students have daily access to a computer in the classroom, consider making a digital design journal. Presentations could then be developed into multimedia presentations for each unit or the entire set. This could add another exciting component to the learning process.

Research and Design Logs:

A **Research and Design Log** should be assigned to each student for every activity. A career research component is also included in the **Research and Design Log**. The log is a good way for students to reflect on their learning and contribution to the group. Drawings and graphs can be completed on graph paper. You will find the **Research and Design Log** (vocabulary terms) in each K'NEX lesson in this guide and on the lesson SCE.

Terms:

The identification and control of variables is a necessary process in any authentic investigation. There may also be some confusion about the terms used to identify the processes of an experiment. Creating and displaying a word wall of terms and definitions can be helpful for the students.

For the purpose of this manual, a **variable** is considered any measurable characteristic or attribute. Any variable that is deliberately changed is referred to as the **independent variable**, (sometimes called the controlled, manipulated, or changed variable) while the variable that will be measured is referred to as the **dependent variable**, (also called the responding, or measured variable). Lastly, any independent variable that is kept the same is referred to as a **constant**.

Student Response Sheets:

The **Student Response Sheets** are specific for each unit and provide a place for the students to record their data and observations. This is where the students are challenged with questions related to their instruction that provoke thought about the model being investigated (Explain) and the concepts involved (Elaborate). Sections of the **Student Response Sheet** are labeled "As a Group" and "On Your Own" to distinguish what portions should be completed as a group and what should be done individually. It is recommended that the teacher reproduce these sheets for the students or direct them to the SCE for the lesson where the forms can also be found.

Challenge Design Briefs:

The **Challenge Design Brief** is designed to extend the students' learning experience beyond the basic activity and to stimulate personal creativity and thought. Allow students to choose from the list or assign specific challenges to be completed. Time constraints and the programming ability of your students may influence how many challenges you expect of your students. There is a print copy of the **Challenge Design Brief** provided in this guide for each lesson and they are also available on the SCE for each lesson.

Team Responsibilities Vs. Individual Tasks:

While collaborative work is encouraged and appropriate in the educational environment, it can become difficult to fairly assess the contributions of all members of the group since some members will become reliant on others. Being able to work cooperatively is a job requirement for most fields today. Also, teamwork is often the best option in a school environment due to the limitations of time and material resources. The problem of fair assessment is often an issue when completing cooperative projects, like the units stressed in this guide.

In order to address the question of fair evaluation, The **Research and Design Log** asks specific questions relating to personal input as well as the **Student Response Sheet** sections "As a Group" and "On Your Own". Guidelines should be in place and presented at the beginning of the unit detailing what is expected of each group member as they work through the unit. Any presentations made by the students should also demonstrate input from all members of the group.



Assessment:

Assessment for each unit can take any form you choose. A list of items that could be considered as part of a student's assessment is included with each lesson in this guide. A general **Self Reflection/Evaluation** rubric and a **Teamwork and Self Evaluation** sheet are provided in print form that you may use to gather valuable information directly from your students. Assessment rubrics and evaluations sheets are provided in the *Resources* section of the guide.

Extension Activities:

While this guide is designed using specific K'NEX models for each unit, it is encouraged that you allow the students to think more creatively if time permits. The software and K'NEX parts allow for limitless creativity.

Web Links in the Lessons:

In many of the lessons, you will find Internet links to useful resources that can help engage the students. Since the Internet is not static, web sites can change overnight. *At the time this document was written, all links were active and relevant.*

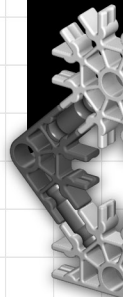
Standards:

The K'NEX STEM Explorations Set is aligned with recommended guidelines from the following:

- NSES Science Content Standards
- ITEEA Standards for Technological Literacy
- NCTM Standards and Expectations
- National Governors Association Center for Best Practices Common Core State Standards for Mathematics

These standard alignments can be found on the following pages.

ITEEA Content Standards Alignments



International Technology & Engineering Educators Association Standards Grades 6-8

Students will develop an understanding of:

THE CHARACTERISTICS AND SCOPE OF TECHNOLOGY

- New products and systems can be developed to solve problems or to help do things that could not be done without the help of technology.
- The development of technology is a human activity and is the result of individual or collective needs and the ability to be creative.
- Technology is closely linked to creativity, which has resulted in innovation.

THE CORE CONCEPTS OF TECHNOLOGY

- Technological systems include input, process, output, and, at times, feedback.
- Systems thinking involves considering how every part relates to others.
- Technological systems can be connected to one another.
- Requirements are the parameters placed on the development of a product or system.
- Different technologies involve different sets of processes.

RELATIONSHIPS AMONG TECHNOLOGIES & THE CONNECTIONS BETWEEN TECHNOLOGY & OTHER FIELDS OF STUDY

- Technological systems often interact with one another.
- Knowledge gained from other fields of study has a direct effect on the development of technological products and systems.

THE CULTURAL, SOCIAL, ECONOMIC, AND POLITICAL EFFECTS OF TECHNOLOGY

- Decisions about the use of products and systems can result in desirable or undesirable consequences.

THE ATTRIBUTES OF DESIGN

- Design is a creative planning process that leads to useful products and systems.
- There is no perfect design.
- Requirements for design are made up of criteria and constraints.

ENGINEERING DESIGN


- Design involves a set of steps, which can be performed in different sequences and repeated as needed.
- Brainstorming is a group problem-solving design process in which each person in the group presents his or her ideas in an open forum.
- Modeling, testing, evaluating, and modifying are used to transform ideas into practical solutions.

THE ROLE OF TROUBLESHOOTING, RESEARCH & DEVELOPMENT, INVENTION & INNOVATION, AND EXPERIMENTATION IN PROBLEM SOLVING

- Invention is the process of turning ideas & imagination into devices and systems. Innovation is the process of modifying an existing product or system to improve it.
- Some technological problems are best solved through experimentation.

THE ABILITIES TO APPLY THE DESIGN PROCESS

- Apply a design process to solve problems in and beyond the laboratory-classroom
- Specify criteria and constraints for the design
- Make two-dimensional and three-dimensional representations of the designed solution.
- Test and evaluate the design in relation to pre-established requirements, such as criteria and constraints, and refine as needed.
- Make a product or system and document the solution.



International Technology & Engineering Educators Association Standards Grades 6-8

Students will develop an understanding of:

THE ABILITY TO USE AND MAINTAIN TECHNOLOGICAL PRODUCTS AND SYSTEMS

- Use computers and calculators in various applications.
- Operate and maintain systems in order to achieve a given purpose.

SELECTION AND USE OF ENERGY AND POWER TECHNOLOGIES

- Energy can be used to do work, using many processes.
- Power systems are used to drive and provide propulsion to other technological products and systems.

SELECTION AND USE OF TRANSPORTATION TECHNOLOGIES

- Transportation vehicles are made up of subsystems, such as structural, propulsion, suspension, guidance, control, and support, that must function together for a system to work effectively.

Used with permission of the ITEEA (www.iteea.org)

NSES Content Standards Alignments

National Science Education Standards Grades 6-8

Students will develop an understanding of:

UNIFYING CONCEPTS AND PROCESSES

- Systems, order, and organization
- Evidence, models, and explanation
- Change, constancy, and measurement
- Form and function

SCIENCE AS INQUIRY

- Abilities necessary to do scientific inquiry
- Understanding about scientific inquiry

PHYSICAL SCIENCE

- Motions and Forces
- Transfer of energy

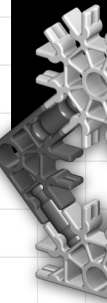
SCIENCE AND TECHNOLOGY

- Abilities of technological design
- Understandings about science and technology

HISTORY AND NATURE OF SCIENCE

- Science as a human endeavor
- Understanding the nature of science

Reprinted with permission from National Science Education Standards, 2001 by the National Academy of Sciences, Courtesy of the National Academies Press, Washington DC.



NCTM Content Standards Alignments

National Council of Teachers of Mathematics Education Standards and Expectations for Grades 6-8

Students will develop an understanding of:

NUMBERS AND OPERATIONS

- Understand numbers, ways of representing numbers, relationships among numbers, and number systems.
- Understand meanings of operations and how they relate to one another.
- Compute fluently and make reasonable estimates.

ALGEBRA

- Understand patterns, relations, and functions.
- Represent and analyze mathematical situations and structures using algebraic symbols.
- Use mathematical models to represent and understand quantitative relationships.
- Analyze change in various contexts.

GEOMETRY

- Specify locations and describe spatial relationships using coordinate geometry and other representational systems.
- Use visualization, spatial reasoning, and geometric modeling to solve problems.

MEASUREMENT

- Understand measurable attributes of objects and the units.
- Apply appropriate techniques.

DATA ANALYSIS AND PROBABILITY

- Formulate questions that can be addressed with data and collect, organize, and display relevant data to answer them.
- Select and use appropriate statistical methods to analyze data.
- Develop and evaluate inferences and predictions that are based on data.

DATA ANALYSIS AND PROBABILITY

- Develop and evaluate inferences and predictions that are based on data.
- Understand and apply basic concepts of probability.

PROCESS

Problem Solving:

- Solve problems that arise in mathematics and in other contexts.
- Apply and adapt a variety of appropriate strategies to solve problems.

Communication:

- Communicate their mathematical thinking coherently and clearly to peers, teachers, and others.
- Use the language of mathematics to express mathematical ideas precisely.

National Council of Teachers of Mathematics Education Standards and Expectations for Grades 6-8

Students will develop an understanding of:

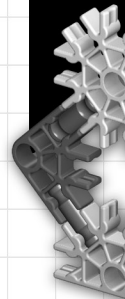
Connections:

- Recognize and apply mathematics in contexts outside mathematics.

Representation:

- Create and use representations to organize, record, and communicate mathematical ideas.
- Select, apply, and translate among mathematical representations to solve problems.

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COMMON CORE STATE STANDARDS - MATHEMATICS ALIGNMENTS

Common Core Mathematics Standards for Grades 6 - 8

Mathematical Practices – Associated with mathematics at all grade levels

- Make sense of problems and persevere in solving them.
- Reason abstractly and quantitatively.
- Construct viable arguments and critique the reasoning of others.
- Model with mathematics.
- Use appropriate tools strategically.
- Attend to precision.
- Look for and make use of structure.
- Look for and express regularity in repeated reasoning.

In Grade 6, instructional time should focus on these critical areas:

- Connecting ratio and rate to whole number multiplication and division and using concepts of ratio and rate to solve problems.
- Writing, interpreting, and using expressions and equations.
- Developing understanding of statistical thinking.

Ratios and Proportional Relationships

- Understand ratio concepts and use ratio reasoning to solve problems.

The Number System

- Compute fluently with multi-digit numbers and find common factors and multiples.

Expressions and Equations

- Apply and extend previous understandings of arithmetic to algebraic expressions.
- Reason about and solve one-variable equations.
- Represent and analyze quantitative relationships between dependent and independent variables.

Statistics and Probability

- Develop understanding of statistical variability.

In Grade 7, instructional time should focus on these critical areas:

- Developing understanding of and applying proportional relationships.
- Developing understanding of operations with rational numbers and working with expressions and linear equations.
- Drawing inferences about populations based on samples.

Ratios and Proportional Relationships

- Analyze proportional relationships and use them to solve real-world and mathematical problems.

STEM Explorations Standards for Mathematics in Grades 6 - 8 (Continued)

The Number System

- Apply and extend previous understandings of operations with fractions to add, subtract, multiply, and divide rational numbers.

Expressions and Equations

- Use properties of operations to generate equivalent expressions.
- Solve real-life and mathematical problems using numerical and algebraic expressions and equations.

In Grade 8, instructional time should focus on these critical areas:

- Grasping the concept of a function and using functions to describe quantitative relationships.

Expressions and Equations

- Analyze and solve linear equations.

Functions

- Define, evaluate, and compare functions.
- Use functions to model relationships between quantities.

Statistics and Probability

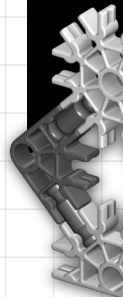
- Investigate patterns of association in bivariate data.

Authors: National Governors Association Center for Best Practices, Council of Chief State School Officers

Title: Common Core State Standards (For Mathematics)

Publisher: National Governors Association Center for Best Practices, Council of Chief State School Officers, Washington D.C.

Copyright Date: 2010



LESSON #1: IS THE CAR READY?

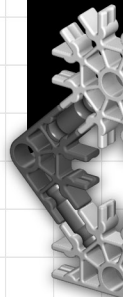
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Main Concepts (STEM):

- **Science**
 - Motion and Energy
- **Technology & Engineering**
 - Power and Propulsion
- **Mathematics**
 - Measurement and Computation

Objectives:	Required Materials:	Optional Materials:
<p><i>Student will be able to:</i></p> <ul style="list-style-type: none"> • Work effectively both independently and in collaborative teams. • Correctly connect and program the K'NEX interface to drive motors and control speed to move the car. • Estimate efficiency of motor output as the percentage of energy to the motors is varied. • Understand and explore the concept of a differential. • Modify their computer programs to control the car for specific purposes. 	<p><i>Teacher will need:</i></p> <ul style="list-style-type: none"> • K'NEX Interface and software • Computer projector and/or whiteboard • Extension cord. <p><i>Students will need:</i></p> <ul style="list-style-type: none"> • K'NEX Interface and components • Computer with K'NEX Computer Control software • K'NEX car model • Metric tape or ruler • Stop watch or clock with a second hand • Masking tape • Printed or Electronic copies of: <ul style="list-style-type: none"> o Research & Design Logs o Student Response Sheets o Challenge Design Briefs o Teamwork & Self-Evaluation forms o Self Reflection/Evaluation Rubrics 	<ul style="list-style-type: none"> • Graph paper • Notebook paper • Colored pencils • Sample K'NEX models (prebuilt car model or similar models to demonstrate motor control and differential operation) • Calculators



TEACHER'S NOTES:

- *This first lesson assumes some introductory work with the K'NEX Interface and programming. For example, the initial Research and Design Log vocabulary page highlights the various blocks the students will use in the flow charts they develop as they write programs. Please review the K'NEX Education STEM Explorations User's Guide for details.*
- *These lessons are developed to guide the students through the learning experience after the model has been built. The construction of the actual initial model for each unit should occur using the interface software, building instruction booklets, and SCEs (Simulated Control Environments). The suggested lesson times do not include the build time, but most models should be able to be constructed by groups in a 45 minute class period.*
- *Students will be asked to construct the model, perform various experiments, chart data, record their thoughts and actions, and develop challenge activities.*
- *Do not assume that all students have experience with K'NEX building materials. You may wish to model construction techniques with the students for practice.*

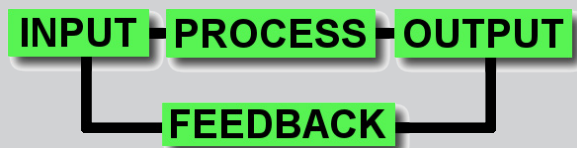
Process

Engagement

1. Introduce the K'NEX "**STEM Explorations**" series to the students and discuss how the lessons will follow a series of experiences that could occur on the "**STEM Explorations**" road trip starting with this one, "**Is the Car Ready?**" where they perform some basic tests to see if their car is ready for the trip. Discuss the meaning of **STEM** and how it will relate to these activities (*details about STEM can be found in the Introduction*). Discuss the process used in the lesson:
 - Students will construct the K'NEX Car model for the lesson and complete the *Engagement* activities,
 - They will be programming their models to run various speed tests and exploring the efficiency of the motors that power the car.
 - They will finish the lesson by completing one or more open-ended challenge activities.
2. Distribute or direct students to the **Research and Design Logs** and **Student Response Sheets** for this unit. Introduce the **Challenge Design Briefs** when the students are ready for the challenge activities and the **Assessment Sheets** at the end of the activity. This will help students focus on the current activities. Links to editable electronic versions of the Research & Design Logs, Student Response Sheets, Design Briefs, Evaluation/Assessment forms and the Cost Per Piece chart can be accessed by the students from the Start Menu, or you can drag and drop the "STEM Explorations Resources" folder from the software CD onto the desktop or a shared drive.
3. Discuss how the **Research and Design Logs** and **Student Response Sheets** will be used.
 - The **Research and Design Log** is a place for students to record their thoughts and actions throughout the entire unit. Page one of the log relates to new vocabulary used in the unit and should be completed at the time the vocabulary is introduced. The second page asks for responses to specific actions and thoughts experienced through the activities. Responses can be completed with each activity or at the end of the unit. It is recommended that students treat this like a journal and record responses immediately, possibly making it a daily writing exercise. By waiting until the end of the unit, it may be difficult to remember everything they experienced for earlier activities. The third page provides the students with a place to sketch anything relevant to the activity that has not been provided elsewhere. They may have sketches of redesigned models, test programs, or data that have not been produced elsewhere. Consider this a space for the groups to brainstorm and record ideas.
 - The Student Response Sheets represent the actual activities to be completed. These sheets can also be printed, copied onto the board, or provided to the students digitally.

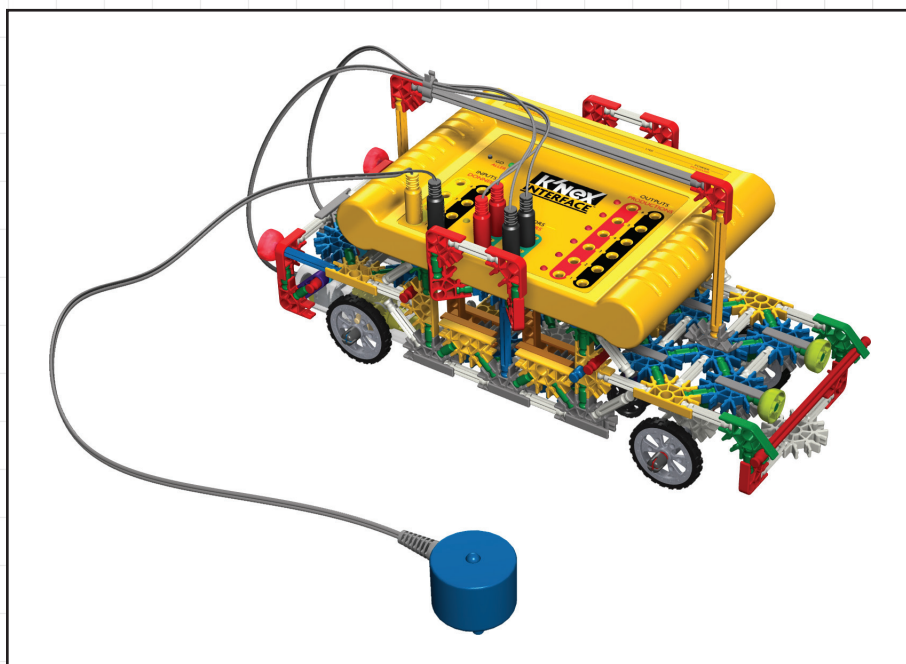
TEACHER'S NOTES:

- This would be a good time to discuss the concepts of energy and force as the capacity for doing work and that the motor output is providing the force to do that work.
- Compare the computer program and design process to the universal systems model **Input-Process-Output-Feedback** loop.



- o **Input** - Resources used by the system. (push button or magnetic switch, start block)
 - o **Process** - The actions necessary to turn the inputs into outputs. The encoding process. (decision and process blocks)
 - o **Output** - The actual results. (motors running, sounds, LEDs on)
 - o **Feedback** - Provides monitoring of the system. (examining results, program self-monitoring through decision blocks)
- Also, begin a basic discussion of the scientific method. More in-depth reference to this will occur in future lessons.
 - Depending on how much time is available and the ability level of your class, you may want to give all or some of the programming to your students. It can be displayed for the students, and then copied into the Student Response Sheets or on graph paper.

9. The easiest way to control the car test is to use a hand-held push button input as shown. Care must be taken to move along with the car so the wire doesn't impede motion.



Here is a sample program that shows a simple one-speed control with a start/stop button. This program requires the students to return to the computer after each speed test to reprogram the motors' speeds. The program on page 21 uses procedures to run all speed tests in sequence.

Component Connections:	
Component:	Location:
Motor 2	Motor B
Motor 1	Motor A
PB Switch	Input 1

The screenshot shows the K'NEX Computer Control Software interface. The main window displays a flowchart for a program titled "1b Car Bumper - Start-Stop.Go - K'NEX Computer Control Software". The flowchart starts with a "Start: Simple Speed Start -> Stop" block. It then enters a loop: a decision diamond "Is Input Push Button On?" leads to a process block "Switch Motor: B Fwd (20), A Fwd(20)" if the answer is "Y". If "N", it loops back to the start of the loop. After the process block, another decision diamond "Is Input Push Button Off?" leads to a process block "Switch Motor: B Off, A Off" if the answer is "Y". If "N", it loops back to the start of the loop. The flowchart ends with a "Stop" block.

The "Text View" pane on the right shows the following code:

```

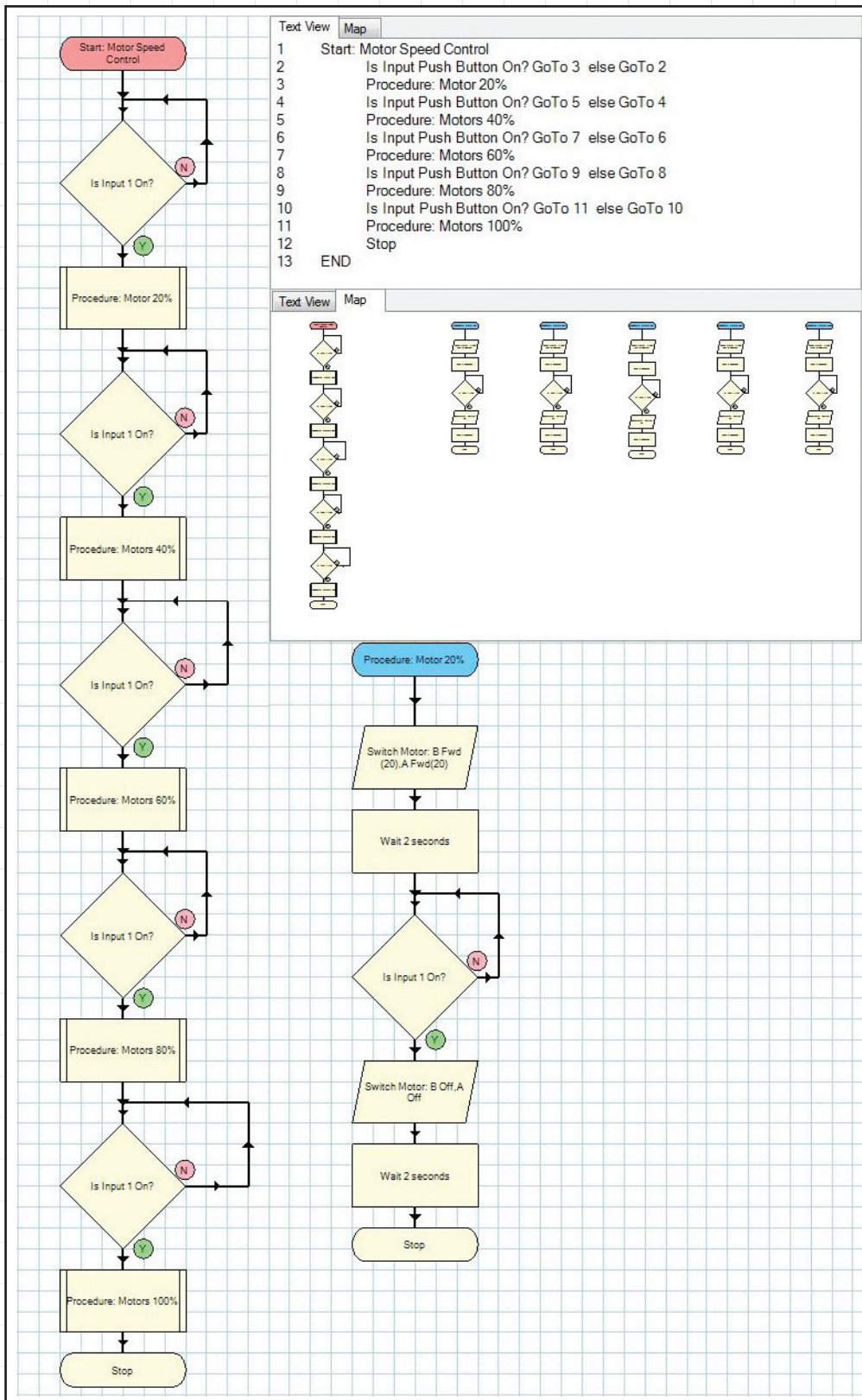
1 Start: Simple Speed Start-Stop
2 Is Input Push Button On? GoTo 3 else GoTo 2
3 Switch Motor: B Fwd(20), A Fwd(20)
4 Is Input Push Button Off? GoTo 5
5 Is Input Push Button On? GoTo 6 else GoTo 5
6 Switch Motor: B Off, A Off
7 GoTo 2
8 END

```

The "I/O Variables" pane at the bottom right shows the following configuration:

Inputs	Outputs	Motors	Sensors
<input type="checkbox"/> 4)	<input type="checkbox"/> 8)	<input type="checkbox"/> 100% ▾ B)	<input type="checkbox"/> 0 <input type="checkbox"/> 4)
<input type="checkbox"/> 3)	<input type="checkbox"/> 7)	<input type="checkbox"/> 100% ▾ A)	<input type="checkbox"/> 0 <input type="checkbox"/> 3)
<input type="checkbox"/> 2)	<input type="checkbox"/> 6)		<input type="checkbox"/> 0 <input type="checkbox"/> 2)
<input checked="" type="checkbox"/> 1) Push Button	<input type="checkbox"/> 5)		<input type="checkbox"/> 0 <input type="checkbox"/> 1)

To insure that the program doesn't skip straight to the "Switch Motor: B Off, A Off" block, add a "Wait 2 seconds" process block to allow time for the student to remove their finger from the button.



This program uses procedures to run all speed tests in sequence. When the program is run, it waits until the push button is pressed, then runs the first procedure (Motors 20%). The procedure then starts the motors at 20%, followed by “Wait 2 seconds” (to allow the student time to remove their finger from the button), runs until the button is pressed again to stop the motors, followed by another wait delay. The program then waits for another button press to run the next procedure (Motors at 40%). After the car is moved back to the start line, the button is pressed to begin the next procedure.

All procedures are the same except for the motor percentage setting. The program will run until all five procedures have been executed.

TEACHER'S NOTES:

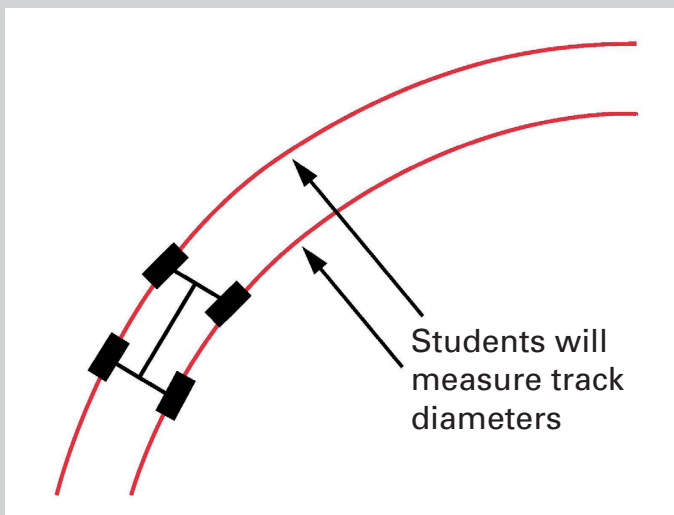
- When the students use this type of program, they will need to run all speed tests, 20%-100%, and record their results, then run them again for the second and third group of times. After all speeds have been run three times, averages can be calculated.
- The front of the vehicle rides on small swivel wheels to reduce friction and allow for turning for later testing. During the testing, the car may not ride straight due to unevenness on the floor, wires pulling off center, or even unmatched motor percentages in the program. Turning should be minimal and not effect testing much, but you could try removing the swivel wheels as a challenge for the students and compare results.

10. After the students have finished the first activity, refer to **Student Response Sheet 2**. This activity relates to questions about how the drive train of a car powers it around a corner. Our K'NEX car uses two motors, one for each drive wheel, while a real car uses one motor to drive both wheels (and all four in the case of four-wheel drive). Students should investigate the problems and solutions to powering around corners, and then review this article.

[How Differentials Work](#)

TEACHER'S NOTES:

- Students may think that a solid axle (both wheels firmly fastened to the axle) is a good idea, but it is not. Several students may have seen this concept on a go-cart, but in cars, it's not used as it will cause excess friction on the tires causing uneven wear, tire slippage on slick surfaces, and poor fuel economy. While the K'NEX car does not have a differential, the motors can be programmed at different percentages to simulate the effect of a differential. In order to reinforce this concept of different tire revolutions and speeds, use the model below:



If you look at the radius of each tire track, you will see they are different. Thus, the outside wheels of the car have to travel a greater distance than the inside wheels. Reinforce this concept with the formula for calculating circle circumference:

Circumference =

$$2 \pi r \text{ (radius)} \quad \text{-or-} \quad \pi d \text{ (diameter)}$$

With different track lengths (circumference), each drive wheel must turn at a different speed.

11. Students will be asked to experiment with different motor speeds to achieve different turning radii. This will provide an extension to their programming knowledge.
12. After students have finished the activity on differentials assign the **Challenge Design Briefs** that will outline several possible challenge activities for you or the students to select from. Time constraints and student interest level may guide the number of challenge activities the students will be required to complete.

Explanation

1. Throughout the activities in this lesson students have been completing **Student Response Sheets**. Allow sufficient time to complete these sheets as they finish each activity so they can demonstrate they are able to explain what they have discovered. Remind students that some sections of the **Student Response Sheets** are to be completed "**As a Group**" while others are to be completed "**On Your Own.**" They should be formulating thoughts, calculations and definitions from their own words.
2. Decide if you want groups to present their results after each *activity or wait until the entire unit is finished* to present their findings. Presentation is an important part of the learning experience since all students may approach these *activities with different thoughts* and ideas. Presentations should include a variety of elements such as descriptions, visual aids and demonstrations.

Elaboration

Students will self-evaluate their challenge solutions based on the criteria provided in the rubric for this activity. Elaboration components are found in the logs and response sheets.

TEACHER'S NOTES:

- Have students complete the **Lesson 1 - "Is the Car Ready?" Self Reflection/Evaluation rubric** so they can self-evaluate their work. The rubric score and your evaluation will make up a portion of the assessment data for this lesson.
- Provide students with a **Teamwork and Self-Evaluation** sheet and review the form with the students before they complete them.

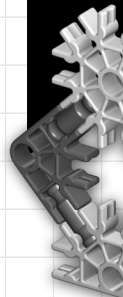
Evaluation

You may use some or all of the following to evaluate student's performance:

- Self Reflection/Evaluation Rubric
- Teamwork and Self Evaluation forms
- Presentation of the Challenge Solution(s)
- Research and Design Logs
- Student Response Sheets
- Design Journal

Extensions

1. After the students have worked through the activities, it is useful to extend the learning through career research and extended activities. Career components have been added to the **Research and Design Logs**, but can be extended by other means such as guest speakers, business tours, etc.
2. Extension activities should be included in any student presentations.





Research and Design Log

Name: _____ Date: _____

Define the following terms below. Be sure to write the definitions in your own words.

Efficiency -

Variable -

Independent Variable -

Dependent Variable -

Constant -

K'NEX Program Start Block -

K'NEX Program Output Block -

K'NEX Program Process Block -

K'NEX Program Decision Block -

K'NEX Program Stop Block -

K'NEX Program Flow Line -



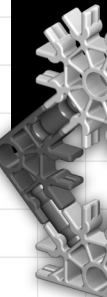
On Your Own

Research and Design Log

Name: _____ Date: _____

Unit: _____ Model: _____

Unit Vocabulary. Be sure to write the definitions in your own words.



Name: _____ Date: _____

Unit: _____ Model: _____

In the space below, list what you have learned through this unit as well as the tasks you have completed. Please be detailed and write in complete sentences.

The following Internet or paper resources were used:

While working through the activity, what problems did you encounter and how were they solved?

What contributions did you make for your own success or the success of the team?

Find a career related to this lesson. Write a brief job description and the education needed.

Name: _____ Date: _____

Speed and Efficiency



As a Group

Explore

- After discussing fuel economy, construct the car model for the lesson. Building instructions are provided on the Building Instruction CD. The car has two drive motors- one for each rear wheel. You will be testing the car to run one meter at each of the following motor speeds: **20%, 40%, 60%, 80% and 100%** to determine if there is a loss or gain in efficiency at each speed.
- There are many ways to program the car to run these trials. **On graph paper**, draw the flow chart for the program you plan to use to control the car, using the symbols below.



Start



Output



Process



Decision

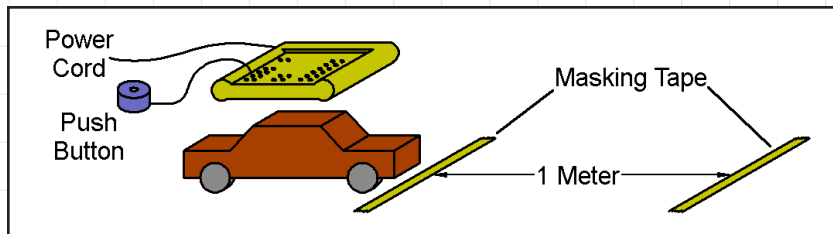


Stop



Flow Line

- Set up your testing area using masking tape to mark a **One Meter** distance for your car to travel. Run your program and, using a stopwatch or watch with a second hand, record the time for each trial *as accurately as possible*. If possible, measure and round time to 1/10th of a second. Run each speed 3 times and record your results below. Calculate the **Average (mean)** time for each motor speed setting.



Observe

	Car Travel Time in Seconds			
Motor %	Test #1	Test #2	Test #3	Average
20%				
40%				
60%				
80%				
100%				

- Graph the motor speed percentages (independent variables) versus the average times (dependent variables) **on a separate sheet of graph paper**.



On Your Own

Elaborate and Explain

- If efficiency doesn't change as motor output is increased 20% each time, the line on your graph would be straight (meaning time is proportional to motor speed). Is your line straight? From the data you collected, what can you determine about the change of motor speed as related to the time it took to travel one meter?

- You have defined some terms relating to **variables** in your *Research and Design Log*. You used two variables and a variety of constants as you completed the experiment above. Identify them in the spaces below.
 - **Independent Variable** - _____
 - **Dependent Variable** - _____
 - **Constants** - _____

- What are some factors that could cause your data to be inaccurate?



As a Group

- Discuss your individual findings as a group and come to a common consensus. What speed or speeds seem to perform the best? Explain the reasons for your answer.

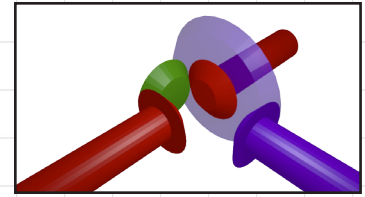
Name: _____

Date: _____



As a Group

Differentials

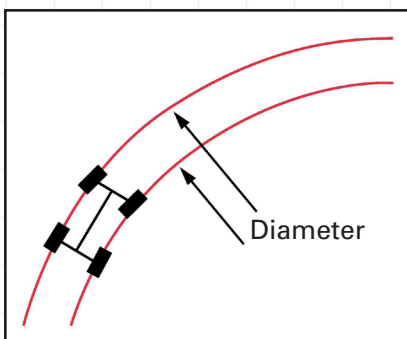


Explore

- This activity relates to questions about how the drive train of a car powers it around a corner. Our K'NEX car uses two motors, one for each drive wheel, while a real car uses one motor to drive both wheels (and all four in the case of four-wheel drive). After reviewing information about drive trains, why wouldn't a solid axle, driving both wheels, work properly?

- In your own words, how does a differential work?

- Program your K'NEX car to turn the tightest possible circle using different motor speed settings. Your car must be able to perform the operation consistently (i.e. minimal slippage with as consistent a loop as possible). **On graph paper**, draw the flow chart for the program you plan to use to control the car, using the programming symbols shown in the previous activity.
- Your car's path will essentially be a circular loop. Measure the diameter of the loop as accurately as possible. A good method to use would be to place a piece of masking tape on the floor at one side of the car's loop and another piece of tape on the floor at the opposite side of the loop. Measure the distance between the two pieces of tape for the **Outer Diameter**. For the **Inner Diameter**, measure the width of the car, double it and subtract this number from the outer diameter. Complete the following:



Use the following formula to determine circumference:

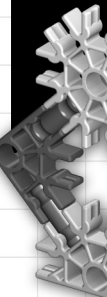
$$\text{Circumference} = \pi \times \text{Diameter}$$

Inner Diameter: _____ cm

Outer Diameter: _____ cm

Inner Circle Circumference: _____ cm

Outer Circle Circumference: _____ cm



- If the K'NEX car wheel has a **diameter** of 4.5 cm, how many times must the wheel turn in order to make it around your circle 1 time? (*Show your work on a separate page.*)

Number of Revolutions for Inner Wheel: _____

Number of Revolutions for Outer Wheel: _____



On Your Own

Elaborate and Explain

- A solid axle on a real car would cause many problems that would negatively impact the performance of the car. What would be some of the negative effects that a solid axle would cause if used?

- How many more revolutions does the outer wheel need to make than the inner wheel?

- How much more distance does the outer wheel need to travel? (*use the circumference formula*)



As a Group

- Discuss your individual findings as a group.

Challenge Design Brief

Lesson #1: Is the Car Ready?

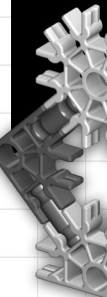
Name: _____ Date: _____



As a Group

Here are several possible design challenges for your group. Use notebook and graph paper to document the activity or activities and fasten them to this sheet.

- Repeat your varying speed test from Student Response Sheet 1. This time, try adding more mass to the car (i.e. box of paperclips, one box at a time or some other small mass object) and see how it affects your time tests. Document your results. *Be careful not to add too much mass and damage the motors. If the motors change sound and seem to strain, stop the test and remove the mass.*
- Remove the swivel wheels so the front wheels touch the ground. Repeat your varying speed test from Student Response Sheet 1. Before you begin, describe how your group thinks the results of the experiment will change after removing the swivel wheels. Document your findings and compare your results with the previous test.
- Redesign the car to only use one motor and remove the swivel wheels so the front wheels touch the ground. Redo your varying speed test from Student Response Sheet 1. Document your finding and compare your results with the previous test.
- Use a ramp one meter long and redo your varying speed test from Student Response Sheet 1 by having the car climb the ramp. Change the angle of the ramp and chart your times for different angles. How does angle affect your results? Document your finding and compare your results with the previous test.
- Reverse the direction of your motors (flip the wires on the control unit) and redo your varying speed test from Student Response Sheet 1. Does changing the car from rear wheel drive to front wheel drive make a difference? Document your finding and compare your results with the previous test.
- Using varying motor speeds and wait process blocks, design a car that can automatically parallel park, turn a perfect figure eight, run an obstacle course, or back up and turn around to go in a different direction. Chart your programs on graph paper and record your results.



Self Reflection/Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____

Complete the Activity Assessment Rubric to provide your impression of how you did with this lesson.

Assessment Rubric			
<i>Circle Responses for each:</i>	Excellent	Good	Acceptable
Research and Design Logs & Worksheets	<p>Student Response Sheets and Design Logs complete with no spelling or grammar errors. All answers on Student Response Sheets are accurate.</p> <p><input type="text"/> 1-10</p>	<p>Student Response Sheets and Design Logs complete with few spelling or grammar errors. Most answers on Student Response Sheets are accurate.</p> <p><input type="text"/> 1-8</p>	<p>Student Response Sheets and Design Logs complete with many spelling or grammar errors. Few answers on Student Response Sheets are accurate.</p> <p><input type="text"/> 1-6</p>
Design & Construction	<p>Your device is very neatly constructed, easy to use, and meets or exceeds expectations outlined in the Design Brief.</p> <p><input type="text"/> 1-10</p>	<p>Your device is neatly constructed, easy to use, and meets expectations outlined in the Design Brief</p> <p><input type="text"/> 1-8</p>	<p>Your device has been constructed, is in useable form, and meets the materials criteria listed in the Design Brief.</p> <p><input type="text"/> 1-6</p>
Design Journals & Presentations	<p>Your Design Journal is complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. It is presented in a neat and orderly fashion.</p> <p><input type="text"/> 1-10</p>	<p>Your Design Journal is mostly complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows some disorder.</p> <p><input type="text"/> 1-8</p>	<p>Your Design Journal is missing 1 or more logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows disorganization.</p> <p><input type="text"/> 1-6</p>
Teamwork/Work Ethic	<p>You worked well with your teammates and interacted well with others. You demonstrated excellent reliability and initiative when working on this challenge.</p> <p><input type="text"/> 1-5</p>	<p>You worked well with your teammates and interacted well with others. You were reliable and demonstrated initiative when working on this challenge.</p> <p><input type="text"/> 1-3</p>	<p>You worked well with your teammates and others. You were generally reliability and usually demonstrated initiative when working on this challenge.</p> <p><input type="text"/> 1</p>
Total Score	<p><input type="text"/> /35</p>		

Teacher Comments:

Teamwork & Self Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____



As a Group

Teamwork and cooperation are necessary skills required for most jobs since businesses typically have many employees that work together in teams rather than lots of individuals working alone. All employees need to contribute equally, using their skill sets to make a project successful while meeting deadlines. If one person fails to contribute adequately, the business or project can fail.

- **Communication Skills:** How well did your group communicate? How could communications within your group be improved?

- **Work Load:** How was work assigned in your group? Did individuals step up to accept responsibility? Were personal skills considered as work was assigned? For larger groups, is it beneficial to assign someone as a leader?

- **Presentation:** How was the unit presentation developed? How did the group determine responsibilities so no one was left out? What improvements could be made for future presentations?



On Your Own

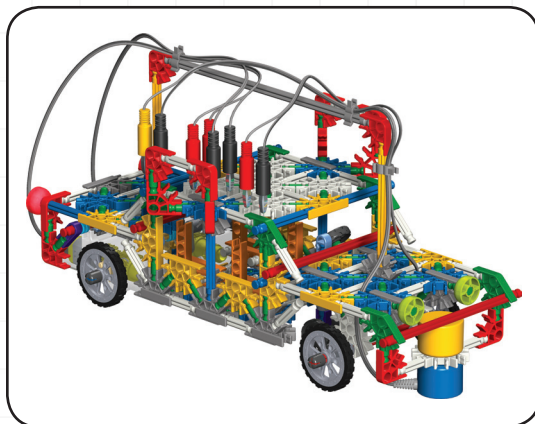
- **Personal Input:** Do you feel you contributed equally with your group? Did you do too much or not enough? Personal contributions to the group are listed in the *Research and Design Log*, but what could you do to work better in a team?

LESSON #2: CRUISE CONTROL - KEEPING YOUR CAR SAFE

4-6x



Model: K'NEX Car



Main Concepts (STEM):

- **Science**
 - Electrical Energy & Power
- **Technology & Engineering**
 - Engineering Design & Mechanical Systems
- **Mathematics**
 - Measurement and Computation

Objectives:	Required Materials:	Optional Materials:
<p>Student will be able to:</p> <ul style="list-style-type: none"> • Work effectively both independently and in collaborative teams. • Correctly connect and program the K'NEX interface to use input switches to drive motors and control the car's path. • Recognize and diagram the parts of a basic electrical circuit. • Define electrical quantities (power, voltage, current and resistance). • Modify their computer programs to control the car for specific purposes. 	<p>Teacher will need:</p> <ul style="list-style-type: none"> • K'NEX Interface and software • Computer projector and/or whiteboard • Extension cord (if power is not close to testing area) • Testing areas: <ul style="list-style-type: none"> o Large tabletop with smooth edge o Surface area with obstacles (books, boxes, walls) for collision tests <p>Students will need:</p> <ul style="list-style-type: none"> • K'NEX Interface and components • Computer with K'NEX Computer Control software • K'NEX car model • Copies of: <ul style="list-style-type: none"> o Research & Design Logs o Student Response Sheets o Challenge Design Briefs o Teamwork & Self-Evaluation forms o Self Reflection/Evaluation Rubrics 	<ul style="list-style-type: none"> • Graph paper • Notebook paper • Colored pencils • Sample K'NEX models (prebuilt car model or similar models to demonstrate push button inputs and buzzer output operations) • Calculators

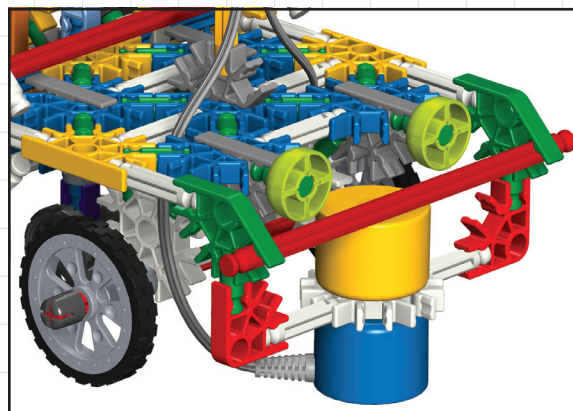
TEACHER'S NOTES:

- Students will use the building instructions, provided on the Building Instruction CD, to make alterations to their car and add a push button switch and buzzer. After the students modify their car, begin the engagement portion of the lesson. Lesson 2 should take 4-6 class periods, depending on how challenge activities are assigned.
- As with lesson 1, students will be asked to construct the model, perform various experiments, chart data, record their thoughts and actions, and develop challenge activities.

Process**Engagement**

1. Keeping in line with the *STEM Exploration* vacation road trip, discuss how the students will be completing several additional tests on their vehicle before they begin their trip. This lesson will guide them as they examine automated systems designed for comfort and safety. While it would be difficult to simulate an actual cruise control system, the students will be creating several automated systems that demonstrate similar principles. Discuss the processes used in the lesson with the students:

- Students will construct the K'NEX tabletop car model for the lesson and complete the *Engagement* activities. This car model consists of a simple modification of the car used in lesson 1. Students will add a buzzer and push button switch to the front of the vehicle. The switch rides in contact with the test surface while the buzzer is mounted directly above it.
- They will be programming their models to run various tests where the vehicle must stay on a tabletop and also respond when the car is run into objects using bumper switches.
- Students will also examine the fundamentals of basic electrical circuits.
- They will finish the lesson by completing one or more open-ended challenge activities.



2. Distribute or direct students to the **Research and Design Logs** and **Student Response Sheets** for this unit. Introduce the **Challenge Design Briefs** when the students are ready for the challenge activities and the **Assessment Sheets** at the end of the activity. This will help students focus on the current activities. These pages are provided at the end of each lesson or in the **Resources** section of the Teacher's Guide. Links to editable electronic versions of the Research & Design Logs, Student Response Sheets, Design Briefs, Evaluation/Assessment forms and the Cost Per Piece chart can be accessed by the students from the Start Menu, or you can drag and drop the "STEM Explorations Resources" folder from the software CD onto the desktop or a shared drive.
3. Discuss that the Research and Design Logs and Student Response Sheets will be used in the same manner as lesson 1.

4. Lesson 2 will examine automated systems that can be used for convenience and car safety. Ask the students the following questions:

- How does a *cruise control system* work on a car?
- Why is it a helpful system?
- What are some of the safety concerns involved with using such a system?

Students may be unfamiliar with cruise control systems. Encourage class discussion or research during this process. Some obvious answers could include:

- Less driver fatigue on long trips.
- Maintain a consistent speed.
- Help fuel economy.
- Safety concerns could include loss of attention, causing failure to brake or stop in time.

5. Students should read an article about cruise control.

[How Cruise Control Systems Work](#)

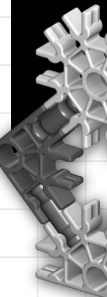
Discuss the results of their research.

Exploration

1. Establish student teams (2-3 students per group), and then review the activity and **Student Response Sheet 1**. Allow students time to discuss the activity in their groups.
2. Students should understand the safe operation of the K'NEX interface and electrical concerns. Review the STEM Explorations *User's Guide* for details.
3. The students should construct the tabletop car model for lesson 2.
4. Review the activity and **Student Response Sheet 1** with the class. Discuss how this activity will allow the students to incorporate more programming features into their models by using the push button switch as an automated *input* device and adding an additional *output* device (buzzer). You may wish to demonstrate how the buzzer will operate.
5. Instruct the students to complete **Student Response Sheet 1**. In this activity, they will program their car model to drive to the edge of a table, stop and sound the buzzer, back up and turn in a different direction, and then drive forward again.
6. Depending on available time and student ability level, you may wish to provide students with a flow chart of the first steps of their program to get them started. Students can create a simple, single flow chart program or a more complex one using procedures. Since they learned how to turn the car in the first lesson using different motor speeds and *Wait* process blocks, the only new component added to this test is the buzzer output. The students will need to develop and diagram the program they will use for the test.

TEACHER'S NOTES:

- *The testing surface should be a large table with plenty of room for the car to maneuver around. The surface needs a smooth edge for the push button switch to ride over, and not get caught on the edge while the car reverses.*
- *Students should be ready to catch the car if it does not stop at the edge due to programming or mechanical errors.*



Here are 2 sample programs that could be used:

Text View Map

```

1    Start: Simple Ledge Control
2    Is Input 1 On? GoTo 3 else GoTo 2
3    Switch Motor: B Fwd(70),A Fwd(70)
4    Is Input 1 Off? GoTo 5 else GoTo 4
5    Switch Motor: B Off,A Off
6    Switch Output: 1 On
7    Wait 1 seconds
8    Switch Output: 1 Off
9    Switch Motor: B Rev(70),A Rev(70)
10   Wait 3 seconds
11   Switch Motor: B Rev(70),A Fwd(70)
12   Wait 4 seconds
13   Switch Motor: B Off,A Off
14   GoTo 2
15   END
                
```

I/O Variables

Inputs	Outputs	Motors	Sensors
<input type="checkbox"/> 8)	<input type="checkbox"/> 6)	<input type="checkbox"/> 100% ▾ B) Motor 2 ...	<input type="text" value="0"/> 4)
<input type="checkbox"/> 7)	<input type="checkbox"/> 5)	<input type="checkbox"/> 100% ▾ A) Motor 1 ...	<input type="text" value="0"/> 3)
<input type="checkbox"/> 6)	<input type="checkbox"/> 4)		<input type="text" value="0"/> 2)
<input type="checkbox"/> 5)	<input type="checkbox"/> 3)		<input type="text" value="0"/> 1)
<input type="checkbox"/> 4)	<input type="checkbox"/> 2)		
<input type="checkbox"/> 3)	<input type="checkbox"/> 1) Buzzer		
<input type="checkbox"/> 2)			
<input checked="" type="checkbox"/> 1) Push Button			

Component Connections:

Component:	Location:
Motor 2	Motor B
Motor 1	Motor A
PB Switch	Input 1
Buzzer	Output 1

The sample tabletop program does not use any *Procedure* blocks and will allow the car to run over an edge of the table one time.

888-ABC-KNEX

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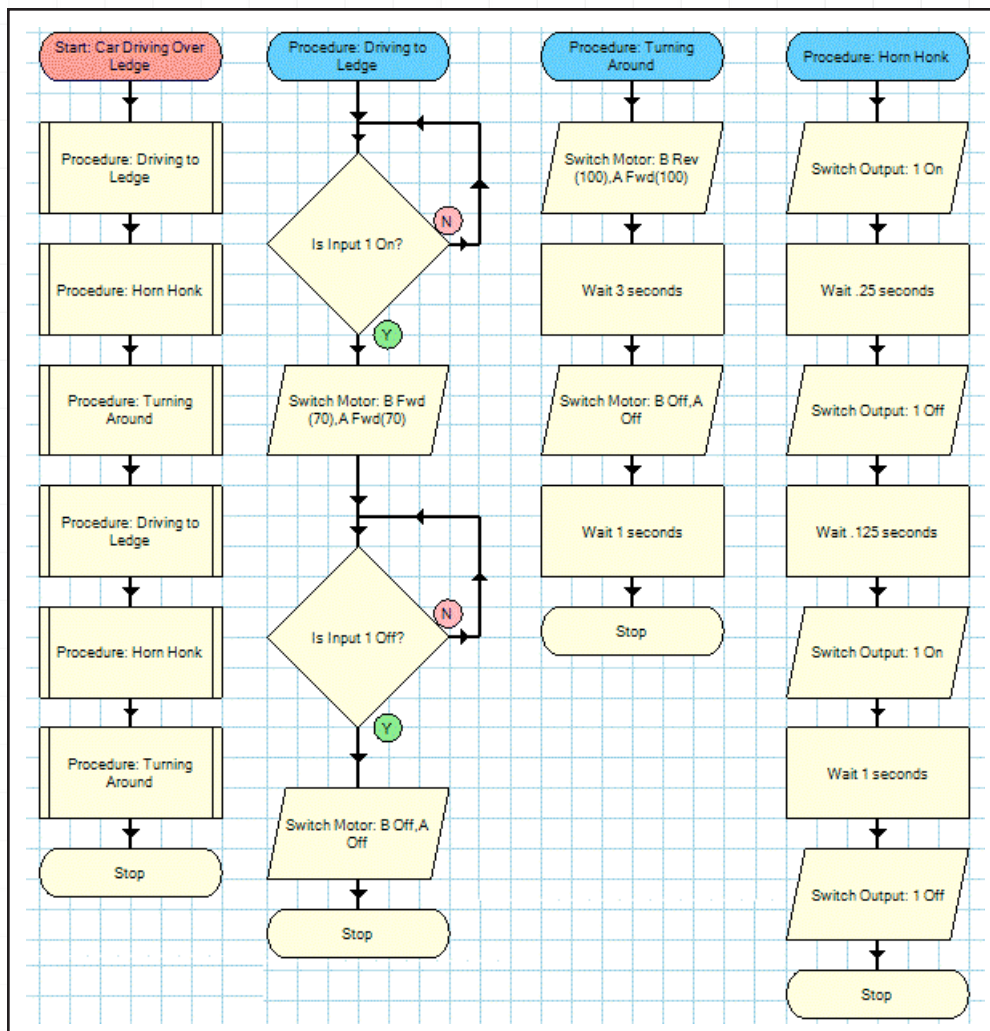
Since the push button switch is closed when the car is resting on the table, the first decision asks if the switch is on. While the switch is on, the car moves forward with both motors set to an equal speed. When the car approaches the edge of the table and the push button switch opens, the motors switch off, and the buzzer turns on (Output1) for one second. After the buzzer turns off, the motors reverse their direction for three seconds, and then turn opposite directions for four seconds. Finally, the car will run forward for two seconds and stop.

When students are ready to begin programming you may have them talk through (or write down) the steps they will need to include in their program. This would not be the formal listing of the steps that they do on graph paper, but rather an informal walkthrough where they begin to organize their programming strategy. This process may help them as they organize their thoughts before they begin programming.

TEACHER'S NOTES:

If you will require the students to turn the car a specific angle (i.e. 90 degrees, 180 degrees) after backing away from the edge, this can be controlled by the number of seconds in the Wait blocks.

This program uses procedures to execute the various steps of the program. While all of the operations are basically similar to those used in the previous flow chart, this program shows a cleaner way to develop the program as each operation is defined in its own procedure. This makes development easier to follow. Again, due to available time and student ability, you may decide which program style will work best.



7. After the students have had sufficient time to test their car and respond to the questions related to the activity on their *Student Response Sheets*, review the vocabulary terms found on the **Research and Design Log**. Definitions are found in these notes and in the *Answer Key*. This vocabulary relates to the second part of the activity where they will be examining some basic electrical properties used in these lessons.
8. Review **Student Response Sheet 2** with the class. Tell the students that they will be examining some fundamentals about electricity and electrical circuits. Since they are building electrical circuits as they program their K'NEX models, it is important to understand some of the principles involved. Explain that there will also be an opportunity to link some of this lesson's information back to the speed tests performed in lesson 1.
9. Review the principles of electricity. If it is assumed that the students have had some previous exposure to the structure of the atom (electrons, protons and neutrons), they should be able to understand the principle of electron flow in a circuit, where outer valence electrons can be released, causing a chain reaction. This discussion can be basic or elaborate depending on available time and the ability level of your students. Some useful web links that can be used with the students are listed below:

[What are amps, watts, volts, and ohms?](#)

[How does electricity work? - 1](#)

[How does electricity work? - 2](#)

TEACHER'S NOTES:

Even though we are working with the low voltage K'NEX Interface where electrical hazards are minimal, electrical safety concerns should be discussed with the students.

Some of these basic rules are:

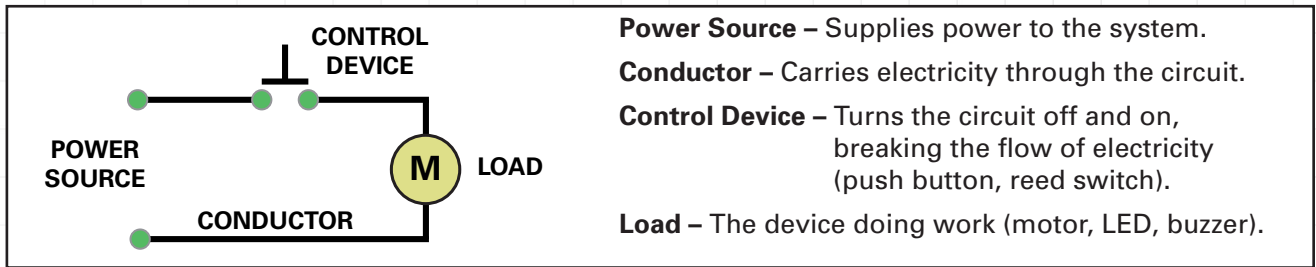
- *Always have adult supervision.*
- *Always make sure the power is off before working on any electrical device.*
- *Never experiment with electricity from a wall outlet. There is a high risk for serious injury!*

10. Discuss the difference between a **conductor** (*materials with low resistance that allow electricity to flow easily*) and an **insulator** (*materials with high resistance and limit electrical flow*). Ask the students to name some materials they think are conductors and some they think are insulators.
11. Discuss the quantities of electricity and their units with the students:
 - **Resistance (R)** – The opposition to the flow of electricity. Measured in **Ohms (Ω)**.
 - **Voltage (V or E)** – The “pressure” under which electricity flows. Measured in **Volts**.
 - **Current (I)** – The “amount” of electricity. Measured in Amperes or **Amps**.
 - **Power (P)** – The rate of electrical energy being converted into work. Measured in **Watts**.

TEACHER'S NOTES:

This could be a good place to use the example of a fire hose to describe electrical quantities. Think of the water pressure in the hose as the voltage (volts) with the amount of water streaming out of the hose as the current (amps). The hose diameter could represent resistance (ohms) in the system. A fire hose and a garden hose could have the same pressure, but because of the larger diameter of the fire hose (less resistance), it will deliver more water than the garden hose. Unlike water, we do not see electric flowing, unless we see a spark jump a void, as with static electricity or lightning.

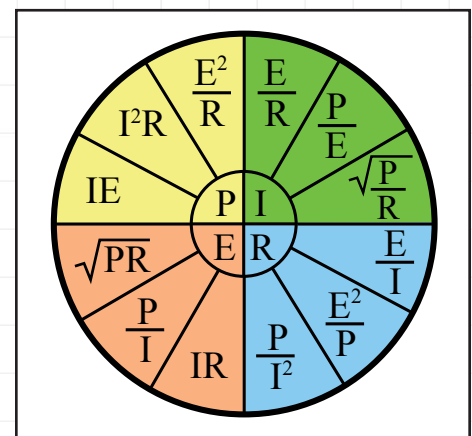
- Ask the students where they may see some of these electrical quantities listed on devices and why it is important to provide this information.
- Discuss the parts of a basic electrical circuit and how they relate to the K'NEX models.



- Discuss how we can calculate various electrical quantities using simple formulas, remembering the symbols and units we use for each.

- Power (P)** – expressed as Watts
- Current (I)** – expressed as Amps
- Resistance (R)** – expressed as Ohms (Ω)
- Voltage (E)** – expressed as Volts

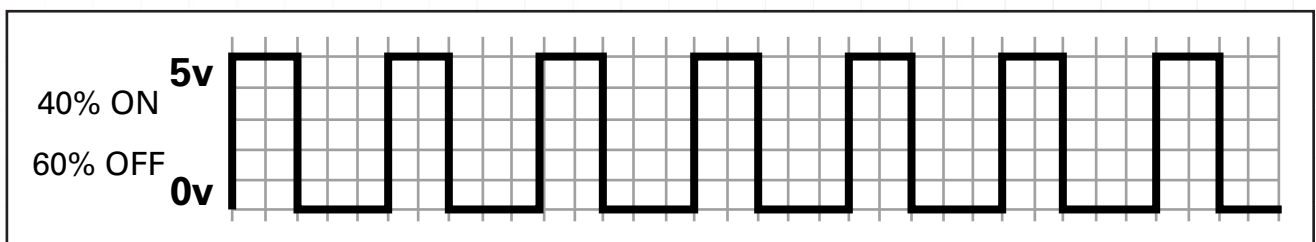
As long as we have 2 quantities, we can solve for any other one. The formula chart to the right supplies you with the correct formula needed to find each quantity. For example, if you are trying to find the wattage (P) used by a circuit and you have the voltage (E) and amperage (I) measurements, you would use the formula: $P = I \times E$. If you were supplied with the voltage (E) and Resistance (R) of a circuit and needed to find current (I), by looking at the chart you would use the formula $I = E/R$.



- In order to apply these concepts to the K'NEX Interface, you will need to determine some electrical measurements. If the K'NEX interface delivered voltage and current to the motor as an *analog* device, it would mean that the voltage would be less for lower motor speed percentages and higher for greater motor speed percentages (similar to using one or more cells, like AA cells, in series to add their voltages together) .

The K'NEX interface is a digital device, meaning that the motor voltage does not change, but is turned on and off in a rapid pulse to control motor speed. This is called *Pulse Width Modulation (PWM)*.

For example, if the motor speed is set to 40%, it means that the motor is turned on 40% of the time, and then turned off for 60% of the time. So that the pulse is not noticed, it is turned on and off 62,000 times per second (62KHz). If the "on" voltage was 5 volts at a motor speed of 40% and graphed on paper, it would look something like the example below:



If graphed, the voltage would jump from 0 volts up to 5 volts and stay on for 40% of the cycle. It would then jump back down to 0 volts for 60% of the cycle. With this occurring so rapidly it would appear that the voltage has been reduced, slowing the motor even though the voltage is only 0 volts or 5 volts. The students will be asked to graph various percentages on the response sheet. In order to use the electrical calculations discussed in step 13, we would need to know what the voltage output is at 100% and how much current is drawn by the motor. Use these measurements for the K'NEX motor at 100% motor speed:

Motor readings at 100%:
5.273 volts
0.270 amps

In order to calculate the current and voltage at lower motor speed percentages, use the following formula:

Voltage or current x percentage

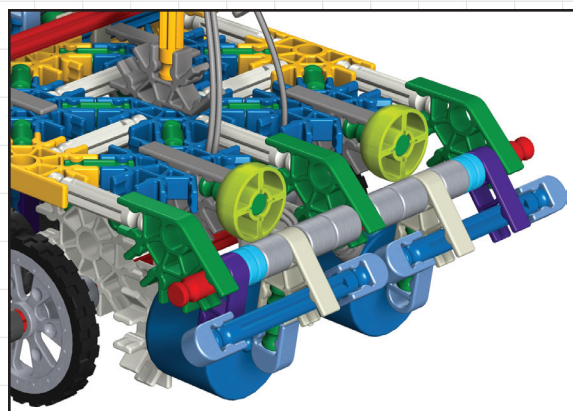
By using the above calculation, you can obtain a simulated voltage or current at various percentages. These numbers can then be used to calculate other electrical quantities. See the example below:

Voltage at 40%
5.273 volts x .40 = 2.109 volts

Current at 40%
0.270 amps x .40 = 0.108 amps

The students will be asked to calculate electrical quantities for their model. Provide them with the voltage and current amounts for 100%.

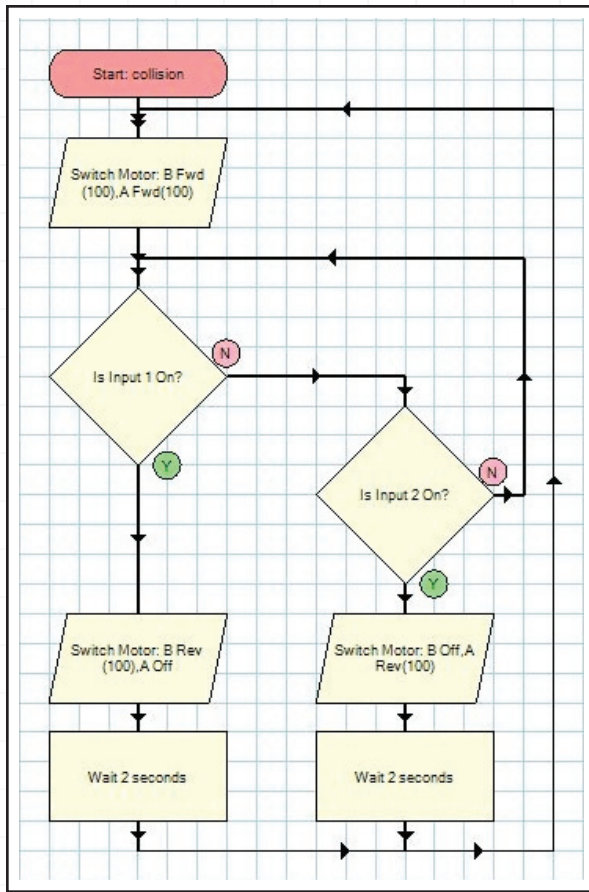
16. After the students have had sufficient time to respond to the questions related to the activity on their *Student Response Sheets* and *Research and Design Logs*, begin the activity on **Student Response Sheet 3**. In this activity, the students will modify their car to use bumper switches to respond to running into objects. The car uses a spit bumper design and two push button switches to determine left and right collision so it can turn correctly.



17. As with every previous exercise, you will need to determine how the students will develop their programs to run the car. This exercise introduces a new problem to the challenge by using two input switches. Here are two sample programs that could be used, but remember that the problem is very open-ended.

Component Connections:

Component:	Location:
Motor 2	Motor B
Motor 1	Motor A
PB Switch	Input 2
Buzzer	Input 1



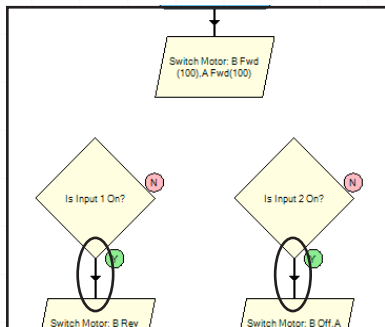
This program uses one procedure to determine collision and the procedure is executed five times before the program terminates.

The motors are switched on and move the car forward. The state of both switches is checked for collision (on). If a switch is triggered, one motor switches off while the other is reversed for 2 seconds, moving the car from the collision state. If a collision occurs for the other switch, the motor output states are programmed in the opposite directions.

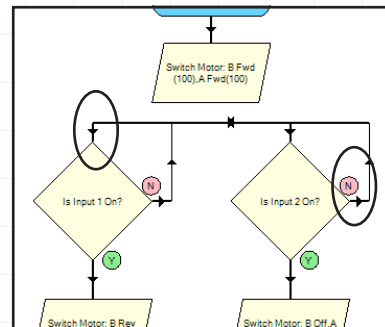
This program is easier to develop but may not always remove the car from the obstacle.

TEACHER'S NOTES:

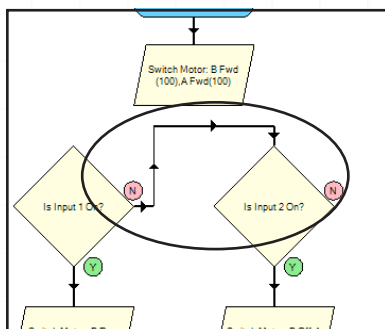
The students may have a problem connecting the two decision blocks to the motor output block because the Flow Lines will only connect from one point. See a solution to this problem below:



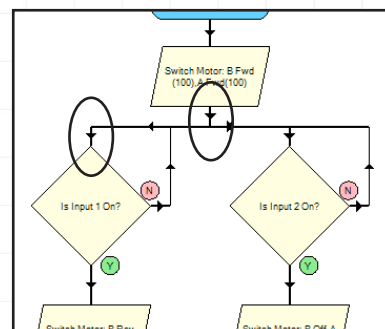
Draw the Flow Lines from the "Yes" bottom connections to the Motor Output blocks.



Draw another Flow Line from the other Decision block's "No" feedback connection to the top of the other Decision block.



Draw a Flow Line from the "No" feedback connection of one Decision block to the top connection of the second Decision block.

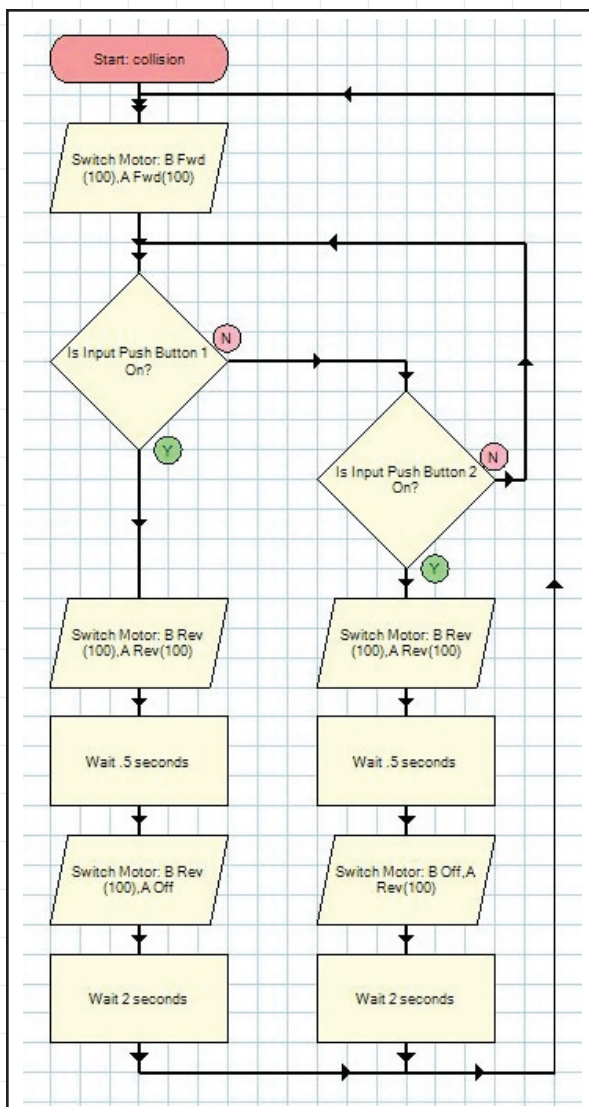


Finally, connect the bottom of the Motor Output block to the left Decision block with a Flow Line.

```

Text View  Map
1  Procedure: collision
2      Switch Motor: B Fwd(100),A Fwd(100)
3      Is Input 1 On? GoTo 4 else GoTo 7
4      Switch Motor: B Rev(100) A Off
5      Wait 2 seconds
6      Stop
7      Is Input 2 On? GoTo 8 else GoTo 3
8      Switch Motor: B Off,A Rev(100)
9      Wait 2 seconds
10     Stop
11     END
    
```

These connections can also be confirmed in the Text View window:



This program operates similar to the first one shown, except it adds some additional maneuvering steps to the procedure. It uses the same connections as well. These steps are added to allow the car to back up before it changes direction.

This procedure is executed four times before the program terminates.

TEACHER'S NOTES:

What happens if both bumper switches are triggered at the same time?

While it is highly unlikely that both switches would send a signal to the program at the same time, there is a possibility that it could happen and cause an output error. Since the program can respond to signal inputs in terms of milliseconds, K'NEX testing of these programs never displayed an error.

18. After students have finished the collision activity, assign the **Challenge Design Briefs** that will outline several possible challenge activities for you or the students to select from. One activity provides the students with an opportunity to calculate the cost of the model. The Cost Per Piece Chart can be found in the Resources section of this guide or in the Student Response Sheet tab of the SCE. You will need to provide pricing for each part. It is recommended that you select dollar amounts for the pieces that do not include cents. You may suggest to students that they can design a simple spreadsheet to calculate the model cost.



Explanation

1. Throughout the activities in this lesson students have been completing **Student Response Sheets**. Allow sufficient time to complete these sheets as they finish each activity so they can demonstrate they are able to explain what they have discovered. Remind students that some sections of the **Student Response Sheets** are to be completed **“As a Group”** while others are to be completed **“On Your Own.”** They should be formulating thoughts, calculations and definitions from their own words.
2. Decide if you want groups to present their results after each *activity* or *wait until the entire unit is finished* to present their findings. Presentation is an important part of the learning experience since all students may approach these *activities with different thoughts* and ideas. Presentations should include a variety of elements such as descriptions, visual aids and demonstrations.

Elaboration

Students will self-evaluate their challenge solutions based on the criteria provided in the rubric for this activity. Elaboration components are found in the logs and response sheets.

TEACHER’S NOTES:

- Have students complete the **Lesson 2 - “Cruise Control” Self Reflection/Evaluation rubric** so they can self-evaluate their work. The rubric score and your evaluation will make up a portion of the assessment data for this lesson.
- Provide students with a **Teamwork and Self-Evaluation** sheet and review the form with the students before they complete them.

Evaluation

You may use some or all of the following to evaluate student’s performance:

- Self Reflection/Evaluation Rubric
- Teamwork and Self Evaluation forms
- Presentation of the Challenge Solution(s)
- Research and Design Logs
- Student Response Sheets
- Design Journal

Extensions

1. After the students have worked through the activities, it is useful to extend the learning through career research and extended activities. Career components have been added to the **Research and Design Logs**, but can be extended by other means such as guest speakers, business tours, etc.
2. Extension activities should be included in any student presentations.



Research and Design Log

Name: _____ Date: _____

Define the following terms below. Be sure to write the definitions in your own words.

Conductor -

Insulator -

Resistance -

Voltage -

Current -

Power -

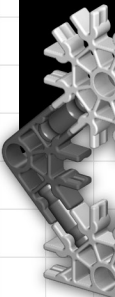
Ampere -

Ohm -

Watt -

Load -

Pulse Width Modulation (PWM) -



Name: _____ Date: _____

Cruise Control: Avoiding Pot Holes and Cliffs



As a Group

Explore

- After discussing how cruise control systems work, construct the car model for the lesson. The car has two drive motors, a buzzer, and a push button switch. Create a program that will stop the car when it arrives at a drop-off (i.e., edge of a table), sounds the horn (buzzer), backs up, and then turns in another direction.
- There are many ways to program the car to run this trial. **On graph paper**, draw the flow chart for the program you plan to use to control the car.
- Set up your testing area. Make sure your surface is large enough for your car to maneuver around on without falling off the edge or tangling wires. **Someone should always be ready to catch the car in case the program has errors or there are mechanical malfunctions.**

Observe

- How did your program perform? Did you need to revise anything?



On Your Own

Elaborate and Explain

- What was the biggest challenge with this activity?

- How could this activity be improved? Explain your answer.

Name: _____ Date: _____

Electrical Circuits and Quantities



As a Group

Explore

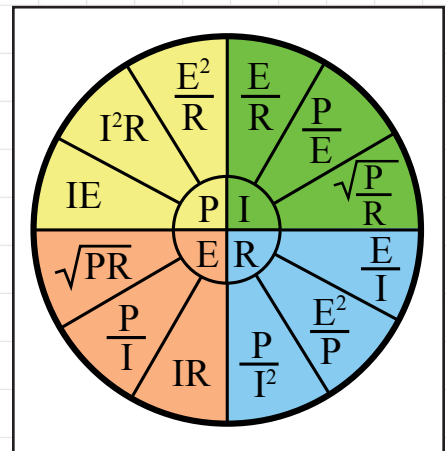
- After reviewing the introduction to electricity, examine your K'NEX car model. There are several electrical circuits working together to make the system operate and all serve a function (*Power Source, Control Device, Conductor, and Load*). List at least four electrical devices used by your car and what function they fall under.
 - o **Power Source** -
 - o **Control Device** -
 - o **Conductor** -
 - o **Load** -

- Your instructor has provided some electrical voltage and current readings for a motor speed of 100%. Using the formula chart and percentage calculations below, calculate the voltage, current, resistance and power for each speed. *Use notebook paper if you need more space.*

Voltage or current x percentage

(for calculations, 20% = .20; 40% = .40; etc)

Motor Speed	Voltage (E)	Current (I)	Resistance (R)	Power (P)
20%				
40%				
60%				
80%				
100%	5.27 volts	0.27 amps		





On Your Own

Observe

- During your lesson discussion, you talked about Pulse Width Modulation (PWM) and how the voltage for the motor is turned on for a percentage of the cycle and turned off for a percentage of the cycle. **On graph paper**, draw the pulse width waveform for each of your tested percentages (20%, 40%, 60%, 80%, and 100%). Use 0 volts and 5 volts for your upper and lower limits.
- Look at the **Power** calculations for the various motor speeds. Graph the power calculations (dependent variable) versus the motor percentages (independent variable). Does your **electrical data** support the **time data** you collected in Lesson # 1 over the one meter track? Do you see any relationships between your thoughts on efficiency from the speed tests over the power calculations you just made? Explain your answer.
- Find a device at home or school that has electrical quantities printed on it (i.e. voltage and current). Calculate the other two quantities studied for that device.



As a Group

Elaborate and Explain

- Discuss your individual findings as a group and come to a common consensus. How do your electrical readings compare to your speed tests from lesson 1? Your timed tests may have displayed loss at lower speeds, but how does that compare to your power calculations? Is your power graph linear or curved? Explain the reasons for your answer.

Name: _____ Date: _____

Cruise Control: Keeping Your Car on Course



As a Group

Explore

- You will now modify your car to have 2 bumper switches. Design your car and write a program so that when the car runs into an object, it backs up, changes direction, and then keeps going. If the right bumper collides with an object, it can turn left to continue. If you collide with something on the left, it will turn right to correct its course.
- There are many ways to program the car to run this trial. **On graph paper**, draw the flow chart for the program you plan to use to control the car.
- Set up your testing area. Make sure your surface is large enough for your car to maneuver around on when hitting obstacles and avoid tangling wires.

Observe

- How did your program perform? Did you need to revise anything? What could happen if both switches are pressed at the same time?

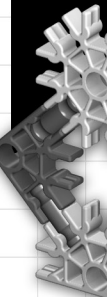


On Your Own

Elaborate and Explain

- What was the biggest challenge with this activity?

- How could this activity be improved? Explain your answer.



Challenge Design Brief

Lesson #2: Cruise Control

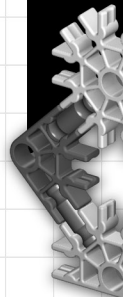
Name: _____ Date: _____



As a Group

Here are several possible design challenges for your group. Use notebook and graph paper to document the activity or activities and fasten them to this sheet.

- Modify your split bumper car program to use a buzzer that signals different sounds for right and left collisions. Chart your programs on graph paper and record your results.
- Challenge another group (or groups) to a friendly competition. Set up an obstacle course using your split bumper car to see who can make it through the course the fastest or farthest. Modify your program if necessary and chart on graph paper.
- Redesign your car so that it combines both activities from Student Response Sheets 1 and 3. Use one push button under the car for a tabletop sensor and one push button for a solid, one piece front bumper. How would you redesign the car to make it a single bumper system? Create a program that can control the car on a course where both hazards are present. Chart your programs on graph paper and record your results.
- How much would this car cost to build? Determine the cost of the parts required to build the model with dual front bumpers using a 'Cost per Piece Chart.' Also, determine how many "mechanics" it would take to build the car, a labor cost per hour, and the total number of hours each employee would be working on the project.



Self Reflection/Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____

Complete the Activity Assessment Rubric to provide your impression of how you did with this lesson.

Assessment Rubric			
<i>Circle Responses for each:</i>	Excellent	Good	Acceptable
Research and Design Logs & Worksheets	Student Response Sheets and Design Logs complete with no spelling or grammar errors. All answers on Student Response Sheets are accurate. <input type="text"/> 1-10	Student Response Sheets and Design Logs complete with few spelling or grammar errors. Most answers on Student Response Sheets are accurate. <input type="text"/> 1-8	Student Response Sheets and Design Logs complete with many spelling or grammar errors. Few answers on Student Response Sheets are accurate. <input type="text"/> 1-6
Design & Construction	Your device is very neatly constructed, easy to use, and meets or exceeds expectations outlined in the Design Brief. <input type="text"/> 1-10	Your device is neatly constructed, easy to use, and meets expectations outlined in the Design Brief <input type="text"/> 1-8	Your device has been constructed, is in useable form, and meets the materials criteria listed in the Design Brief. <input type="text"/> 1-6
Design Journals & Presentations	Your Design Journal is complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. It is presented in a neat and orderly fashion. <input type="text"/> 1-10	Your Design Journal is mostly complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows some disorder. <input type="text"/> 1-8	Your Design Journal is missing 1 or more logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows disorganization. <input type="text"/> 1-6
Teamwork/Work Ethic	You worked well with your teammates and interacted well with others. You demonstrated excellent reliability and initiative when working on this challenge. <input type="text"/> 1-5	You worked well with your teammates and interacted well with others. You were reliable and demonstrated initiative when working on this challenge. <input type="text"/> 1-3	You worked well with your teammates and others. You were generally reliability and usually demonstrated initiative when working on this challenge. <input type="text"/> 1
Total Score	<input type="text"/> /35		

Teacher Comments:

Teamwork & Self Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____



As a Group

Teamwork and cooperation are necessary skills required for most jobs since businesses typically have many employees that work together in teams rather than lots of individuals working alone. All employees need to contribute equally, using their skill sets to make a project successful while meeting deadlines. If one person fails to contribute adequately, the business or project can fail.

- **Communication Skills:** How well did your group communicate? How could communications within your group be improved?

- **Work Load:** How was work assigned in your group? Did individuals step up to accept responsibility? Were personal skills considered as work was assigned? For larger groups, is it beneficial to assign someone as a leader?

- **Presentation:** How was the unit presentation developed? How did the group determine responsibilities so no one was left out? What improvements could be made for future presentations?

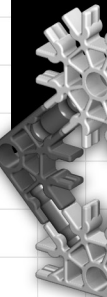


On Your Own

- **Personal Input:** Do you feel you contributed equally with your group? Did you do too much or not enough? Personal contributions to the group are listed in the *Research and Design Log*, but what could you do to work better in a team?

LESSON #3: BEGINNING THE JOURNEY

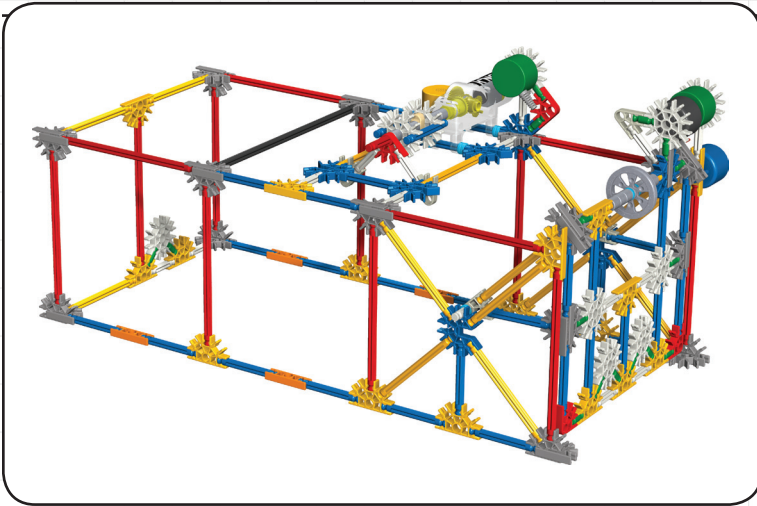
4-6 X



Model: K'NEX Push Car & Garage

Main Concepts (STEM):

- **Science**
 - Mechanical Advantage
- **Technology & Engineering**
 - Pulleys & Systems
- **Mathematics**
 - Ratios and Predictions



Objectives:	Required Materials:	Optional Materials:
<p>Students will be able to:</p> <ul style="list-style-type: none"> • Work effectively both independently and in collaborative teams. • Correctly connect and program the K'NEX interface to operate a garage door with control devices. • Recognize mechanical advantage in pulley systems. • Calculate force and distance in pulley systems. • Modify their computer programs to control the car for specific purposes. 	<p>Teacher will need:</p> <ul style="list-style-type: none"> • K'NEX Interface and software • Presentation system • Extension cord (if power is not close to testing area) <p>Students will need:</p> <ul style="list-style-type: none"> • K'NEX Interface and components • Computer with K'NEX Computer Control software • K'NEX push car & garage models • Metric ruler • Masking tape • Copies of: <ul style="list-style-type: none"> ○ Research & Design Logs ○ Student Response Sheets ○ Challenge Design Briefs ○ Teamwork & Self-Evaluation forms ○ Self Reflection/Evaluation Rubrics 	<ul style="list-style-type: none"> • Graph paper • Notebook paper • Colored pencils • Sample K'NEX models (prebuilt car and garage model and/or other model to demonstrate reed switch operation) • Sample pulley models or images (block & tackle, hoist, etc.) • Calculators

TEACHER'S NOTES:

- After the students modify their car from lesson 2 to be a push car model and construct the garage model, begin the engagement portion of the lesson. Lesson 3 should take 4-6 class periods, depending on how challenge activities are assigned.
- As with previous lessons, students will be asked to construct the model, perform various experiments, chart data, record their thoughts and actions, and develop challenge activities.
- The students will be introduced to a new input device for this lab. They will be using a reed switch with a magnet as the trigger device.

Process

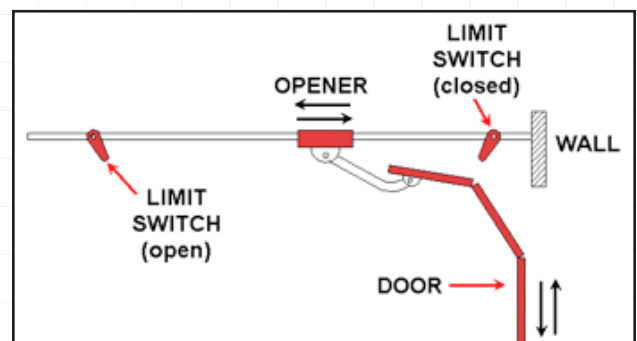
Engagement

1. Keeping in line with the *STEM Exploration* road trip theme, discuss with the students that it is time to begin the road trip, but first, they must get the car out of the garage. While they may do this every day at home with their families, they may not give the operation of a garage door opener any thought. This lab is designed to give them some insight as to how this system actually works. Discuss the processes used in the lesson:
 - Students will construct the K'NEX car and garage models for the lesson and complete the *Engagement* activities. This car model consists of some simple modifications from lesson 2 where the students remove the electronics from the vehicle. The garage is built using reed switches and magnets to control the door. While the reed switches and magnets are in place at the beginning of the unit, they will not be used until the second portion of this lesson. Discussion of the reed switch operation should occur at the appropriate time.
 - They will be programming their garage model to open and close using time delays, and then using reed switches.
 - Students will also examine the fundamentals of pulley systems as they explore mechanical advantage and simple machines.
 - They will finish the lesson by completing one or more open-ended challenge activities.
2. Distribute or direct students to the **Research and Design Logs** and **Student Response Sheets** for this unit. Introduce the **Challenge Design Briefs** when the students are ready for the challenge activities and the **Assessment Sheets** at the end of the activity. This will help students focus on the current activities. These pages are provided at the end of each lesson or in the **Resources** section of the Teacher's Guide. Links to editable electronic versions of the Research & Design logs, Student Response Sheets, Design Briefs, Evaluation/Assessment forms and the Cost Per Piece chart can be accessed by the students from the Start Menu, or you can drag and drop the "STEM Explorations Resources" folder from the software CD onto the desktop or a shared drive.
3. Discuss that the **Research and Design Logs** and **Student Response Sheets** will be used in the same manner as lesson 1.

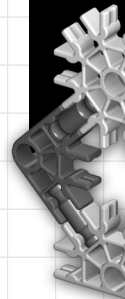
Engage in a discussion or brainstorming activity where the students discuss how they think a garage door is controlled. What stops the door at both ends of its travel? Is it timed or does it use other means to control the travel?

Here is a website that discusses the operation:

[Operation of a garage door opener](#)



Above is a simple diagram of how *limit switches* can be used to control the door.



Exploration

1. Establish student teams (2-3 students per group), and then briefly review the activity and **Student Response Sheet 1**. Allow students time to discuss the activity in their groups.
2. Students should understand the safe operation of the K'NEX interface and electrical concerns. Review the STEM Explorations *User's Guide* for details.
 - a. Regulated voltage for the interface and binary computer input/output.
 - b. Proper wire and connection handling.
3. The students should construct the K'NEX push car and garage model for the lesson.
4. Review the vocabulary terms found on the **Research and Design Log**. Definitions are found in these notes and in the *Answer Key*.
5. Review the activity on Students Response Sheet 1 with the class. If your students are familiar with simple machines, mechanical advantage, and work, this is an excellent opportunity to review these concepts as they apply to the pulley. The following are some of the terms that will be used throughout this lesson:

- **Force** - a push or pull. Expressed in **Newtons (N)**.
- **Torque** - a force-like quantity in a rotational system. $\text{Torque} = (\text{Force}) \times (\text{Lever Arm Length})$. Expressed in **Newton-Meters (Nm)**.
- **Work** - the product of the force applied to an object along its direction of movement and the distance the object moves while force is applied. $\text{Work} = \text{Force} \times \text{Distance}$. Expressed in **Newton-Meters (Nm)**.

Ask students how a pulley works and how pulleys can be used to move heavy objects with little effort and/or change the direction of the force. Ask the students identify everyday use of pulleys.

Some examples include:

- o Flag Pole
- o Crane
- o Engine Hoist
- o Boat Rigging
- o Tow Truck
- o Hand Brakes on Bicycle
- o Elevator
- o Garage Door
- o Window Blinds

Discuss how pulley systems can provide Mechanical Advantage by multiplying the input force. In pulley systems, the input force is multiplied by the number of supporting cords lifting the load. This also represents the mechanical advantage of the system. Sample calculations will be provided later in the notes. Pulley systems can change force, directional movement, and rate.

Apply the concepts of rotational motion and linear motion to the operation of the garage door. Ask the students to identify how many changes of motion occur in the system.

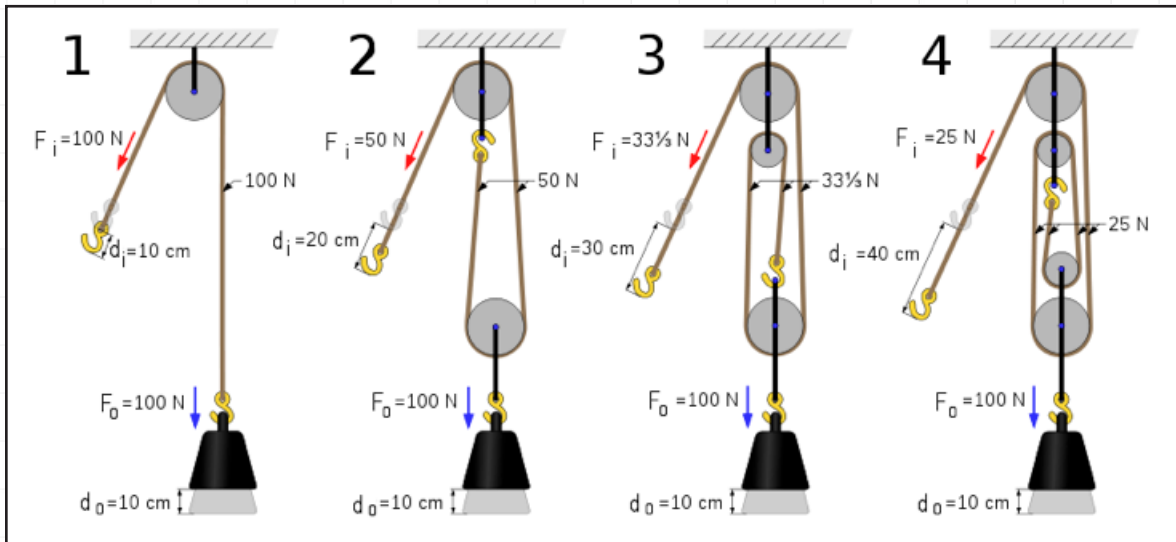
6. To help the students understand the concept of pulley systems, they can review the information found on the sample websites listed below:

[Pulley Simulation](#)

[How a Block & Tackle Works](#)

[Mechanical Advantage](#)

7. Reinforce the concept of mechanical advantage in pulley systems with the students and how force and distance can change by using different configurations. "With enough pulleys, a person can lift a car." Calculate force and distance in pulley systems using the following graphic.



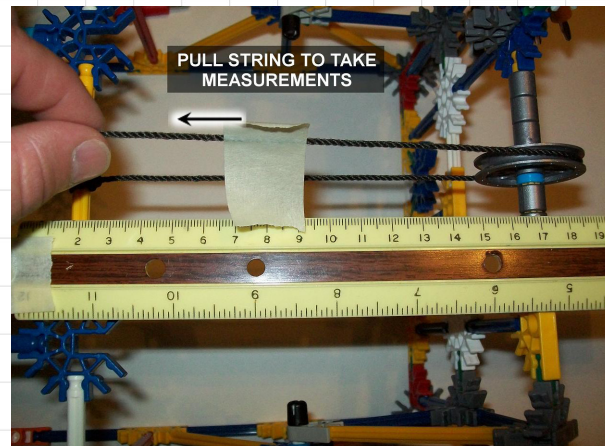
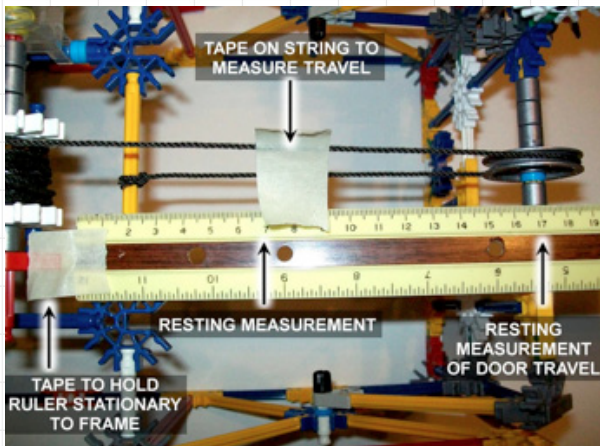
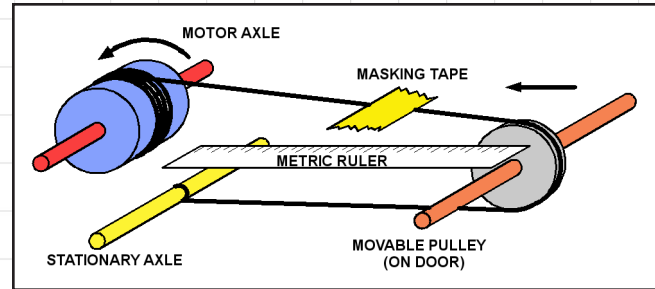
You and the students will notice that the first example has 1 support cord (do not include the cord being pulled upon). With 1 cord, the mechanical advantage of the system is 1. By using the formula $F_i = F_o / \text{number of support cords}$, you will see that $F_i = F_o$, therefore, the system is only changing the direction of the motion and not multiplying force or distance. The second example has 2 cords with a mechanical advantage of 2. With 50 N of input force, the output will be 100 N, but the mass would only travel half as far as the cord was pulled. This continues with the examples of 3 and 4 support cords as well.

TEACHER'S NOTES:

- *Reproduce or display the graphic above for the students and describe how the number of pulleys and loops can be used to calculate input and output forces and distances.*
- *Tell students that even though the calculations above show a perfect system, efficiency is never 100% due to loss in the system. Ask the students to identify some of the things causing loss (i.e. friction in the pulleys' axles and rope bend (resistance to the bending of the rope around the pulley), and even stretching of the cord).*
- *Create some sample models and calculations to determine work in, work out, and mechanical advantage for the students using the following formulas (using figures from the graphic above):*
 - o **Mechanical Advantage = number of support cords**
 - o $F_i = \frac{F_o}{\text{number of support cords}}$
 - o **Work In = $F_i \times d_i$**
 - o **Work Out = $F_o \times d_o$**
 - o $F_i \times d_i = F_o \times d_o$
- *With every system, there are advantages and disadvantages. You sacrifice distance for force (and vice-versa). If you use a pulley to multiply the amount of force applied to move an object, you must pull the cord farther to lift the object the desired distance.*
- ***Which cords are support cords?** In the examples above, the cord is wrapped around a stationary pulley that only changes direction of force and is not a support cord. If the cord being pulled upon wrap around a movable pulley, it becomes a support cord, like the system on the K'NEX garage.*

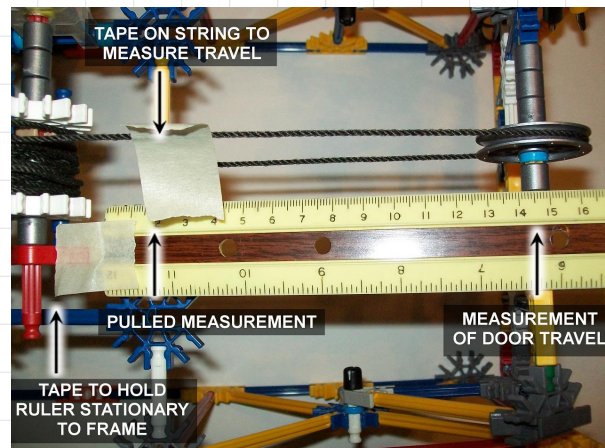
8. Instruct the students to set up their testing area for the activity on **Student Response Sheet 1**. This first activity does not require the use of the K'NEX Interface or program. They will be performing tests on the pulley system used on the garage door.

Students will be asked to complete a few sample pulley calculations. They will then predict force ratios and how much the door will rise as string is wound onto the motor spool of their K'NEX garage model. The students will then place a piece of masking tape on the string and measure how much the door rises when the string is pulled by hand a set distance to test their predictions. The procedure for the test is pictured here:



The photo above shows the initial setup of the experiment. The ruler is taped into place so that it doesn't move during the test. The tape fastened to the string is used as a pointer for accurate measure.

The upper right photo shows the string being pulled 50 mm (from 7 cm down to 2 cm). Note the door's movable pulley starting at 17 cm.



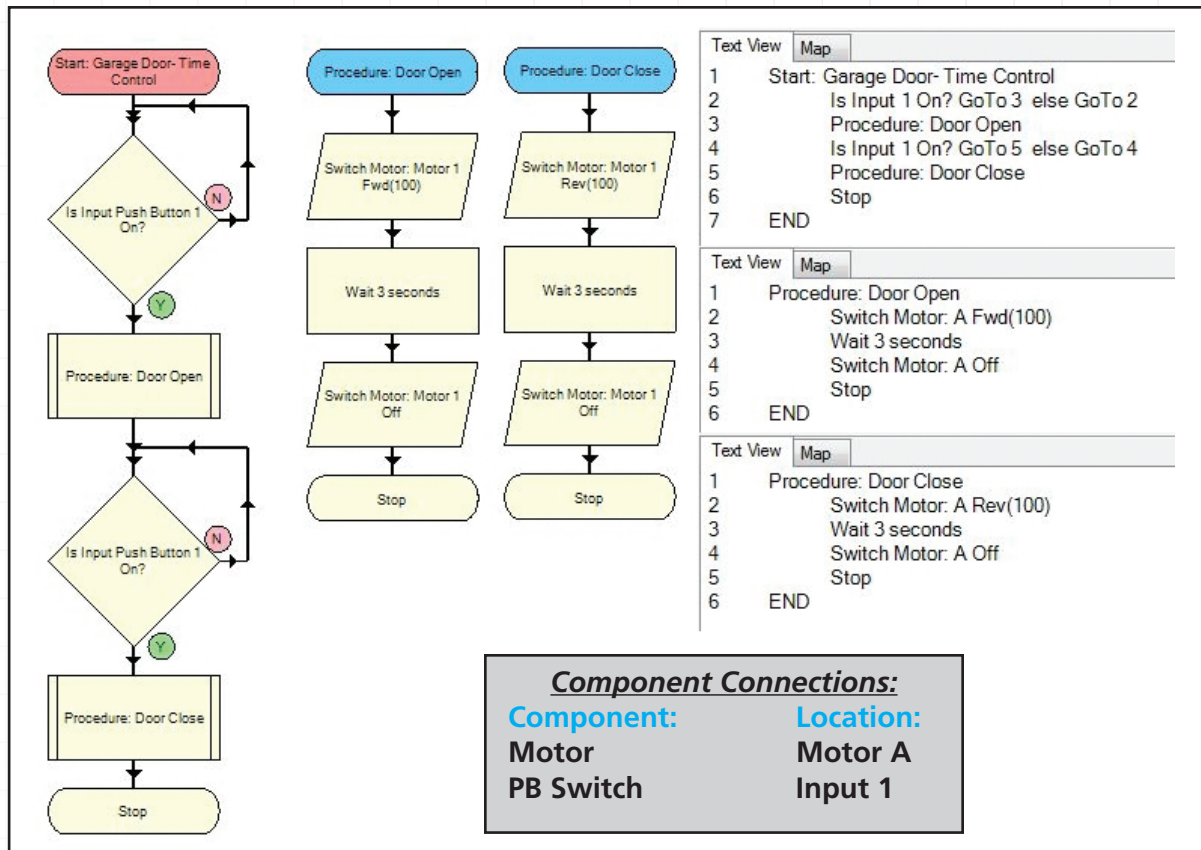
The photo to the right shows the door's pulley moved to approximately 14.5 cm (145 mm), a total travel of 25 mm. This system has 2 cords with a mechanical advantage of 2. The input force will be multiplied by 2 while the distance traveled is cut in half. While it may appear that there is only one cord in the calculation since we are pulling on the other, both cords calculate into the system since the pulley is movable.

There is also a lever action working with the door as well, but that does not factor into this equation as we are only calculating the advantage of the pulley system. The lever action (door swinging on a pivot) also provides some mechanical advantage to the system.

TEACHER'S NOTES:

Allow the students ample time to complete the tests and discuss their results as a group.

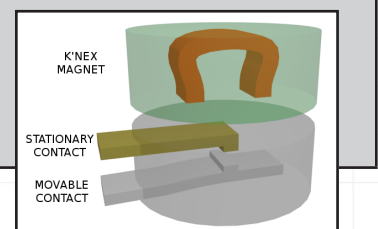
- After the students have finished the first activity, refer to **Student Response Sheet 2**. This activity will allow the students to develop programs to test the garage door operation. The first test will experiment with timed opening and closing. Remind the students that they will not be using the reed switches or buzzer for the first experiment. The only input and output devices they will be using on the K'NEX garage are the push button switch and motor.
- Ask the students if using *Wait* blocks would be practical for the operation of the door (start the motor, wait a few seconds, and then stop the motor). Even though this is the method the students should use for the first test, it can experience problems of consistent operation. Discuss the answers the students provide.
- Students should complete the timing program section of the activity and discuss their results. A sample program that could be used for this test is shown below:



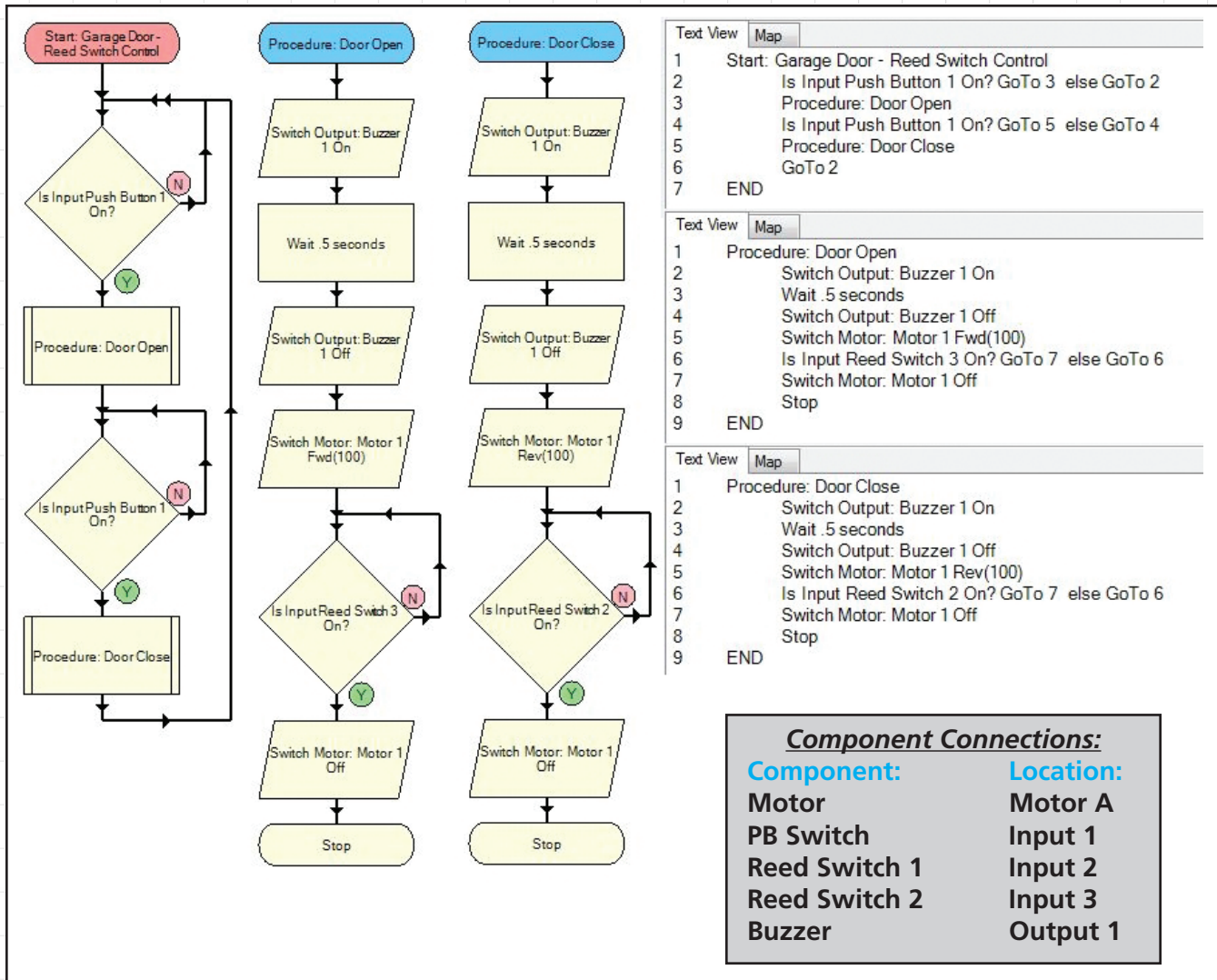
- The program uses the push button switch as Input 1. When the switch is pressed, the *Door Open* procedure is run with the motor at 100%. At this speed, it takes approximately 3 seconds to open the door completely. At the second button press, the *Door Close* procedure runs for 3 seconds.
- After the students have had time to run the test and answer the questions, review the operation of a reed switch with them. Reed switches use magnets to trigger them. Demonstrate how the magnet needs to be in close proximity to the switch for proper operation. Explain how the use of reed (or other) switches can be used for better accuracy and reliability than a timed system.
- Have students add the Reed Switches and Magnets to the Garage Model per the building instructions.

TEACHER'S NOTES:

A reed switch consists of a stationary contact and a movable contact that is triggered by a magnetic field. The K'NEX magnet must be within a few millimeters of the reed switch to operate correctly.



15. Students will also be asked about safety in garage door systems in the response sheet. For this test, they will be asked to sound a buzzer alarm when operating the door. There are several ways to develop a program for this test. One possible solution is displayed here:



16. The students should construct the K'NEX push car and garage model for the lesson.

17. The program uses two procedures to open and close the door. The push button switch (*Input 1*) signals operation as with the previous example. The buzzer (*Output 1*) sounds for .5 seconds before the motor operates the door in each procedure. *Input 2* and *Input 3* represent the reed switches and are used to stop the motors when they are triggered. This program uses *Input 2* as the reed switch that is triggered when the door is closed. The program also assumes that the door starts in the closed position. The students may develop programs that sense the door's position or even sound the buzzer differently.

18. After students have finished the activity on Student Response Sheet 2 and have had sufficient time to respond to the questions individually and as a group, assign the **Challenge Design Briefs** that will outline several possible challenge activities for you or the students to select from. Time constraints and student interest level may guide the number of challenge activities the students will be required to complete.



Explanation

1. Throughout the activities in this lesson students have been completing **Student Response Sheets**. Allow sufficient time to complete these sheets as they finish each activity so they can demonstrate they are able to explain what they have discovered. Remind students that some sections of the **Student Response Sheets** are to be completed **“As a Group”** while others are to be completed **“On Your Own.”** They should be formulating thoughts, calculations and definitions from their own words.
2. Decide if you want groups to present their results after each *activity* or *wait until the entire unit is finished* to present their findings. Presentation is an important part of the learning experience since all students may approach these *activities with different thoughts* and ideas. Presentations should include a variety of elements such as descriptions, visual aids and demonstrations.

Elaboration

Students will self-evaluate their challenge solutions based on the criteria provided in the rubric for this activity. Elaboration components are found in the logs and response sheets.

TEACHER’S NOTES:

- Have students complete the **Lesson 3 - “Beginning the Journey” Self Reflection/Evaluation rubric** so they can self-evaluate their work. The rubric score and your evaluation will make up a portion of the assessment data for this lesson.
- Provide students with a **Teamwork and Self-Evaluation** sheet and review the form with the students before they complete them.

Evaluation

You may use some or all of the following to evaluate student’s performance:

- Self Reflection/Evaluation Rubric
- Teamwork and Self Evaluation forms
- Presentation of the Challenge Solution(s)
- Research and Design Logs
- Student Response Sheets
- Design Journal

Extensions

1. After the students have worked through the activities, it is useful to extend the learning through career research and extended activities. Career components have been added to the **Research and Design Logs**, but can be extended by other means such as guest speakers, business tours, etc.
2. Extension activities should be included in any student presentations.



On Your Own

Lesson #3: Beginning the Journey

Research and Design Log

Name: _____ Date: _____

Define the following terms below. Be sure to write the definitions in your own words.

Force -

Newton -

Torque -

Work -

Newton-Meter (Nm) -

Mechanical Advantage -

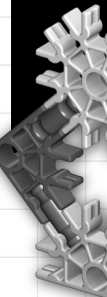
Simple Machines -

Reed Switch -

Pulley -

Block and Tackle -

Energy Loss -



Name: _____ Date: _____

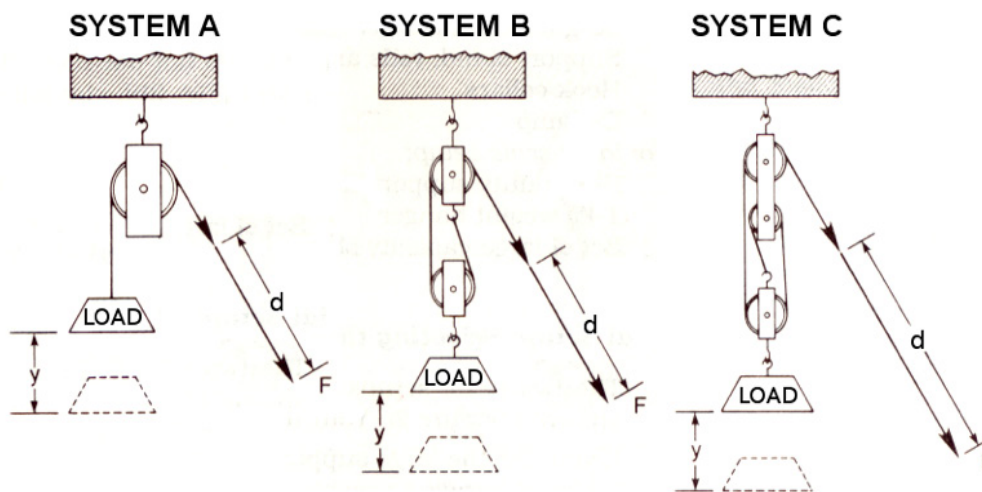


On Your Own

Pulley Systems

Explore

- After discussing pulley systems in class, examine the 3 examples below and record the missing information in the chart provided. Remember that the cord being pulled upon does not count in the system. Do not forget to include units.



SYSTEM	Number of Support Cords (C)	Mechanical Advantage (MA)	Input Force (F)	Distance Input Force Moves (d)	Distance the Load is Lifted (y)	Work Input (W)
A				.05 m		
B				.06 m		
C				.06 m		

Given: Load = 120 N
Useful formulas: Input Force = Load / MA; $y = d / MA$; Work Input = Fd



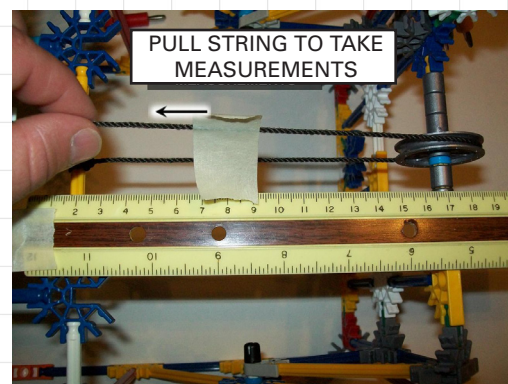
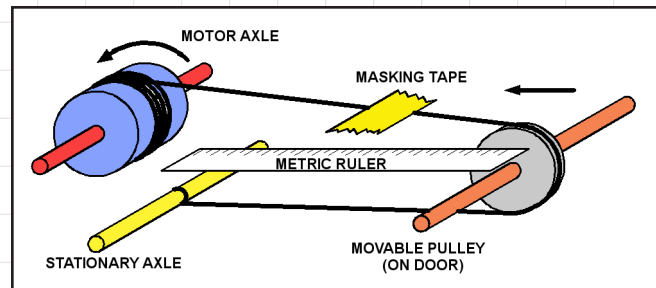
As a Group

- You will not be using the Interface for this first test. The goal of this activity will be to investigate the pulley system used on the garage door of the K'NEX garage. Construct the Garage and Push Car models.

- For the K'NEX garage door system, discuss the following as a group and record your predictions:
 - o Examine the garage model. Pinch the string on the pulley and pull to determine how the door opens and closes. Describe how the door operates.
 - o Do you think the pulley system at the top of the garage door provides any mechanical advantage? Explain why.
 - o If the motor provides 10 Newtons of force and pulls the pulley at the top of the door toward the rear of the garage. How much force will be applied to lift the garage door?

Observe

- Set up your testing area so you can measure the movement of the garage door and string. To do this, place a piece of masking tape on the top pulley string (as shown) to use as a pointer (be careful not to wrap it so it would be difficult to remove).
- Record the pointer's location on the ruler. Also, record the location of the moveable pulley on the ruler. Pinch the cord as shown and pull the masking tape pointer toward the rear of the garage 50 mm (5 cm). Record the new locations of the pointer and the moveable pulley.



You may need to tape the metric ruler to the K'NEX frame to keep it stationary for accurate measurements. Repeat the test several times to get an accurate measurement.

Name: _____ Date: _____

Controlling the Garage Door



As a Group

Explore

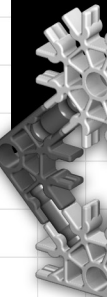
- It is now time to develop a program that operates the garage door. For this first test, you will only be using the push button input and the motor output to develop a simple timed operation. When the button is pressed, the door will use Wait blocks and run the door as long as needed to open far enough to allow the car to enter the garage. When the button is pressed a second time, the door will run using Wait blocks again and must close completely. You must determine:

- An appropriate motor speed for the test.*
- An appropriate wait time for opening and closing.*

There are many ways to develop a program to complete this operation. **On graph paper**, draw the program you plan to use. **Start with a low time delay of about 2 seconds and work your way up to an appropriate time that opens and closes the door. By starting with a high number, the system may try to keep running with the door completely open, causing the motor to stall or slip.**

Perform the test 5-10 times to see if the door opens and closes exactly the same every time.

- The motor provides a turning force called **Torque**. If the motor does not supply enough torque to overcome the weight of the door (which also uses a pulley system to reduce needed force), the door won't open. If you reduce the motor speed percentage too much, it may not provide enough torque. What motor speed and times worked the best?
- After running the test several times, did the door continue to open and close exactly the same every time? If not, what problems occurred?
- Program your K'NEX garage to use the reed switches and buzzer. Safety is always a concern with garage doors, so your buzzer should sound every time before the door begins to open and close. Instead of programming timed motor runs, the reed switches should be used to stop the door at the open and closed limits. There are many ways to develop a program to complete this operation. **On graph paper**, draw the program you plan to use.
Perform the test 5-10 times to see if the door opens and closes exactly the same every time.
- After running the test several times, did the door continue to open and close exactly the same every time? If not, what problems occurred?



Name: _____ Date: _____



As a Group

Here are several possible design challenges for your group. Use notebook and graph paper to document the activity or activities and fasten them to this sheet.

- Rewrite your program to use only one reed switch, the buzzer, and the push button switch. Design the program so that it opens when the push button is pressed, has a time delay to allow the car to enter or exit, then automatically closes. Chart your program on graph paper and record your results.
- Garage door openers typically include automatic lighting for safety. Lights typically come on when the door is opened or closed and stay on for a set amount of time before turning off to allow the occupant to leave the garage. Using a K'NEX LED output device, simulate an automatic light on your garage that turns on when the door opens or closes and stays lit for a few seconds after the door is finished traveling. Chart your program on graph paper and record your results.
- Rewrite your program to include a second push button switch to simulate a control at another doorway. Change your program so it will operate from either switch. Chart your program on graph paper and record your results.
- Due to handicap laws, fire alarm systems now include flashing lights along with a sound to alert people with vision or hearing problems. Redesign your program so the buzzer goes on and off during the entire door operation along with a blinking LED. Chart your program on graph paper and record your results.
- Design a system that can sense if the door is open or closed and operate the door accordingly so that it opens or closes correctly. Chart your program on graph paper and record your results.
- **The Ultimate Challenge!** Design a program that uses at least 3 of the above systems in your program (i.e. an LED lit the entire cycle, sounds the buzzer, uses 2 push button locations, and senses if the door is open or closed and runs accordingly). Chart your program on graph paper and record your results.
- How much would it cost to build this garage? Determine the cost to construct the garage with your challenge components using a 'Cost per Piece Chart.' Also, determine how many "contractors" it would take to build the garage, a labor cost per hour, and the total number of hours each employee would be working on the project.

Self Reflection/Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____

Complete the Activity Assessment Rubric to provide your impression of how you did with this lesson.

Assessment Rubric			
<i>Circle Responses for each:</i>	Excellent	Good	Acceptable
Research and Design Logs & Worksheets	<p>Student Response Sheets and Design Logs complete with no spelling or grammar errors. All answers on Student Response Sheets are accurate.</p> <p><input type="text"/> 1-10</p>	<p>Student Response Sheets and Design Logs complete with few spelling or grammar errors. Most answers on Student Response Sheets are accurate.</p> <p><input type="text"/> 1-8</p>	<p>Student Response Sheets and Design Logs complete with many spelling or grammar errors. Few answers on Student Response Sheets are accurate.</p> <p><input type="text"/> 1-6</p>
Design & Construction	<p>Your device is very neatly constructed, easy to use, and meets or exceeds expectations outlined in the Design Brief.</p> <p><input type="text"/> 1-10</p>	<p>Your device is neatly constructed, easy to use, and meets expectations outlined in the Design Brief</p> <p><input type="text"/> 1-8</p>	<p>Your device has been constructed, is in useable form, and meets the materials criteria listed in the Design Brief.</p> <p><input type="text"/> 1-6</p>
Design Journals & Presentations	<p>Your Design Journal is complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. It is presented in a neat and orderly fashion.</p> <p><input type="text"/> 1-10</p>	<p>Your Design Journal is mostly complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows some disorder.</p> <p><input type="text"/> 1-8</p>	<p>Your Design Journal is missing 1 or more logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows disorganization.</p> <p><input type="text"/> 1-6</p>
Teamwork/Work Ethic	<p>You worked well with your teammates and interacted well with others. You demonstrated excellent reliability and initiative when working on this challenge.</p> <p><input type="text"/> 1-5</p>	<p>You worked well with your teammates and interacted well with others. You were reliable and demonstrated initiative when working on this challenge.</p> <p><input type="text"/> 1-3</p>	<p>You worked well with your teammates and others. You were generally reliability and usually demonstrated initiative when working on this challenge.</p> <p><input type="text"/> 1</p>
Total Score	<p><input type="text"/> /35</p>		

Teacher Comments:

Teamwork & Self Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____



As a Group

Teamwork and cooperation are necessary skills required for most jobs since businesses typically have many employees that work together in teams rather than lots of individuals working alone. All employees need to contribute equally, using their skill sets to make a project successful while meeting deadlines. If one person fails to contribute adequately, the business or project can fail.

- **Communication Skills:** How well did your group communicate? How could communications within your group be improved?

- **Work Load:** How was work assigned in your group? Did individuals step up to accept responsibility? Were personal skills considered as work was assigned? For larger groups, is it beneficial to assign someone as a leader?

- **Presentation:** How was the unit presentation developed? How did the group determine responsibilities so no one was left out? What improvements could be made for future presentations?



On Your Own

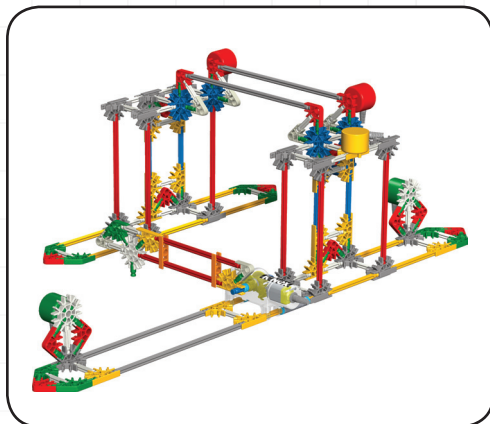
- **Personal Input:** Do you feel you contributed equally with your group? Did you do too much or not enough? Personal contributions to the group are listed in the *Research and Design Log*, but what could you do to work better in a team?

LESSON #4: THE HIGHWAY RIDE

4-6 X



Model: K'NEX Push Car & Toll Gate



Main Concepts (STEM):

- **Science**
 - Simple Machines and Lever Classes
- **Technology & Engineering**
 - Design and Innovation
- **Mathematics**
 - Measurement and Computation

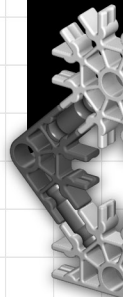
Objectives:	Required Materials:	Optional Materials:
<p>Students will be able to:</p> <ul style="list-style-type: none"> • Work effectively both independently and in collaborative teams. • Correctly connect and program the K'NEX interface to operate a Toll Gate with control devices. • Recognize simple machines and the three classes of levers. • Calculate force, distance and mechanical advantage in levers. • Modify their computer programs to automate toll gate operation. 	<p>Teacher will need:</p> <ul style="list-style-type: none"> • K'NEX Interface and software • Computer projector and/or whiteboard • Extension cord (if power is not close to testing area) <p>Students will need:</p> <ul style="list-style-type: none"> • K'NEX Interface and components • Computer with K'NEX Computer Control software • K'NEX push car & toll gate models • Copies of: <ul style="list-style-type: none"> o Research & Design Logs o Student Response Sheets o Challenge Design Briefs o Teamwork & Self-Evaluation forms o Self Reflection/Evaluation Rubrics 	<ul style="list-style-type: none"> • Graph paper • Notebook paper • Colored pencils • Sample K'NEX models (prebuilt car and toll gate models and/or other models to demonstrate levers and other simple machines) • Examples of simple machines • Calculators

TEACHER'S NOTES:

- *The push car will be used for this lesson with a toll gate model. After the groups have constructed both models using the Instruction Booklet, begin the engagement portion of the lesson. Lesson 4 should take 4-6 class periods, depending on how challenge activities are handled.*
- *As with previous lessons, students will be asked to construct the models, perform various experiments, chart data, record their thoughts and actions, and develop challenge activities.*
- *This lesson will focus on the science, technology and mathematics of simple machines.*

Process**Engagement**

1. Keeping in line with the *STEM Exploration* road trip theme, discuss with the students that they have now hit the highway and are on their way. As with many trips, they have come upon a toll gate that they must pass through. Toll gates were once (and many still are) operated by a person that collected the toll and opened the gate for the vehicle to pass. Today, many have been switched over to automated systems where the gate senses the car and tolls are automatically charged to the driver's account. This lab is designed to give the students some insight as to how this system can be simulated with K'NEX while examining the concepts of simple machines. Discuss the processes used in the lesson:
 - Students will construct the K'NEX push car and toll gate models for the lesson and complete the *Engagement* activities. This push car is the same model used in lesson 3. The toll gate is initially constructed using a push button switch, buzzer, LEDs, and a motor.
 - In the first activity, students will program their toll gate to simulate a toll booth attendant controlling the system. In the second activity, they will develop programming for an automated system using reed switches and a magnet.
 - Students will also examine the fundamentals of simple machines with a focus on levers.
 - They will finish the lesson by completing one or more open-ended challenge activities.
2. Distribute or direct students to the **Research and Design Logs** and **Student Response Sheets** for this unit. Introduce the **Challenge Design Briefs** when the students are ready for the challenge activities and the **Assessment Sheets** at the end of the activity. This will help students focus on the current activities. These pages are provided at the end of each lesson or in the **Resources** section of the Teacher's Guide. Links to editable electronic versions of the Research & Design logs, Student Response Sheets, Design Briefs, Evaluation/Assessment forms and the Cost Per Piece chart can be accessed by the students from the Start Menu, or you can drag and drop the "STEM Explorations Resources" folder from the software CD onto the desktop or a shared drive.
3. Discuss that the **Research and Design Logs** and **Student Response Sheets** will be used in the same manner as in previous lessons. Please refer back to the lesson 1 *Engagement* section if review is necessary.
4. Engage in a discussion or brainstorming activity where the students discuss how they think an automated toll gate works. Ask them why some bridges and roads collect tolls while others do not. Do they know the history of the toll road? Toll roads were originally started by individuals and corporations that were later controlled by the government.
Click here for... [A history about toll roads](#)





Exploration

1. Establish student teams (2-3 students per group), and then briefly review the activity and **Student Response Sheet 1**. Allow teams time to discuss the activity in their groups.
2. Students should understand the safe operation of the K'NEX interface and electrical concerns. Review the STEM Explorations *User's Guide* for details.
 - a. Regulated voltage for the interface and binary computer input/output.
 - b. Proper wire and connection handling.
3. The students should construct the K'NEX push car and toll gate models for the lesson.
4. Review the vocabulary terms found on the **Research and Design Log**. Definitions are found in these notes and in the *Answer Key*.
5. Review the activity for **Student Response Sheet 1** with the class. Note to the students that the K'NEX toll gate model uses a simple lever for the gate. Discuss how this activity will introduce the students to the concepts of simple machines. They have already experienced a simple machine in the last unit - *the pulley*. By definition, simple machines are tools that make work easier and have few or no moving parts. They also use energy to do work.
6. Review the six simple machines:
 - **Lever** - a board or bar that rests on a turning point called a **fulcrum**. The object the lever moves is called the load. The closer the load is to the fulcrum, the easier it is to move. Examples of levers are:
 - o *A hammer used to pull a nail*
 - o *Bottle Opener*
 - o *Crow Bar*
 - o *Seesaw*
 - **Inclined Plane** - a flat surface that is higher at one end and used to move a load to a higher or lower place. Inclined planes can make work easier by using less force and energy to move objects. Examples of inclined planes are:
 - o *Car Ramp*
 - o *Slanted Road*
 - o *Ski Slope*
 - o *Sliding board*
 - **Wheel and Axle** - an axle is a rod that passes through the wheel, allowing the wheel to turn. Examples of wheels and axles are:
 - o *Wheelbarrow*
 - o *Screwdriver*
 - o *Door Knobs*
 - o *Gears in devices*
 - **Screw** - an inclined plane that wraps around itself. Used to hold things together or raise and lower objects. Examples of screws include:
 - o *Jar Lids*
 - o *A stool or chair that can rise*
 - o *Car Jacks*
 - o *Bolts and Nuts*

- **Wedge** - made up of two inclined planes or at least one slanted side, it is used to push two objects apart. The planes meet to form a sharp edge and move to do work. Examples of wedges include:
 - o Nails
 - o Axes
 - o Knives
 - o Log Splitter
- **Pulley** - a wheel with a grooved rim around which a cord passes. It acts to multiply a force and/or change the direction of a force applied to the cord. Examples of pulleys include:
 - o Flag Pole
 - o Crane
 - o Engine Hoist
 - o Boat Rigging
 - o Tow Truck

TEACHER'S NOTES:

It may be useful to have examples of simple machines available to show the students. Also, have the students think of examples around the home or classroom.

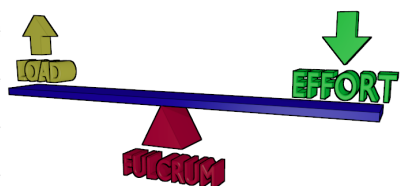
7. To help the students understand the concept of simple machines, they can review the information found on the sample websites listed below:

[Simple machines and other machine elements](#)

[Simple machine information from the Franklin Institute](#)

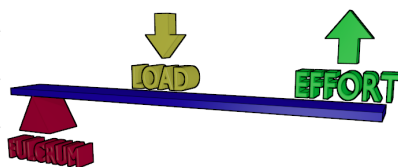
[Interactive site with simple machine information](#)

8. Since this lesson will focus on levers, discuss the different types of levers with the students:



1st Class Lever

The fulcrum is between the effort (force) and the load. This type of lever can either multiply the effort or distance output depending on the location of the fulcrum. The effort and load move in opposite directions.



2nd Class Lever

The fulcrum is located at one end of the lever and the effort at the other end. The load is located between the two. The effort and load move in the same direction. The effort is multiplied while the distance the load travels decreases.



3rd Class Lever

The fulcrum is located at one end and the load at the other end. The effort is applied between the two. The effort and load move in the same direction. It always requires more effort to lift, but the distance the load travels is multiplied.

TEACHER'S NOTES:

After discussing the different types of levers, ask the students to give examples of each type of lever and how force or distance are increased or decreased. Here are several websites that can be useful for this discussion:

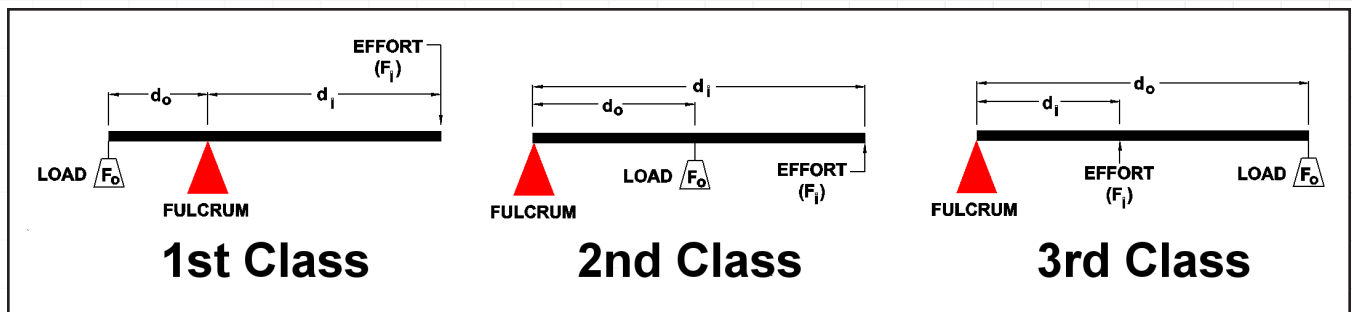
[Levers](#)

[Classes of Levers - First, Second & Third](#)

[Mechanics in Exercise: Levers](#)

9. Discuss how forces, distances and mechanical advantage can be calculated for levers with the students. The following examples use these formulas:

$$F_i \times d_i = F_o \times d_o \text{ or } F_i = (F_o \times d_o) / d_i$$
$$MA = d_i / d_o$$
$$\text{Input Work} = F_i \times d_i$$
$$F_i = \text{Effort Force}$$
$$F_o = \text{Load Force}$$
$$d_i = \text{Effort Distance to Fulcrum}$$
$$d_o = \text{Load Distance to Fulcrum}$$



TEACHER'S NOTES:

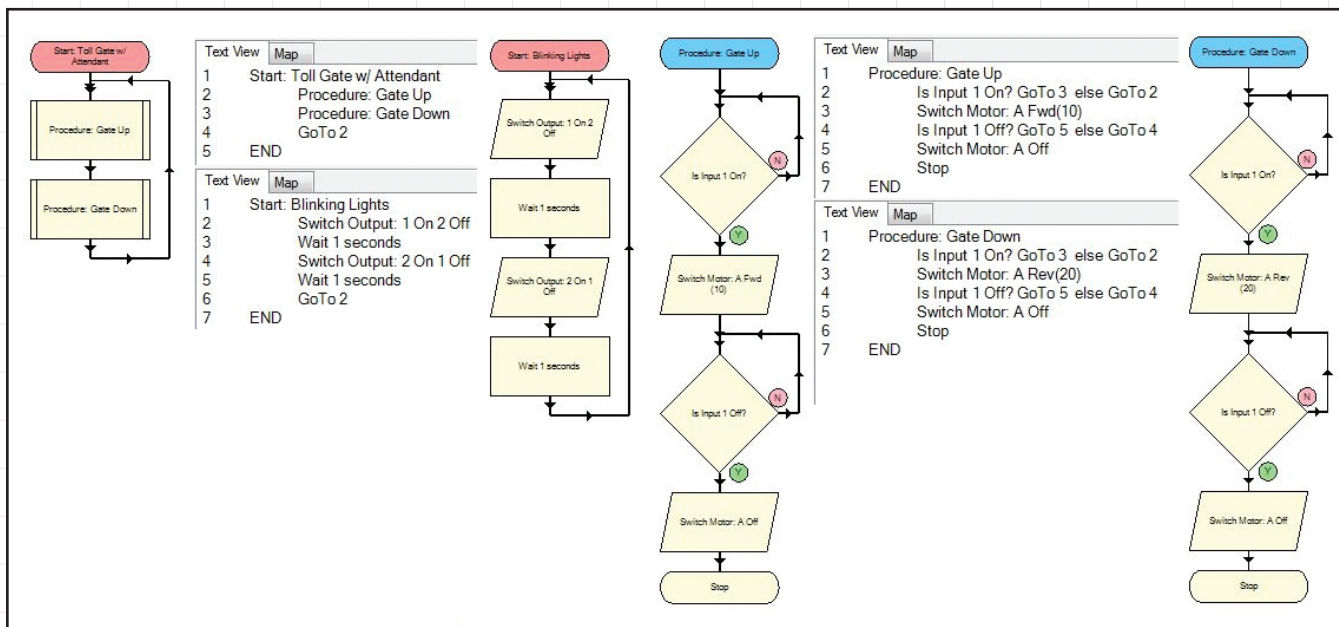
Reproduce or display the graphics above for the students and complete a few sample calculations for each lever class with the students. Discuss the benefits and disadvantages of each class of lever.

10. After the students have an understanding of levers, have the students complete **Student Response Sheet 1**. The first activity asks the students to create a toll booth that could be manually operated by a toll booth attendant. There is also a section related to levers.

11. When developing a program to control the gate, the students will have the option of trying to develop a program using wait blocks or by simply releasing the button to stop the gate. *If you wish to limit student options, have them create the program to run the motor without wait blocks.* Without the use of reed switches and magnets, accurate control can be difficult. This will allow the students an opportunity to experiment with different ideas. A simple "Up-Down" program without wait blocks is shown:

Component Connections:	
Component:	Location:
Motor	Motor A
PB Switch	Input 1
LEDs	Outputs 1,2
Buzzer	Output 3

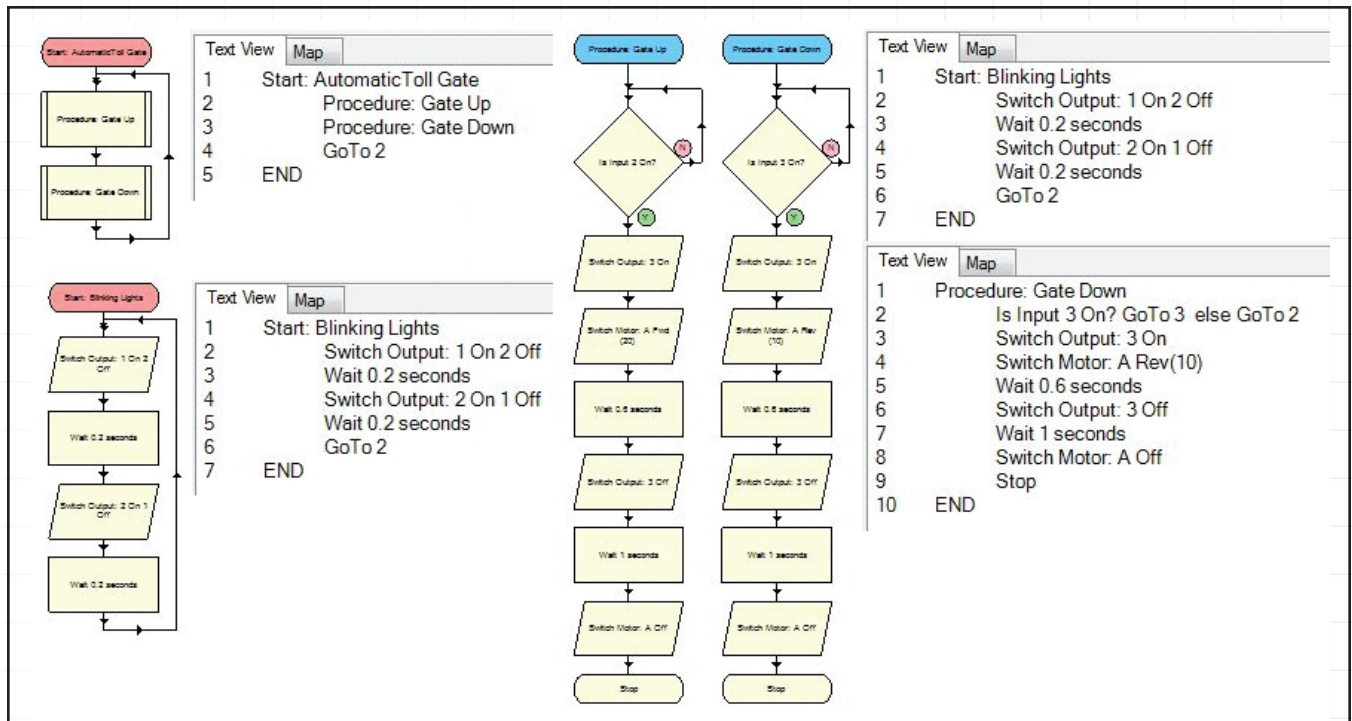
This program uses two start blocks. We are starting two programs to run simultaneously- the toll booth operation program and a blinking light program that would be used to attract the attention of oncoming cars. You will notice that the blinking light program does not have a stop block. It continues until the program exits. This is the first example of a program without a stop block that is allowed to cycle for the entire program. Motor speed will also need to be set so the gate opens and closes at an appropriate speed. Since the gate is a 3rd class lever (increase of distance output, but requires a larger effort), it will probably need a higher motor percentage to open the gate than to close the gate at a consistent and reasonable speed. This program requires the operator to watch the gate and know when to release the push button. If the students elect to use wait blocks to control the open/close cycles, they will need to experiment with appropriate times and speeds. As suggested in previous labs, depending on available time and student ability level, you may wish to provide students with a flow chart of the first steps of their program to get them started.



12. After the students have had ample time to finish the first activity, refer to **Student Response Sheet 2**. This activity will automate the toll gate operation and simulate a more modern approach using reed switches through a simple modification to the gate and car. Students will add the Reed Switches and Magnet to their models and be asked to answer some questions about simple machines as they relate to their K'NEX models.

13. This second program will ask the students to utilize a reed switch to sense the incoming car and simulate collecting the toll and opening the gate. A second reed switch senses the car exiting the toll booth and closes the gate. They must also incorporate several safety features in their design. A sample program that could be used is shown:

Component Connections:	
Component:	Location:
Motor	Motor A
PB Switch	not used
Reed Switch 1	Input 2
Reed Switch 2	Input 3
LEDs	Outputs 1,2
Buzzer	Output 3



Notice that the two running programs do not have **End** blocks. The one chart cycles the “Gate Up” and “Gate Down” procedures endlessly while the other chart cycles the blinking LEDs. The two procedure charts sense the condition of the Reed Switches (inputs 2 and 3) to sound the buzzer (output 3) and operate the gate. While the actual activities ask the students to create a program that can cycle the gate three times, you can demonstrate this endless loop technique to them.

TEACHER’S NOTES:

Make sure the students pay close attention to the location of the magnet on their car. If the magnet does not line up adequately with the reed switch, their program will not function properly. Students should push the car so the magnet passes as close as possible to the reed switches it passes as it moves through the toll gate.

14. After students have finished the activity on Student Response Sheet 2 and have had sufficient time to respond to the questions individually and as a group, assign the **Challenge Design Brief** that will outline several possible challenge activities for you or the students to select from.

Explanation

1. Throughout the activities in this lesson students have been completing **Student Response Sheets**. Allow sufficient time to complete these sheets as they finish each activity so they can demonstrate they are able to explain what they have discovered. Remind students that some sections of the **Student Response Sheets** are to be completed "**As a Group**" while others are to be completed "**On Your Own**." They should be formulating thoughts, calculations and definitions from their own words.
2. Decide if you want groups to present their results after each *activity* or *wait until the entire unit is finished* to present their findings. Presentation is an important part of the learning experience since all students may approach these *activities with different thoughts* and ideas. Presentations should include a variety of elements such as descriptions, visual aids and demonstrations.

TEACHER'S NOTES:

- Assign the **Lesson 4 - "The Highway Ride" Self Reflection/Evaluation rubric** to the students so they can complete a self-evaluation of their work. The rubric score and your evaluation will make up a portion of the assessment data for this lesson.
- Provide students with a **Teamwork and Self-Evaluation** sheet and review the form with the students before they complete them.

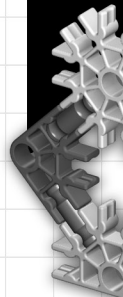
Evaluation

You may use some or all of the following to evaluate student's performance:

- Self Reflection/Evaluation Rubric
- Teamwork and Self Evaluation forms
- Presentation of the Challenge Solution(s)
- Research and Design Logs
- Student Response Sheets
- Design Journal

Extensions

1. After the students have worked through the activities, it is useful to extend the learning through career research and extended activities. Career components have been added to the **Research and Design Logs**, but can be extended by other means such as guest speakers, business tours, etc.
2. Extension activities should be included in any student presentations.





Research and Design Log

Name: _____ Date: _____

Define the following terms below. Be sure to write the definitions in your own words.

Simple Machines -

Lever -

Inclined Plane -

Wheel and Axle -

Screw -

Wedge -

Pulley -

Fulcrum -

1st Class Lever -

2nd Class Lever -

3rd Class Lever -

Name: _____ Date: _____

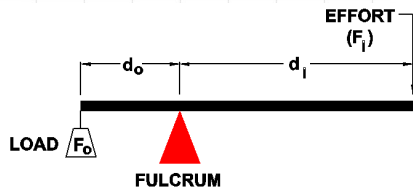


On Your Own

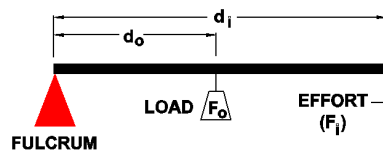
Simple Machines: Levers

Explore

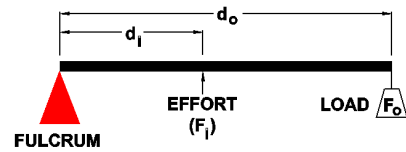
- After discussing levers in class, examine the 3 lever classes below and record the missing information in the chart provided, then answer the questions related to the data. Show all work on the back of this sheet or on notebook paper. Remember to include units.



1st Class



2nd Class



3rd Class

Given:

Load (F_o) =
100 N

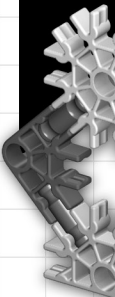
F_i = Effort Force
 F_o = Load Force
 d_i = Effort Distance to Fulcrum
 d_o = Load Distance to Fulcrum

Formulas:
 $F_i \times d_i = F_o \times d_o$
 $F_i = (F_o \times d_o) / d_i$
 $MA = d_i / d_o$
Input Work = $F_i \times d_i$

Lever Class	Input Effort (F_i)	Input Distance (d_i)	Output Distance (d_o)	Mechanical Advantage (MA)	Which has been increased: Force or Distance?	Input Work (W)
Class 1	N	0.4 m	0.2 m			Nm
	N	0.2 m	0.4 m			Nm
Class 2	N	0.6 m	0.3 m			Nm
	N	0.6 m	0.2 m			Nm
Class 3	N	0.3 m	0.6 m			Nm
	N	0.1 m	0.6 m			Nm

Elaborate and Explain

- After completing the chart above, can both force and distance ever be increased at the same time with a lever? Explain your answer.



- Can a 1st class lever be used to increase force or distance? Explain your answer.
- Can a 2nd class lever be used to increase force or distance? Explain your answer.
- Can a 3rd class lever be used to increase force or distance? Explain your answer.
- List at least 5 examples for each lever class that can be found around the home or at school.
 - o Class 1 -
 - o Class 2 -
 - o Class 3 -
- What class of lever does the K'NEX toll gate fall under and does it increase output distance or force? Explain your answer.



As a Group

Explore

- Discuss your answers to the lever questions and make sure everyone in the group has a good understanding of levers before moving on to the K'NEX programming activity below. Construct the basic K'NEX push car, if not still assembled from a previous activity, and the toll gate.
- Create a program that would simulate manual operation of the toll gate. In the early days of toll booth operation, an attendant would collect the toll, open the gate for you to pass, and then close the gate. You will be using the K'NEX motor, push button, and 2 LEDs for this activity. Your program should follow these guidelines:
 - o *For safety, you must determine an appropriate speed for the gate to open and close and also program the LEDs to blink alternately as a warning for approaching cars. The LEDs should blink continuously for the entire program.*
 - o *You can either develop the program so that the gate moves while the button is pressed or uses wait blocks to run each cycle. (i.e. press and hold the button and release it when the gate is fully open or closed as opposed to pressing the button and the motor runs for a set amount of time and stops after that time).*
 - o *The program should be able to cycle the gate to open and close at least 3 times.*

There are many ways to develop a program to complete this operation so brainstorm as a group to develop a strategy. **On graph paper**, draw the program you plan to use.

Name: _____ Date: _____



As a Group

The Automated Toll Gate

Explore

- It is now time to develop a program that completely automates the toll gate process. Imagine a system where the toll booth senses your approach, collects the toll electronically (charges your account), opens the gate, and then closes it behind you. Modify your toll gate to include 2 reed switches and add a magnet to your car. The magnet must be located at a level on the car that can trigger the reed switches as the car passes them. *When testing, make sure the magnet passes the reed switches as close as possible for them to trigger.* Most automatic pass systems used on toll gates today require the driver to slow down and not stop completely, allowing for faster operation. Your program must address the following:
 - *Flashing safety lights.*
 - *A buzzer that sounds for a second or two before the gate opens or closes for safety.*
 - *An entrance reed switch that senses the incoming car and opens the gate using an appropriate motor speed and wait time to open fully.*
 - *An exit reed switch that senses the car leaving and closes the gate using an appropriate motor speed and wait time to close fully.*
 - *The program should be able to cycle the gate to open and close at least 3 times.*

There are many ways to develop a program to complete this operation so brainstorm as a group to develop a strategy. **On graph paper**, draw the program you plan to use. **Start with a low time delay of about 1-2 seconds and work your way up to an appropriate time that opens and closes the gate. By starting with a high number, the system may try to keep running with the gate completely open, stalling the motor or causing it to slip.**

- What motor speed (or speeds) and times worked the best? Why did you choose these speeds and times?
- After running the test several times, did the gate continue to open and close exactly the same every time? If not, what problems occurred?
- Did you encounter any problems with the operation of the reed switches? Explain.



On Your Own

Elaborate and Explain

- Instead of using two reed switches to operate the gate, you could use one reed switch on the approach side to control the following:
 - o Opening time of the gate
 - o Wait time for the car to exit
 - o Closing time of the gate

While this could sound like a more efficient way to operate the toll gate using only one switch, what could be some of the advantages/disadvantages of such a system?

- Throughout this lesson, you have used a variety of simple machines. List as many simple machines used in your K'NEX models as you can for each type below. Some may not have been used in this activity so think back to all your previous K'NEX models and activities for examples.

- o Lever -
- o Inclined Plane -
- o Wheel and Axle -
- o Screw -
- o Wedge -
- o Pulley -

- Looking back at lesson 1, you identified different variables in your testing. What are some of the variables found in your K'NEX toll gate and programming?

o Independent Variable - _____

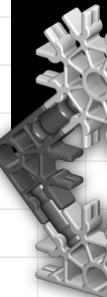
o Dependent Variable - _____

o Constants - _____



As a Group

- Discuss your individual findings as a group.



Challenge Design Brief

Lesson #4: The Highway Ride

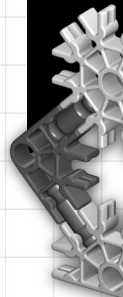
Name: _____ Date: _____



As a Group

Here are several possible design challenges for your group. Use notebook and graph paper to document the activity or activities and fasten them to this sheet.

- Rewrite your program to use only one reed switch instead of two. Timing will be very important so that a car can exit before the gate closes. Chart your program on graph paper and record your results.
- By having the gate cycle using wait blocks, variations in electricity and time may cause problems with the gate cycling completely (leaving a partially open gate). Redesign your gate to use a magnet and reed switch to limit its motion in one direction, much like you did for the garage door lesson and one reed switch to sense the car entering the toll booth. Chart your program on graph paper and record your results.
- **The Ultimate Challenge!** Design the toll gate to operate exactly as stated in the above challenge, but redesign your gate with a counter weight system to balance the gate (meaning that it would require the same effort to raise the gate as it would to lower it at the same speed). Chart your program on graph paper and record your results.
- How much would this toll booth cost to build? Determine the cost of the parts required to build the model using a 'Cost per Piece Chart.' Also, determine how many "mechanics" it would take to build the toll booth, a labor cost per hour, and the total number of hours each employee would be working on the project.



Self Reflection/Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____

Complete the Activity Assessment Rubric to provide your impression of how you did with this lesson.

Assessment Rubric			
<i>Circle Responses for each:</i>	Excellent	Good	Acceptable
Research and Design Logs & Worksheets	Student Response Sheets and Design Logs complete with no spelling or grammar errors. All answers on Student Response Sheets are accurate. <input type="text"/> 1-10	Student Response Sheets and Design Logs complete with few spelling or grammar errors. Most answers on Student Response Sheets are accurate. <input type="text"/> 1-8	Student Response Sheets and Design Logs complete with many spelling or grammar errors. Few answers on Student Response Sheets are accurate. <input type="text"/> 1-6
Design & Construction	Your device is very neatly constructed, easy to use, and meets or exceeds expectations outlined in the Design Brief. <input type="text"/> 1-10	Your device is neatly constructed, easy to use, and meets expectations outlined in the Design Brief <input type="text"/> 1-8	Your device has been constructed, is in useable form, and meets the materials criteria listed in the Design Brief. <input type="text"/> 1-6
Design Journals & Presentations	Your Design Journal is complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. It is presented in a neat and orderly fashion. <input type="text"/> 1-10	Your Design Journal is mostly complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows some disorder. <input type="text"/> 1-8	Your Design Journal is missing 1 or more logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows disorganization. <input type="text"/> 1-6
Teamwork/Work Ethic	You worked well with your teammates and interacted well with others. You demonstrated excellent reliability and initiative when working on this challenge. <input type="text"/> 1-5	You worked well with your teammates and interacted well with others. You were reliable and demonstrated initiative when working on this challenge. <input type="text"/> 1-3	You worked well with your teammates and others. You were generally reliability and usually demonstrated initiative when working on this challenge. <input type="text"/> 1
Total Score	<input type="text"/> /35		

Teacher Comments:

Teamwork & Self Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____



As a Group

Teamwork and cooperation are necessary skills required for most jobs since businesses typically have many employees that work together in teams rather than lots of individuals working alone. All employees need to contribute equally, using their skill sets to make a project successful while meeting deadlines. If one person fails to contribute adequately, the business or project can fail.

- **Communication Skills:** How well did your group communicate? How could communications within your group be improved?

- **Work Load:** How was work assigned in your group? Did individuals step up to accept responsibility? Were personal skills considered as work was assigned? For larger groups, is it beneficial to assign someone as a leader?

- **Presentation:** How was the unit presentation developed? How did the group determine responsibilities so no one was left out? What improvements could be made for future presentations?

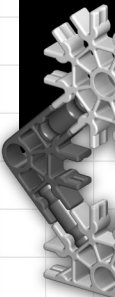


On Your Own

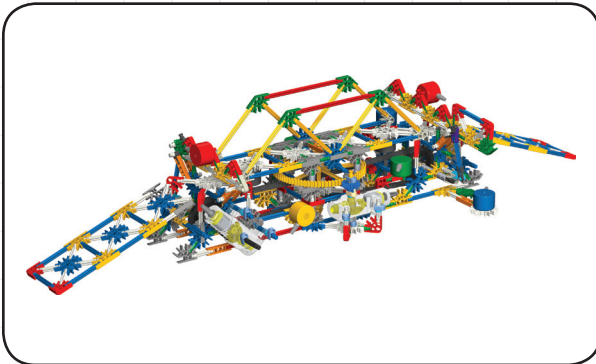
- **Personal Input:** Do you feel you contributed equally with your group? Did you do too much or not enough? Personal contributions to the group are listed in the *Research and Design Log*, but what could you do to work better in a team?

LESSON #5: OVER THE RIVER

5-7 X



Model: K'NEX Swing Bridge



Main Concepts (STEM):

- **Science**
 - Mechanical Advantage in Gear Drives
- **Technology & Engineering**
 - Gears and Chain Drivers
- **Mathematics**
 - Computations and Ratios

Objectives:	Required Materials:	Optional Materials:
<p>Student will be able to:</p> <ul style="list-style-type: none"> • Work effectively both independently and in collaborative teams. • Correctly connect and program the K'NEX interface to control the swing bridge. • Recognize and understand the features of chain drives, cranks and cams. • Modify their computer programs to control the swing bridge for specific purposes. 	<p>Teacher will need:</p> <ul style="list-style-type: none"> • K'NEX Interface and software • Computer projector and/or whiteboard • Extension cord (if power is not close to testing area) <p>Students will need:</p> <ul style="list-style-type: none"> • K'NEX Interface and components • Computer with K'NEX Computer Control software • K'NEX swing bridge model • Copies of: <ul style="list-style-type: none"> ○ Research & Design Logs ○ Student Response Sheets ○ Challenge Design Briefs ○ Teamwork & Self-Evaluation forms ○ Self Reflection/Evaluation Rubrics 	<ul style="list-style-type: none"> • Graph paper • Notebook paper • Colored pencils • Sample K'NEX models (prebuilt swing bridge or similar models to demonstrate gears and chains) • Sample geared devices (mechanical toys, household appliances, pencil sharpener, etc.) • Calculators

TEACHER'S NOTES:

- Students will use the building instructions, provided on the Building Instruction CD, to build the swing bridge. After the students construct the swing bridge, begin the engagement portion of the lesson. Lesson 5 should take 5-7 class periods, depending on how challenge activities are handled.
- As with previous lessons, students will be asked to construct the model, perform various experiments, chart data, record their thoughts and actions, and develop challenge activities.
- The K'NEX swing bridge has some components that may be difficult to time correctly. Make sure the students follow the assembly instructions carefully.

Process

Engagement

1. Keeping in line with the *STEM Exploration* vacation road trip, discuss how the students have passed the toll gate and have now encountered a *Swing Bridge* on their route. A swing bridge is a type of moveable bridge that allows river traffic to pass. This lesson will introduce them to gear and chain drives while programming the bridge to operate. Discuss the processes used in the lesson with the students:
 - Students will construct the K'NEX swing bridge model and complete the *Engagement* activities. The swing bridge model uses gears to rotate the bridge and a chain drive to control the gates. Students will experience the challenges of timing the chain drive so the gates operate properly.
 - Students will construct the K'NEX swing bridge model and complete the Engagement activities. The swing bridge model uses gears to rotate the bridge and a chain drive to control the gates. Students will experience the challenges of timing the chain drive so the gates operate properly.
 - They will be programming their model to run various tests where the bridge and gates operate correctly with one another.
 - Students will also examine the fundamentals of gear ratios and chain drives.
 - They will finish the lesson by completing one or more open-ended challenge activities.
2. Distribute or direct students to the **Research and Design Logs** and **Student Response Sheets** for this unit. Introduce the **Challenge Design Briefs** when the students are ready for the challenge activities and the **Assessment Sheets** at the end of the activity. This will help students focus on the current activities. These pages are provided at the end of each lesson or in the **Resources** section of the Teacher's Guide. Links to editable electronic versions of the Research & Design logs, Student Response Sheets, Design Briefs, Evaluation/Assessment forms and the Cost Per Piece chart can be accessed by the students from the Start Menu, or you can drag and drop the "STEM Explorations Resources" folder from the software CD onto the desktop or a shared drive.
3. Discuss that the **Research and Design Logs** and **Student Response Sheets** will be used in the same manner as lesson 1.
4. Lesson 5 introduces the students to a swing bridge which is a type of moveable bridge. The students may not understand the purpose of this type of bridge or the different styles of movable bridges. This would be an ideal time to discuss moveable bridges with the students and why they are important for water traffic. While there are many different styles of moveable bridges, the students may be most familiar with *draw*, *bascule*, and *swing bridges*. This would provide an excellent opportunity for the students to find images on the internet that represent the various styles of moveable bridges that could be shared in class discussion.
5. A website with animated images of moveable bridges can be found here:

[Moveable Bridges](#)

Exploration

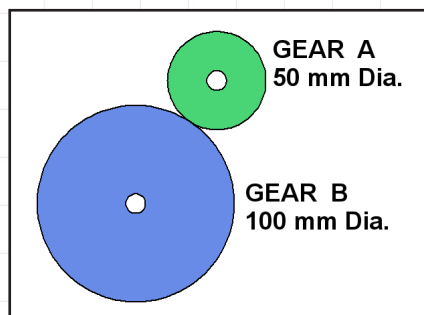
1. Establish student teams (2-3 students per group), and then review the activity and **Student Response Sheet 1**. Allow students time to discuss the activity in their groups.
2. Students should understand the safe operation of the K'NEX interface and electrical concerns. Review the STEM Explorations *User's Guide*, if needed.
3. The students should construct the K'NEX swing bridge model. This model is constructed using 2 push button switches to control the gates, a buzzer, 2 LEDs, and 2 motors. Later challenges will include reed switches and magnets.
4. Review the activity and **Student Response Sheet 1** with the class. Discuss how this activity will introduce the students to two new devices that use the concepts of simple machines to operate: the gear and the chain and sprocket. Like all simple machines, these devices are used to multiply force and distance. Because gears and chains can be developed in direct ratios to one another, they can also be used for precise timing of operations (i.e. clocks, engines). They will also be introduced to the concept of cranks and cams which can be used to change the rotational motion of gears and chains into linear motion. This rotational to linear conversion occurs in the K'NEX swing bridge gates.
5. Review the concept of gears and gear ratios. The K'NEX swing bridge uses 2 gears to rotate the bridge. There is a small gear on the motor and a large gear on the base of the bridge. To introduce the students to gears before the classroom discussion, it may be helpful to have them review a website like:

[Gears](#)

Gears can be used for:

- Reversing the direction of rotation.
- Multiplying the rotation (distance) or force (increasing or decreasing the speed or force).
- Moving the rotational motion to a different axis.
- Keeping the rotational axes of two gears synchronized (meaning the two shafts are turning in exact proportion to one another).

A gear combines the simple machine concepts of a wheel and axle and a lever. The gears spin on their axles while the gear teeth act as small levers that push against each other, causing one gear to rotate the other (transferring the energy from one gear to the other). There is also a mechanical advantage present in a gear system that occurs by varying the diameters of the gears. By varying the diameters of the gears and keeping the same size gear tooth and form for both gears, precise ratios can be developed. These ratios will multiply force and distance. For example, a larger gear may be easier to spin, but will spin slower and vice-versa. Compare this to the example of a door knob or faucet. If you replace the handle on either with a smaller diameter knob (or just the shaft), it become harder to rotate. Gears act much the same way in regards to diameter.



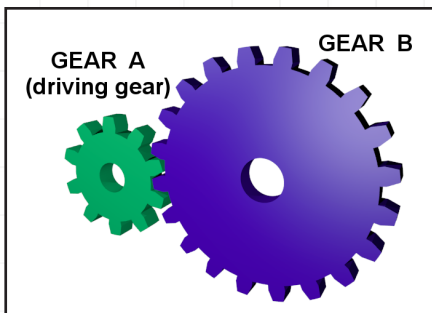
The example to the left shows two gears with the teeth removed to make initial discussion easier. Gear A is 50 mm in diameter while Gear B is 100 mm in diameter. Since Gear A is $\frac{1}{2}$ the diameter of Gear B, Gear A will revolve two times with every one rotation of Gear B. The gears also revolve in opposite directions. Gear ratios are expressed as:

$$\text{Gear Ratio} = X:1$$

In the next example, the gear ratio is **2:1**. We also need to express if the system is geared UP or DOWN. This is determined by knowing which gear is the Input or Driving gear and which gear is the Output or Driven gear. If Gear B has the motor attached to it and is driving Gear A, this system would be considered geared up because the driven gear is rotating twice as much as the driving gear.

If Gear A has the motor attached to it and is driving Gear B, it is considered *geared down* since the driven gear is rotating $\frac{1}{2}$ as much as the driving gear. In the past two lessons we discussed mechanical advantage in simple machines. If the system is geared up, the driven gear will spin twice as fast as the driving gear, but output force is cut in half. If the system is geared down, speed is reduced, but force is doubled.

Since gears use teeth to keep from slipping, we will actually count teeth rather than use diameters to determine ratios. This also prevents inaccuracies due to minor differences in diameters. Here are some sample gear ratio examples that can be discussed with the students:



Ratio = # of teeth on larger gear / # of teeth on smaller gear : 1

Gear B = 20 teeth

Gear A = 10 teeth

Ratio = 20 T / 10 T : 1

Ratio = 2:1, geared down

With Gear A as the input, or driving gear, Gear B will spin half as fast, but provide two times the input force.

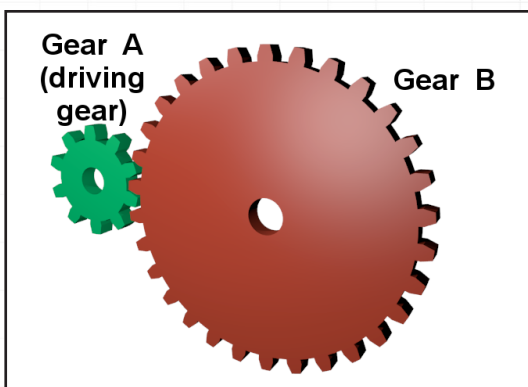
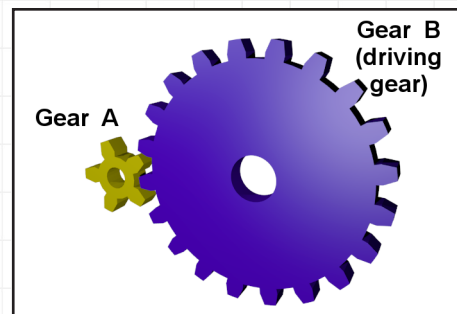
Gear B = 20 teeth

Gear A = 5 teeth

Ratio = 20 T / 5 T : 1

Ratio = 4:1, geared up

With Gear B as the input, or driving gear, Gear A will spin four times faster than Gear B, but will only provide $\frac{1}{4}$ of the input force.



Gear B = 30 teeth

Gear A = 10 teeth

Ratio = 30 T / 10 T : 1

Ratio = 3:1, geared down

With Gear A as the input, or driving gear, Gear B will spin $\frac{1}{3}$ as fast, but provide three times the input force.

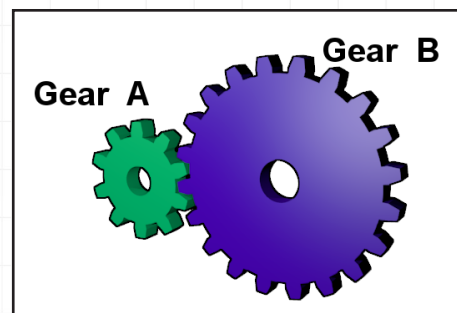
Gear B = 15 teeth

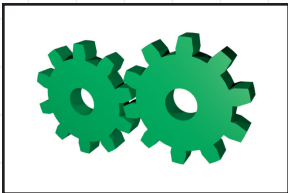
Gear A = 10 teeth

Ratio = 15 T / 10 T : 1

Ratio = 1.5:1, geared up

With Gear B as the input, or driving gear, Gear A will spin 1.5 times faster than Gear B, but will only provide $\frac{2}{3}$ of the input force.





Both gears have 10 teeth

Ratio = 10 T / 10 T : 1

Ratio = 1:1, not geared up or down

This type of gear system can only provide the benefit of changing rotational direction, moving the rotational axis to another location, or keeping rotation synchronized. It does not provide a mechanical advantage to the system.

TEACHER'S NOTES:

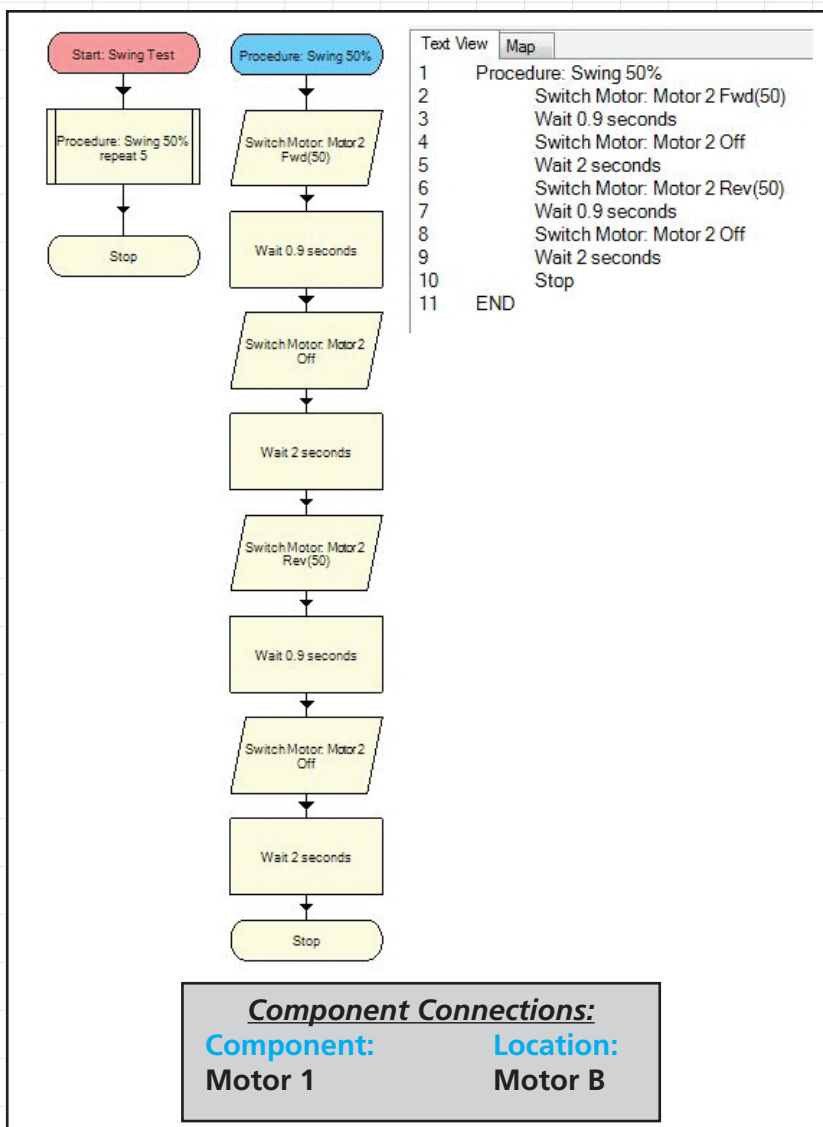
While working through this discussion about gears, it would be helpful to have physical examples available to demonstrate these principles. Examples could include a pencil sharpener, old disassembled kitchen appliances, multi-speed bike, or mechanical toys. Devices should be disabled for safety.


If any students display an interest in cars (many have experienced driving computer games), you can use the example of an automotive transmission. When in a low gear (first or second), you are gearing the engine output down for low speed, but increasing force (good for pulling out or going up hills). Higher gears allow you to cruise on the highway, giving you speed, but decreasing force. That is why you slow down on hills and need to shift down to a lower gear (or the car automatically shifts down). One definition of the term "overdrive" refers to a gear that causes the transmission to spin faster than the engine's speed.

6. Instruct the students to complete **Student Response Sheet 1** and the first five vocabulary terms found on the **Research and Design Log**. These definitions relate to the gear discussion they have just completed.

7. In this activity, the students will program their bridge to rotate at several speeds and times to determine accuracy. The sample program shown uses a procedure to rotate the bridge open, pause, and then rotate it back. The procedure is set to repeat 5 times. They can create 3 procedures for all speed tests or reprogram for each speed.

Depending on available time and student ability level, you may wish to provide students with a flow chart of the first steps of their program to get them started. The students will need to develop and diagram the program they will use for the test.



- 
8. After the students have had sufficient time to test their bridge and respond to the questions related to the activity on their *Student Response Sheets*, review the remaining vocabulary terms found on the **Research and Design Log**. Definitions are found in these notes and in the *Answer Key*. This vocabulary relates to the second part of the activity where they will be examining chain drives, belts, cranks and cams.
9. Review **Student Response Sheet 2** with the class. Tell the students that they will be examining some fundamentals about chains, belts, cranks and cams. The K'NEX swing bridge uses a chain drive system to operate the gates. A chain or belt drive is used to link two or more rotational shafts together over a distance. For a belt system, pulleys are used with the belt looping around them. For chain drive systems, sprockets are used. Chain drive systems have a benefit over simple belt drives in that they act like gears that do not slip and can provide accurate timing. Simple belt drives rely on friction to turn the pulleys which can allow for slippage and added friction in the system. A modified belt system is used on many devices today in place of chains called a toothed or cogged belt. These belts are used in car engines and computer printers for accurate timing.
- Another device used in the K'NEX Bridge is a simple crank. A crank is useful for converting rotary motion into linear motion. A crank is used to lower the gates on the bridge.
10. Review the principles of belts and chains. The students should be familiar with chain drives on bicycles. Ask them why we use chain drives instead of belt drives or gears on a bicycle? Answers should relate to belts slipping, increased friction, large gears or gears too far apart on a bicycle to be useful. Discuss that chain sprocket ratios can be calculated the same as gear ratios since sprockets have teeth similar to gears. This can be related to the various gears on a bicycle.

TEACHER'S NOTES:

To help students understand the principles of chains and belts, it would be useful to have examples of belt and chain drives for them to see. You can also find images on the internet or have students search for examples. This could also provide a good opportunity to examine some of the history and evolution of belt and chain drives. Farming and industry once used wide leather belts to drive machinery that later evolved to v-belts and flat multi-grooved belts.

11. Discuss the concept of cranks and cams. Although cranks and cams can perform similar operations, they are defined differently.
- o A crank is a device for transmitting rotary motion, consisting of a handle or arm attached at right angles to a shaft.
 - o A cam is a projection on a rotating part on machinery, designed to make sliding contact with another part while rotating and to impart reciprocal or variable motion to it.

While cams typically only convert rotary motion to linear motion, cranks can convert motion both directions. For example, a gasoline engine converts the linear motion of the piston into rotary motion, but an air compressor converts the rotary motion of the motor into linear motion to compress air. While both systems use a crank, one converts linear to rotary while the other converts rotary to linear. The K'NEX swing bridge uses a crank to raise and lower the gates.

For more information about cranks and cams along with animations, review the following websites:

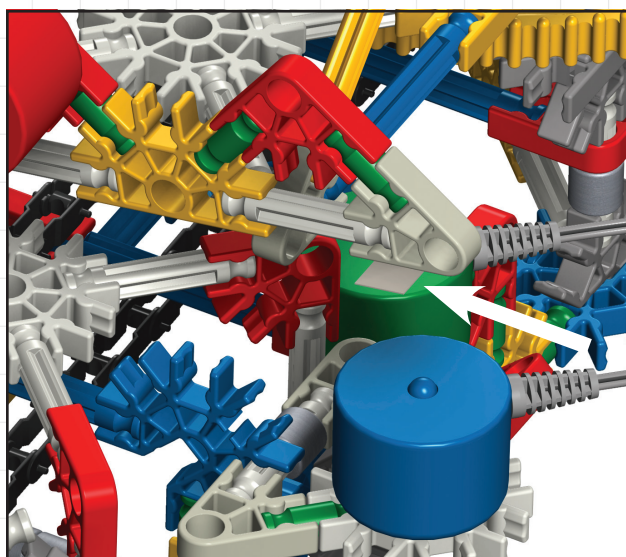
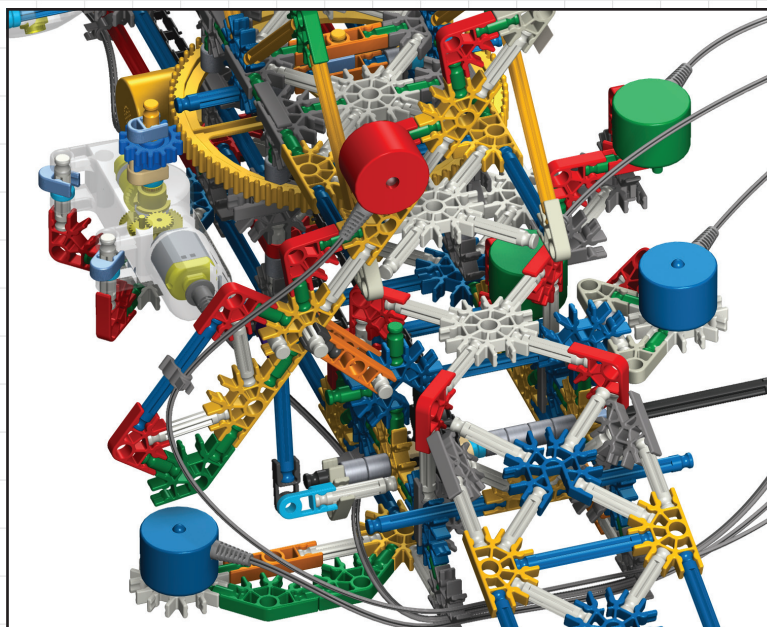
[3D Animations - Cranks, Cams & More](#)
[Cranks & Cams](#)

12. Student Response Sheet 2 will ask the students questions about cranks, cams and gears while developing a program that will operate the gates while rotating the bridge.

TEACHER'S NOTES:

The chain drive on the K'NEX Bridge requires accurate timing for the gates to function correctly. The students will need to make sure the sprockets are aligned so both gates rise and close adequately to demonstrate their operation.

- The gate positions are controlled using push button limit switches. The K'NEX model may need slight adjustments for the gate to consistently hit the switches.



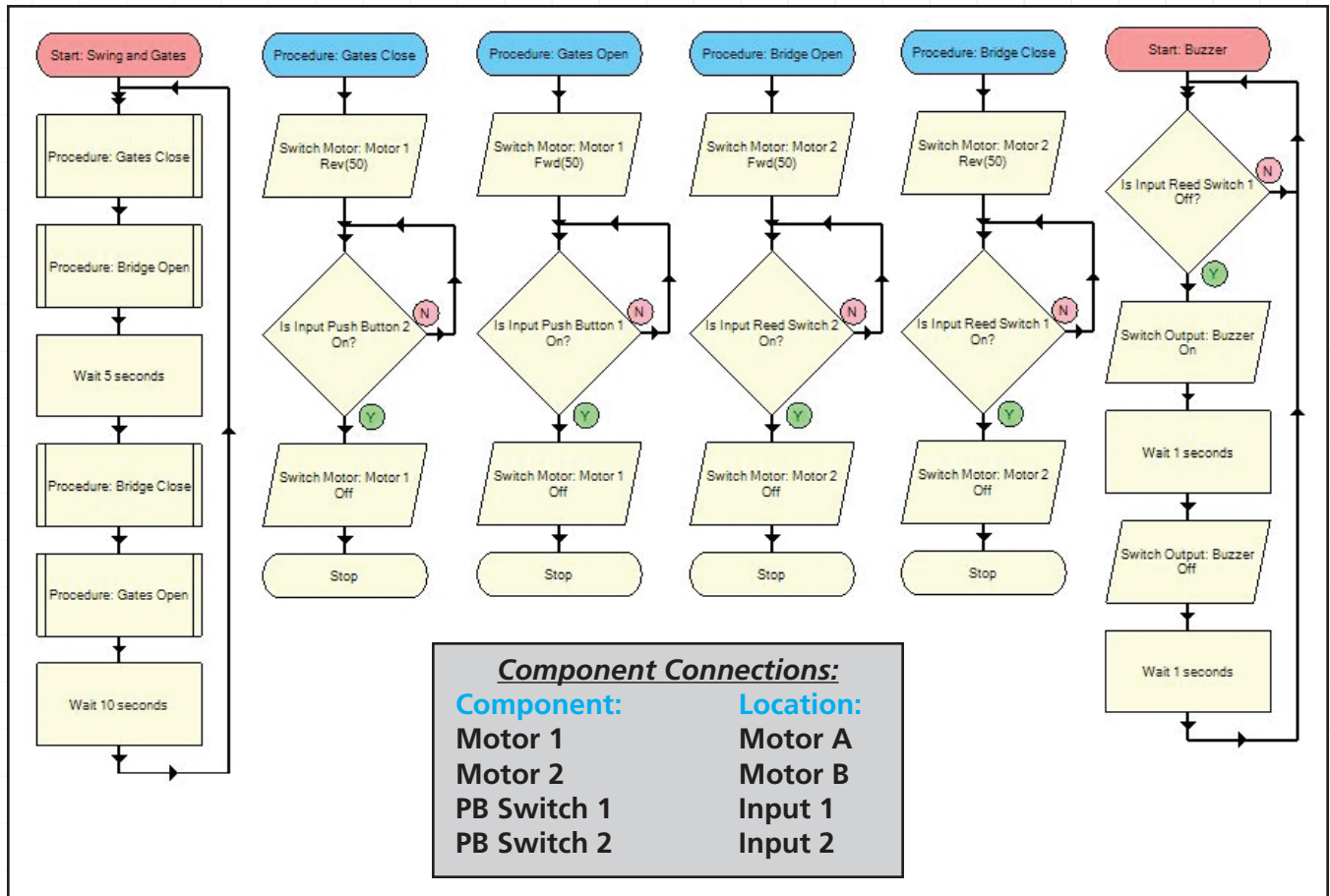
TEACHER'S NOTES:

The students may need to select a motor speed that is less than 100%. Running the motor for the gates at a high speed will increase the chance of the gate missing the switches or running the gates too far, causing the linkage to jam.

To ensure the Push Button is pressed with each trial, students may tape a small piece of cardboard to the gate to increase the size of the contact point for the switches.

- When students are ready to begin programming you may have them talk through (or write down) the steps they will need to include in their program. This would not be the formal listing of the steps that they do on graph paper, but rather an informal walkthrough where they begin to organize their programming strategy. This process may help them as they organize their thoughts before they begin programming.

The programming activity for the swing bridge in Student Response Sheet 2 will require the students to open and close the gates and swing the bridge in a realistic operation. A sample program is displayed here:



The program displayed starts with the gates in an open position and the bridge in place for car traffic. The procedure "Gates Close" is executed with the motors set at 50% and using input 1 as the "gates closed" contact push button switch. After 2 seconds, the procedure "Bridge Open" is executed with the swing motor set to 50% for slow, smooth operation. The *Wait* operation should be set to swing the bridge approximately 90 degrees. After 2 seconds, the bridge closes (same procedure as "Bridge Open" except for reversed motor direction) and then the gates open (same procedure as "Gates Close" except for reversed motor direction and input switch).

The students may still experience difficulty with rotating the bridge perfectly using wait blocks. The challenge activities will solve this problem by using a magnet and reed switches for rotational limits.

- After the students have had sufficient time to test their bridge and respond to the questions related to the activity on their *Student Response Sheets*, assign the **Challenge Design Briefs** that will outline several possible challenge activities for you or the students to select from. Most activities require adding reed switches and a magnet to the bridge.

A sample program can be found in the *Answer Sheets* for teacher reference. It may also be presented to the students depending on available time and ability level. Advise the students to use the component connection shown.

Component Connections:	
Component:	Location:
Motor 1	Motor A
Motor 2	Motor B
PB Switch 1	Input 1
PB Switch 2	Input 2
Reed Switch 1	Input 3
Reed Switch 2	Input 4
LEDs	Outputs 1,2
Buzzer	Output 3

Explanation

1. Throughout the activities in this lesson students have been completing **Student Response Sheets**. Allow sufficient time to complete these sheets as they finish each activity so they can demonstrate they are able to explain what they have discovered. Remind students that some sections of the **Student Response Sheets** are to be completed "**As a Group**" while others are to be completed "**On Your Own**." They should be formulating thoughts, calculations and definitions from their own words.
2. Decide if you want groups to present their results after each *activity* or *wait until the entire unit is finished* to present their findings. Presentation is an important part of the learning experience since all students may approach these *activities with different thoughts* and ideas. Presentations should include a variety of elements such as descriptions, visual aids and demonstrations.

Elaboration

Students will self-evaluate their challenge solutions based on the criteria provided in the rubric for this activity. Elaboration components are found in the logs and response sheets.

TEACHER'S NOTES:

- Assign the **Self Reflection/Evaluation** rubric to the students so they can self-evaluate their work. The rubric score and your evaluation will make up a portion of the assessment data for this lesson.
- Provide students with a **Teamwork and Self-Evaluation** sheet and review the form with the students before they complete them.

Evaluation

You may use some or all of the following to evaluate student's performance:

- Self Reflection/Evaluation Rubric
- Teamwork and Self Evaluation forms
- Presentation of the Challenge Solution(s)
- Research and Design Logs
- Student Response Sheets
- Design Journal

Extensions

1. After the students have worked through the activities, it is useful to extend the learning through career research and extended activities. Career components have been added to the **Research and Design Logs**, but can be extended by other means such as guest speakers, business tours, etc.
2. Extension activities should be included in any student presentations.



Research and Design Log

Name: _____ Date: _____

Define the following terms below. Be sure to write the definitions in your own words.

Gear -

Gear Tooth -

Gear Ratio -

Gear Up -

Gear Down -

Chain Drive -

Sprocket -

Belt Drive -

Tooth or Cogged Belt -

Crank -

Cam -



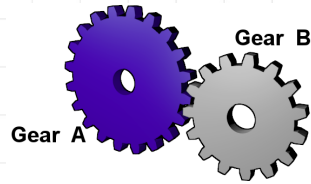
On Your Own

Explore

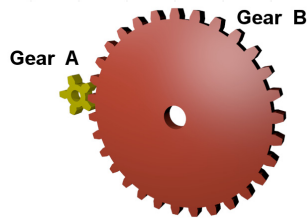
- For more experience with gear ratios, complete the following exercises:

Input force for all examples: 100N

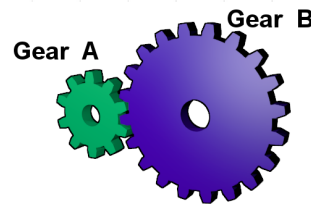
Gear A is the input (driving) gear for all examples.



EXAMPLE 2



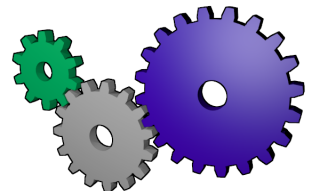
EXAMPLE 1



EXAMPLE 3

Example	Gear A # of Teeth (T_a)	Gear B # of Teeth (T_b)	Gear Ratio ($T_{larger} / T_{smaller}$)	Gear Up/Down	Output Force (N)
1			:1		
2			:1		
3			:1		

- The example below adds a third gear to the system between the input and output gears called an idler. Does it add to the gear ratio of the system? What are the possible benefits of this system? Explain your answer.



As a Group

- Discuss your individual findings as a group.

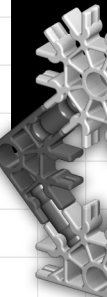
Name: _____ Date: _____



As a Group

Here are several possible design challenges for your group. Use notebook and graph paper to document the activity or activities and fasten them to this sheet.

- Change your program from Student Response Sheet 2 to use reed switches and a magnet to accurately swing the bridge. Chart your programs on graph paper and record your results.
- While the gates are closed, a real bridge would include blinking lights to warn approaching cars the bridge cannot be crossed. Modify your program to include blinking LEDs when the gates are lowered for safety. Chart your programs on graph paper and record your results.
- **The Ultimate Challenge!** Develop your program to include the following features:
 - o The gates lower with blinking LEDs while the gates are down.
 - o The bridge swings using the reed switches and magnet for limit control.
 - o The buzzer sounds (or beeps) while the bridge is opening and closing (or during the entire cycle).
 - o The gates open and the LEDs stop blinking.
 - o Chart your programs on graph paper and record your results.
- You are a civil engineer given the challenge of building this bridge. How much would this bridge cost to build? Determine the cost of the parts required to build the model using a 'Cost per Piece Chart.' Also, determine how many "construction workers" it would take to build the bridge, a labor cost per hour, and the total number of hours each employee would be working on the project.



Self Reflection/Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____

Complete the Activity Assessment Rubric to provide your impression of how you did with this lesson.

Assessment Rubric			
<i>Circle Responses for each:</i>	Excellent	Good	Acceptable
Research and Design Logs & Worksheets	<p>Student Response Sheets and Design Logs complete with no spelling or grammar errors. All answers on Student Response Sheets are accurate.</p> <p><input type="text"/> 1-10</p>	<p>Student Response Sheets and Design Logs complete with few spelling or grammar errors. Most answers on Student Response Sheets are accurate.</p> <p><input type="text"/> 1-8</p>	<p>Student Response Sheets and Design Logs complete with many spelling or grammar errors. Few answers on Student Response Sheets are accurate.</p> <p><input type="text"/> 1-6</p>
Design & Construction	<p>Your device is very neatly constructed, easy to use, and meets or exceeds expectations outlined in the Design Brief.</p> <p><input type="text"/> 1-10</p>	<p>Your device is neatly constructed, easy to use, and meets expectations outlined in the Design Brief</p> <p><input type="text"/> 1-8</p>	<p>Your device has been constructed, is in useable form, and meets the materials criteria listed in the Design Brief.</p> <p><input type="text"/> 1-6</p>
Design Journals & Presentations	<p>Your Design Journal is complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. It is presented in a neat and orderly fashion.</p> <p><input type="text"/> 1-10</p>	<p>Your Design Journal is mostly complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows some disorder.</p> <p><input type="text"/> 1-8</p>	<p>Your Design Journal is missing 1 or more logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows disorganization.</p> <p><input type="text"/> 1-6</p>
Teamwork/Work Ethic	<p>You worked well with your teammates and interacted well with others. You demonstrated excellent reliability and initiative when working on this challenge.</p> <p><input type="text"/> 1-5</p>	<p>You worked well with your teammates and interacted well with others. You were reliable and demonstrated initiative when working on this challenge.</p> <p><input type="text"/> 1-3</p>	<p>You worked well with your teammates and others. You were generally reliability and usually demonstrated initiative when working on this challenge.</p> <p><input type="text"/> 1</p>
Total Score	<p><input type="text"/> /35</p>		

Teacher Comments:

Teamwork and Self-Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____



As a Group

Teamwork and cooperation are necessary skills required for most jobs since businesses typically have many employees that work together in teams rather than lots of individuals working alone. All employees need to contribute equally, using their skill sets to make a project successful while meeting deadlines. If one person fails to contribute adequately, the business or project can fail.

- **Communication Skills:** How well did your group communicate? How could communications within your group be improved?

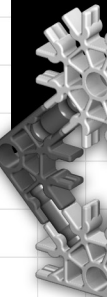
- **Work Load:** How was work assigned in your group? Did individuals step up to accept responsibility? Were personal skills considered as work was assigned? For larger groups, is it beneficial to assign someone as a leader?

- **Presentation:** How was the unit presentation developed? How did the group determine responsibilities so no one was left out? What improvements could be made for future presentations?



On Your Own

- **Personal Input:** Do you feel you contributed equally with your group? Did you do too much or not enough? Personal contributions to the group are listed in the *Research and Design Log*, but what could you do to work better in a team?



LESSON #6: TAKING A SPIN AT THE PARK

4-6 X



Model: K'NEX Amusement Park Ride



Main Concepts (STEM):

- **Science**
 - Gravity and Newton's Laws of Motion
- **Technology & Engineering**
 - Amusement Park Ride Design
- **Mathematics**
 - Measurement and Computation

Objectives:	Required Materials:	Optional Materials:
<p>Student will be able to:</p> <ul style="list-style-type: none"> • Work effectively both independently and in collaborative teams. • Correctly connect and program the K'NEX interface to control the amusement park ride. • Calculate distance and speed for the amusement park ride. • Recognize and understand Newton's three laws of motion and G-forces. • Modify their computer programs to control the ride for specific challenges. 	<p>Teacher will need:</p> <ul style="list-style-type: none"> • K'NEX Interface and software • Computer projector and/or whiteboard • Extension cord (if power is not close to testing area) <p>Students will need:</p> <ul style="list-style-type: none"> • K'NEX Interface and components • Computer with K'NEX Computer Control software • K'NEX amusement park ride model • Stopwatch or clock with second hand • Printed or Electronic copies of: <ul style="list-style-type: none"> o Research & Design Logs o Student Response Sheets o Challenge Design Briefs o Teamwork & Self-Evaluation forms o Self Reflection/Evaluation Rubrics 	<ul style="list-style-type: none"> • Graph paper • Notebook paper • Colored pencils • Sample K'NEX models (prebuilt amusement park ride, rollercoaster or similar models to demonstrate amusement park ride technology) • Calculators

TEACHER'S NOTES:

- Students will use the building instructions to build the amusement park ride. After the students construct the ride, begin the engagement portion of the lesson. Lesson 6 should take 4-6 class periods, depending on how challenge activities are assigned.
- As with previous lessons, students will be asked to construct the model, perform various experiments, chart data, record their thoughts and actions, and develop challenge activities.
- The K'NEX amusement park ride uses 2 motors, 2 LEDs and a buzzer. For portions of the lesson, students will also need a push button switch to be able to control their program.
- The chain controlling the seat rotation may be tight and require students to build carefully.

Process

Engagement

1. Keeping in line with the *STEM Exploration* vacation road trip, discuss how the students have now reached one of their vacation spots - *an amusement park*. The first ride they encounter in the park is a revolving type of ride. This ride can be slow and relaxing (like a Ferris wheel) or an exciting, fast-paced ride that can make a rider sick! This lesson will introduce them to Newton's laws of motion and gravitational forces (G-forces) while programming the ride to operate. Discuss the processes used in the lesson with the students:
 - Students will construct the K'NEX amusement park ride model for the lesson and complete the *Engagement* activities. The amusement park ride uses one motor to rotate the swing arm and one motor to rotate the seat. If the seat arm motor is not engaged, it will keep the seat facing the same direction the entire time, like on a Ferris wheel.
 - They will be programming their model to run various tests to determine safe operating speeds for riders.
 - Students will also examine the fundamentals of Newton's laws of motion.
 - They will finish the lesson by completing one or more open-ended challenge activities.
2. Distribute or direct students to the **Research and Design Logs** and **Student Response Sheets** for this unit. Introduce the **Challenge Design Briefs** when the students are ready for the challenge activities and the **Assessment Sheets** at the end of the activity. This will help students focus on the current activities. These pages are provided at the end of each lesson or in the **Resources** section of the Teacher's Guide. Links to electronic versions of the logs, vocabulary worksheets, Student Response Sheets, Design Briefs, Evaluation/Assessment forms and the Cost Per Piece chart) can be accessed by the students from the Start Menu, or you can drag and drop the "STEM Explorations Resources" folder from the software CD onto the desktop or a shared drive.
3. Discuss that the **Research and Design Logs** and **Student Response Sheets** will be used as in previous lessons.
4. Lesson 6 introduces the students to the concepts of a spinning amusement park ride where they will need to examine some basic laws of motion and safe speeds for riders.
5. Discuss with the students that while amusement park rides can be fun, there is a lot of physics involved in their design to make them fun and safe. While part of the excitement is the speed of the ride; fast turns, surprises, and scares all add up to the thrill of the ride. While rides continue to evolve to increase this thrill factor, some basic physics need to be followed so riders do not become injured.
6. Have the students discuss their favorite amusement park rides and what makes these rides exciting. To introduce them to the physics behind the rides, visit a website like the one below:

[Physics Behind Amusement Park Rides](#)

Exploration

1. Establish student teams (2-3 students per group), and then review the activity and **Student Response Sheet 1**. Allow students time to discuss the activity in their groups.
2. Students should understand the safe operation of the K'NEX interface and electrical concerns. Review the STEM Explorations *User's Guide* for details.
3. The students should construct the K'NEX amusement park ride model. This model is constructed using 2 motors, 2 LEDs, a buzzer and a push button switch. There is also a chain drive used to control the swing and rotation of the rider seat.
4. Review the activity and **Student Response Sheet 1** with the class. Discuss how this activity will introduce the students to Newton's laws of motion and gravitational forces. They may have heard the term "G-force" in flight and rocketry movies or even related to amusement park rides. Students will be examining the concept of G-force while calculating speeds and distances related to the ride.
5. Review *Newton's laws of motion* with the students. Sir Isaac Newton is known for his 3 laws for moving objects. The students may already know some facts about Sir Isaac Newton, like his ideas on gravity (the apple falling on his head). The three laws are:

- **Newton's First Law of Motion:**

An object at rest will remain at rest unless acted on by an unbalanced force. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an unbalanced force. This is also called the "Law of Inertia".

Inertia means something has a tendency to do nothing or to remain unchanged. This law basically means that an object will keep doing what it is doing unless some force acts upon it. While in space or in a vacuum, an object will continue in motion, essentially forever, because there are few other forces to act upon the object. On earth, factors such as gravity, air resistance, and surface friction tend to disrupt an object's motion causing it to slow down and stop.

- **Newton's Second Law of Motion:**

Acceleration is produced when a force acts on a mass. The greater the mass (of the object being accelerated) the greater the amount of force needed (to accelerate the object).

This law basically states that a heavier object will require more force to move it than a lighter object. For example, it's easier to kick a soccer ball than a concrete block. The second law can be expressed through the formula *Force = Mass x Acceleration (F=ma)*.

- **Newton's Third Law of Motion:**

For every action there is an equal and opposite re-action.

Whenever you push on something, it is also pushing back.

TEACHER'S NOTES:

Ask the students to provide examples of the three laws of motion they see on a daily basis. It may also be a good opportunity to examine the various amusement park rides discussed earlier and relate these laws to those rides.

6. For more details about Sir Isaac Newton and the laws of motion, review a website such as:

[Newton's Laws of Motion 1](#)

[Newton's Laws of Motion 2](#)

[Newton's Laws of Motion - Interactive](#)

7. Review *gravity* with the students. Sir Isaac Newton is also credited with discovering gravity when he fell asleep under an apple tree and an apple fell on his head, leading him to discover the reason for the phenomena.

Gravity is defined as the force that attracts a body toward the center of the earth, or toward any other physical body having mass.

It is the force that keeps us grounded and keeps all the planets and stars in place. You may keep the discussion of gravity as simple or as complex as you wish with the students. Normal gravity is considered to have an acceleration of 9.8 m/s².

8. Review the concept of *g-force* with the students.

G-force is a unit of force equal to the force exerted by gravity; used to indicate the force to which a body is subjected when it is accelerated.

Survey the students to see if any have heard this expression used to describe the forces placed on a pilot, racecar driver, or astronaut. Standing still, a person is subjected to 1g. An astronaut at take-off may experience 3g for an extended period of time. If a person weighs 150 pounds, they would feel like they weigh 450 pounds at 3g. Some roller coasters can provide short bursts of 5g or 6g which would make that person feel like they weigh 900 pounds. People can handle large g-forces for short periods of time, (as displayed in the everyday events below) but could experience health problems if the forces are extended over longer periods of time. Even forces of only 2g-3g experienced over long periods of time can have detrimental effects on the human body.

Tell the students that they experience elevated g-forces during everyday events. Some studies give the following numbers:

<p style="text-align: center;"> <i>Sneeze – 2.9g</i> <i>Cough – 3.5g</i> <i>Crowd jostle – 3.6g</i> <i>Slap on back – 4.1g</i> <i>Hop off step – 8.1g</i> <i>Plop down in chair – 10.1g</i> </p>

More information about these numbers and other g-force information can be found at:

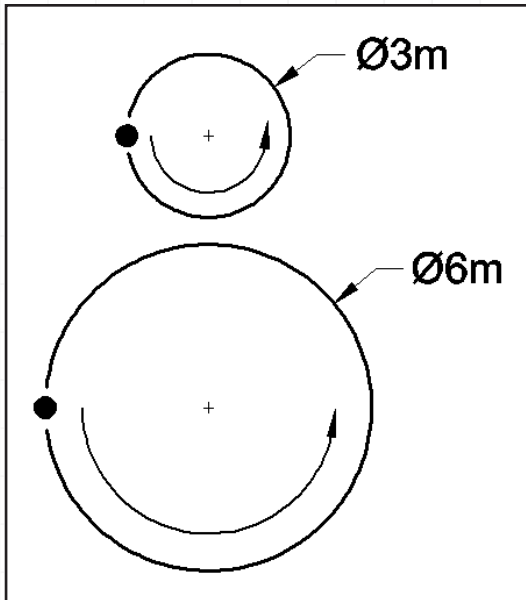
[International Association of Amusement Parks and Attractions - G-Forces](#)

[The Effects of G-Forces on the Body](#)

Most amusement park ride designers will keep G-forces below 6g. Roller coasters may approach this number or even pass it slightly for short periods of time. Rides that spin at a constant rate, like our K'NEX model or the *Gravitron* ride (a ride that spins and you stick to the walls) **will usually not pass 4g**. This speed is a safe maximum for most riders for rides spinning at a constant rate for a minute or more.

While it would be interesting to have the students calculate G-forces for the amusement park ride, it would be difficult for middle school students to complete and understand the concepts and calculations. Instead, the students will focus on safe speeds and distances for the ride.

9. Discuss calculating ride speeds with the students. Today's roller coasters and other rides can reach about 130 km/h (80 mph). Since the type of ride the students have constructed spins in a circle, radius and circumference need to be calculated over time to determine speed. As the students begin to consider speed and distance, discuss how two rides with different diameters spinning at the same revolutions per minute will require the riders to travel at different distances and speeds to make the revolutions (the smaller ride has a smaller circumference, meaning less distance to travel). See the example below:



Here are two rides that spin at 1 rpm (revolution per minute). The smaller ride has a diameter of 3 meters while the larger ride has a diameter of 6 meters. The dot represents the rider sitting at the edge of the ride. By using the calculation of circumference = πd , the rider travels a distance of about 9.42 meters in one minute, or revolution on the smaller ride. The rider on the larger ride travels a distance of about 18.84 meters in that same minute, or revolution. The rider of the larger ride is traveling twice as fast as the rider on the smaller ride even though both rides made one revolution in a minute.

The students will need to calculate rider speed for various motor speed percentages to determine safe speeds for their K'NEX amusement park ride. Some data that they will need to know for their calculations are:

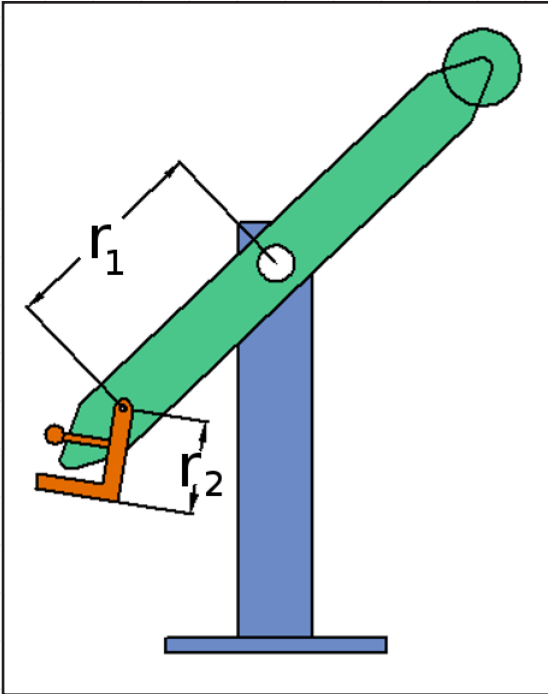
- **The radius of the object spinning.** In the case of this amusement park ride, it would be the swing arm or the seat arm length. For our calculations to work, we will need to determine a scale for the actual full-size ride.
- **The frequency or revolutions/second.** Frequency is defined as the rate at which something occurs or is repeated over a particular period of time or in a given sample. We will be determining our angular speed as *Revolutions per Second (RPS)*. For our ride, it would work best to measure the number of revolutions over several seconds (15-30) and then divide by that number to obtain the frequency.
- **Linear velocity of the ride.** The angular speed (RPS) will be converted to a linear direction for easier calculations.
- **The circumference of the spinning object.** In order to determine the actual speed of the ride, we will need to know the circumference of the arm's loop. The formula for circumference was used in Lesson 1 and is $Circumference = 2\pi r$ (radius) or πd (diameter).

TEACHER'S NOTES:

When the students are ready to complete the calculations on Student Response Sheet 1, it is recommended that you complete several sample calculations with the students so they are comfortable with the operations and units. For example, to obtain Kilometers/Hour, the students will need to convert their meters/second answer. Since there are 3600 seconds in one hour and 1000 meters in a kilometer, their formula will be **$KPH = Velocity \times (3600 \text{ sec/hour}) (1 \text{ km} / 1000 \text{ m})$** . After practicing several examples with the students, it may be helpful to display the formulas for the students as they work on Student Response Sheet 1. A sample problem is displayed here.

Here is a sample calculation for the amusement park ride using the previous page information:

Assume that our K'NEX amusement park ride was scaled up to a real size ride. If we were to measure some key components of our model, like the seat, the scale of the model is approximately 1:8. By using this number, we come up with these radii measurements:



Radius of the swing arm (r_1): 8m

Radius of the seat arm: (r_2): 2m

By using the above radii, the students can determine some actual speeds for the ride. The students will first develop a program that will run the motors at various motor speed percentages for 20 seconds (*wait blocks can only go up to 25 seconds*) and count the number of rotations during that time period. By dividing the number of rotations by 20, they will have an answer for frequency or *revolutions per second*.

For our example, the students observed the swing arm rotate 9 times during 20 seconds with the motor speed at 100%. By dividing 9/20, the students have 0.45 revolutions per second (rps). This arm is rather long so making a full revolution in less than 2 seconds is fast.

The first step is to determine the *circumference* of the arm. The students will need to calculate the circumference of the swing arm and the seat arm. To determine the *circumference* of the swing arm, we use the radius of 8m (r_1) and calculate the following:

$$\text{Circumference} = 2 \pi r$$

$$C = 2 (3.14) 8 \text{ m}$$

$$C = 6.28 \times 8 \text{ m}$$

$$C = 50.24 \text{ m}$$

The next step is to determine the velocity of the arm as it spins. Since this example spins at 0.45 rps (9 revolutions in 20 seconds or 9/20), we need to determine the distance traveled in one second. Since the calculation uses the circumference distance and the time duration of a revolution, the final units are meters/second. To determine the linear velocity of the arm, we calculate the following:

$$\text{Velocity} = \text{circumference} \times \text{frequency (rps)}$$

$$V = 50.24 \text{ m/revolution} \times 0.45 \text{ revolutions/sec}$$

$$V = 22.608 \text{ m/s}$$

Now that we know a linear distance per second, we will convert this to something the students can relate to better, like kilometers/hour (KPH). Since there are 3600 seconds in one hour and 1000 meters in a kilometer, we can calculate:

$$\begin{aligned} \text{KPH} &= V \times (3600 \text{ sec/hour}) (1 \text{ km} / 1000 \text{ m}) \\ \text{KPH} &= (22.608 \text{ m/sec} \times 3600 \text{ sec/hour}) (1 \text{ km} / 1000 \text{ m}) \\ \text{KPH} &= (81388.8 \text{ m/hour}) (.001 \text{ km/m}) \\ \text{KPH} &= 81.389 \text{ km/hour} \end{aligned}$$

Finally, if the students would be more comfortable with miles per hour (MPH), we can use the following conversion (one mile = 1.609 kilometers):

$$\begin{aligned} \text{MPH} &= (81.389 \text{ km/hour}) (1 \text{ mile} / 1.609 \text{ km}) \\ \text{MPH} &= (81.389 \text{ km/hour}) (0.6215 \text{ miles/km}) \\ \text{MPH} &= 50.584 \text{ miles/hour} \end{aligned}$$

It is recommended that you review several sample problems with the students, paying close attention to the units so the students can follow them through the calculations. It would also be beneficial to display these formulas and examples as they work through the response sheet.

While this speed is less than many roller coasters may experience, remember that this is a ride spinning at a constant speed. Spinning rides like these (including swings, gravity-type rides) typically do not exceed 56-64 KPH (35-40 MPH). Here are some typical speeds of various rides:

For the first Student Response Sheet, the students will be testing the swing arm and the seat arm at five different motor speeds to determine the best speeds for the ride.

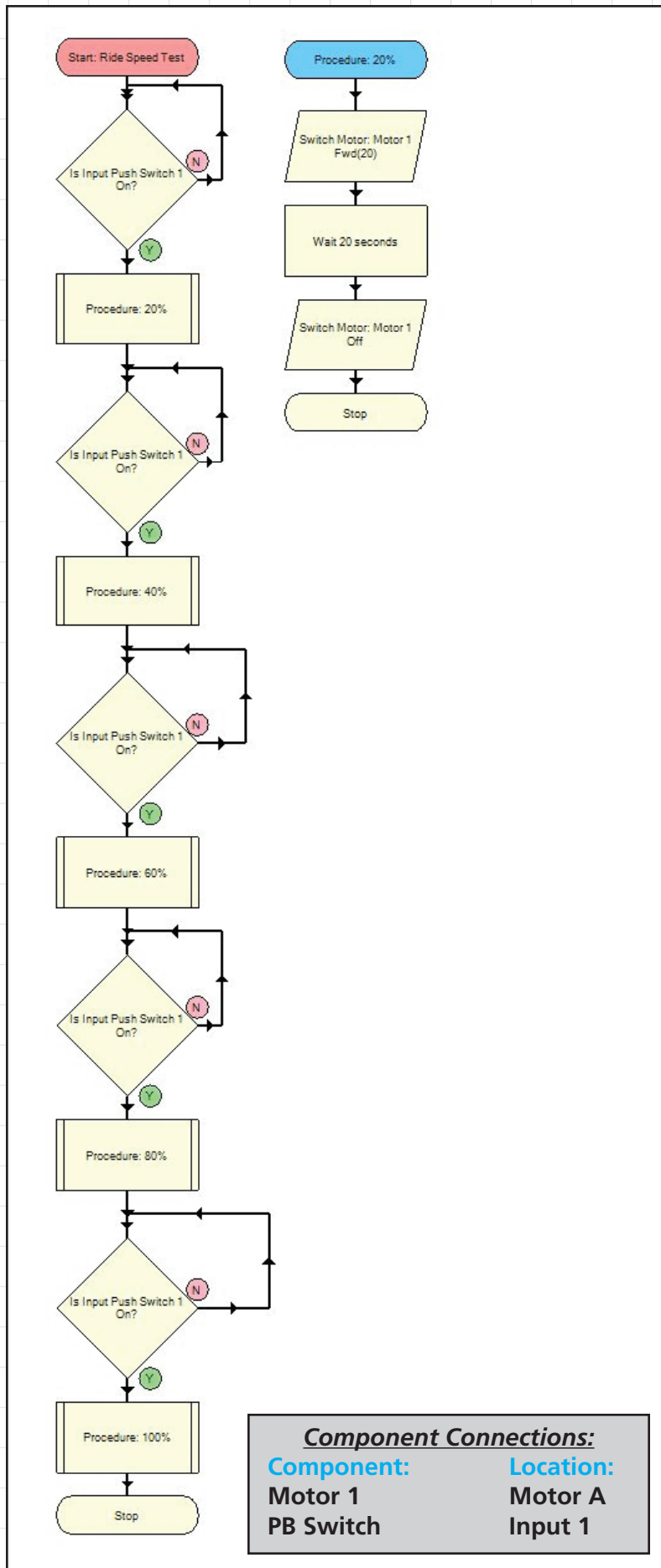
Ferris Wheel	6-9 KPH	(4-6 MPH)
Carousel (inside horses and outside horses):	6-11 KPH	(4-7 MPH)
Tilt-a-Whirl type ride:	21 KPH	(13 MPH)
Small Coaster	32 KPH	(20 MPH)
Wave Swing type ride:	43 KPH	(27 MPH)
Gravity type (extreme) ride:	56-64 KPH	(35-40 MPH)
Large Roller Coaster	up to 130 km/h	(80 mph)

10. Instruct the students to complete Student Response Sheet 1 and the vocabulary terms found on the Research and Design Log.

11. In this activity, the students will develop a program to test the motors at five different motor speeds: 20%, 40%, 60%, 80% and 100% to determine the best speed for a mild and extreme ride. The same program can be used to test both motors since the motors are tested one at a time. They can develop a program that tests one speed at a time or all five speeds in sequence (as we did in lesson 1). Each motor speed can be programmed to run for 20 seconds where students count the revolutions during the operation. The revolution count can then be divided by 20 to obtain revolutions/second (f). A sample program is displayed here.

Note that only one of the five procedures is shown. All procedures are identical except for the motor speed percentage.

Depending on available time and student ability level, you may wish to provide students with a flow chart of the first steps of their program to get them started. The students will need to develop and diagram the program they will use for the test.

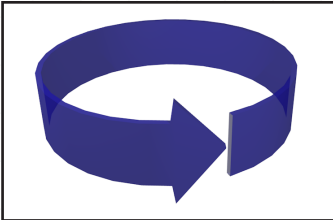


Component Connections:	
Component:	Location:
Motor 1	Motor A
PB Switch	Input 1

TEACHER'S NOTES:

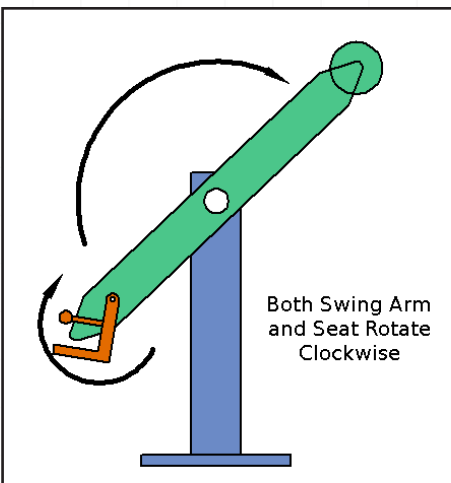
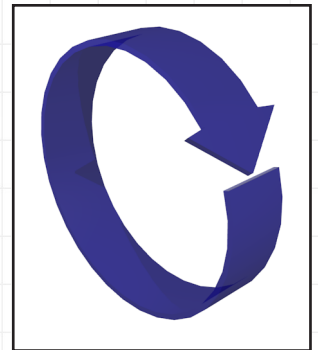
While students are running their speed tests and completing calculations on Student Response Sheet 1, encourage the groups to run the tests multiple times to obtain consistent results. They may even want to use a stopwatch or clock with a second hand to double check times. Partial revolutions should be included as decimals. Remind students to divide their results by 20 seconds to obtain the frequency of revolutions/second. Student results may vary greatly due to motor and voltage variations between K'NEX sets. Friction within the model may greatly affect results as well.

12. As the students work through the lesson, determine a good time to discuss the effects of combining forces and speeds on the ride in order to decide which motor speeds to use. While students are designing a ride that runs at a constant speed over time, the effects of normal gravity, spin direction and combining the forces of both arms need consideration. While the students were introduced to the concept of G-forces, they worked with speed calculations instead. This discussion could revolve around both gravity and speed effects. *While developing exact calculation for these effects would be difficult for middle school students, they should be able to formulate some educated guesses. (Students might guess that vertical rides have over 2 g of force at the bottom of the ride in order for the rider to remain in the seat at the top of the spin. In horizontal rides like the carousel, they may believe outward forces push the rider away from the axis of spin and the force may increase the further they are from the axis of rotation.)*



When a ride spins horizontally at a consistent speed, the effect of normal gravity is pulling the riders down and all the g-forces produced from the ride appear to the rider to be forcing them outward. If the ride produces 4g of outward force, it would be enough to keep the riders stuck to the wall. This would equal the 56-64 KPH speed discussed previously.

When a ride spins vertically (like our K'NEX ride), the effects of normal gravity will calculate into our ride's rotational forces. For example, while the riders are moving downward in the rotation, gravity will compensate for some of the ride's downward force. If the ride is spinning at 1g, the riders will feel weightless and in a "freefall" mode because the effects of gravity will counteract the spin and create a zero g effect. This same ride will give the riders an effect of 2g on the upward part of the rotation.

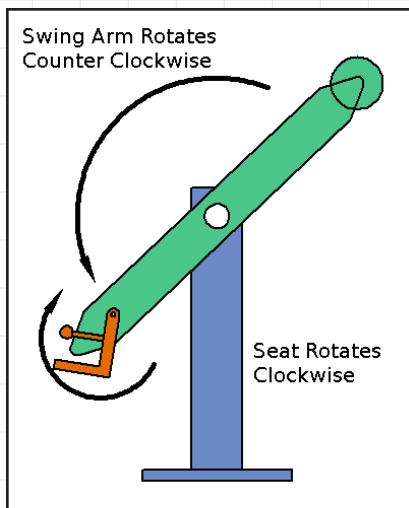


Apply these concepts to the K'NEX ride:

There is a question on the Student Response Sheet that asks the students to decide the direction of rotation for the swing arm and seat. After they have given it some thought, review these diagrams with them and initiate discussion.

Both swing arm and seat revolve the same clockwise direction as shown by the arrows in the diagram.

While this sounds like a good option, it can cause an effect much like a whip. The seat is at the end of a long lever and, as it approaches its outside distance of rotation, it will add to the rotation of the arm. Imagine that same effect on the downward sweep of the arm where gravity is added. Have the students imagine a seat spinning at 30 KPH and the swing arm revolving at 20 KPH. At one point of the ride, the effect on the rider would be 50 KPH.



Swing arm and seat revolve in opposite directions (the arm moves counter clockwise and the seat clockwise).

This option will counteract some of the added forces of the combined revolutions. While the seat is in its inner most rotation point, there is some added effect, but it is minimized because it shortens the swing arm distance, thus, lowering the speed of the arm.

In either case, the students will need to consider rotation directions and the sum of the forces or speeds. Review the typical speeds for various rides that were previously discussed with the students or post them so they can be referred to as the students work.

TEACHER'S NOTES:

While the students are testing the K'NEX motors at even percentages, remember that the motors can be programmed at 10% intervals. Since the students have graphed their ride speeds, they can estimate in-between percentages and use them for their final programming. For example, the students may have calculated 10 Km/h at 20% and 20 Km/h at 40%, but would like to program their ride using something in-between; they can estimate that the ride would have 15 Km/h at 30%.

13. After the students have had sufficient time to test their ride and respond to the questions related to the activity on their *Student Response Sheets*, summarize the activity with the class.

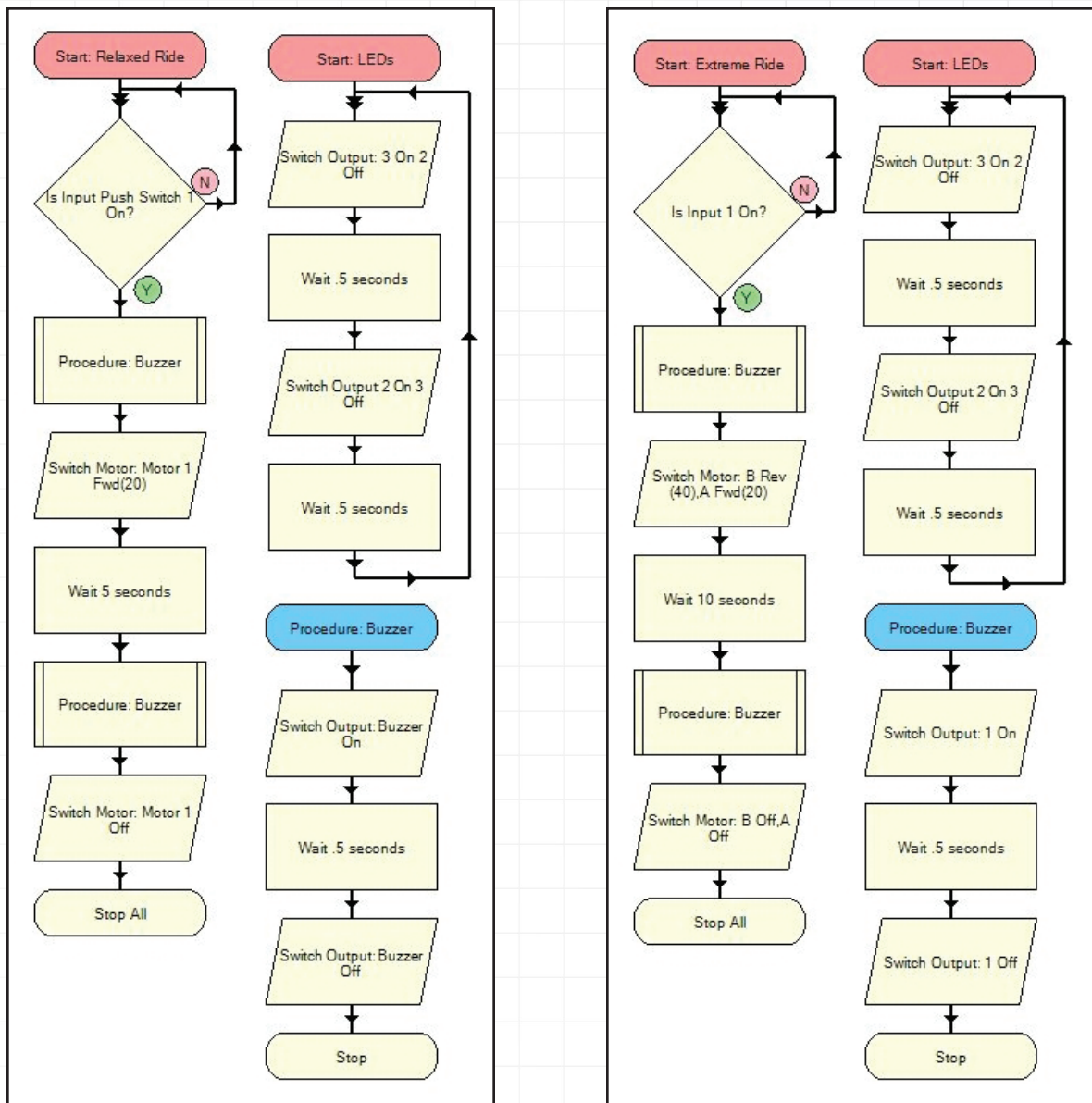
14. Review **Student Response Sheet 2** with the class. Now that the students have determined the motor speeds, g-forces, and rotational directions, it is now time to create some ride programs. They will be asked to create two ride programs for this activity: a mild and relaxing ride (like a Ferris Wheel) and a heart-pounding, high excitement ride. They will also be required to use the LEDs and buzzer.

The mild ride should be one suitable for all ages. It should only use the swing arm motor and keep the seat upright during the entire ride. It should also expose the riders to speeds similar to a carousel ride (6-11 KPH or 4-7 MPH).

The heart-pounding, high excitement ride should use both motors and expose the riders to rider speeds within the guidelines discussed.

TEACHER'S NOTES:

While the programs required for this portion of the assignment are flexible in development and can be rather simple, the students will have difficulty making the ride run for 30 seconds. The Wait blocks will only allow a maximum time of about 25 seconds. The solution is to add two 15-second Wait blocks in sequence.



This sample program uses two start blocks and one procedure. The one start block executes a looping sequence for the LEDs. They do not have an end block and loop the entire time.

The push button switch on Input 1 starts the ride operation. It executes the Buzzer procedure and then runs the swing arm motor at 20%. From calculations, this provides less than 1g of force which should be relaxing for most riders. The students may use different percentages depending on their own thoughts and calculations. To run the motor for 30 seconds, 2-15 second Wait blocks were added.

The only variation to the extreme ride program was to include *Motor B* in the *Output* blocks. Again, student will select their own motor percentages and directions as per previous discussions. They may also choose to run the LEDs and Buzzer differently.

Component Connections:

Component:	Location:
Motor 1	Motor A
Motor 2	Motor B
PB Switch	Input 1
Buzzer	Output 1
LEDs	Outputs 2,3

15. Review the principles of chain and gear drives discussed in the previous lesson. Students will be asked some basic questions about the drive systems and simple machines on the amusement park ride.

16. After the students have had sufficient time to test their rides and respond to the questions related to the activity on their *Student Response Sheets*, distribute the **Challenge Design Briefs** that will outline several possible challenge activities for you or the students to select from. A sample program for the *Ultimate Challenge* can be found in the *Answer Sheets*.

Explanation

1. Throughout the activities in this lesson students have been completing **Student Response Sheets**. Allow sufficient time to complete these sheets as they finish each activity so they can demonstrate they are able to explain what they have discovered. Remind students that some sections of the **Student Response Sheets** are to be completed "**As a Group**" while others are to be completed "**On Your Own**." They should be formulating thoughts, calculations and definitions from their own words.
2. Decide if you want groups to present their results after each *activity* or *wait until the entire unit is finished* to present their findings. Presentation is an important part of the learning experience since all students may approach these *activities with different thoughts* and ideas. Presentations should include a variety of elements such as descriptions, visual aids and demonstrations.

Elaboration

Students will self-evaluate their challenge solutions based on the criteria provided in the rubric for this activity. Elaboration components are found in the logs and response sheets.

TEACHER'S NOTES:

- Assign the **Self Reflection/Evaluation** rubric to the students so they can self-evaluate their work. The rubric score and your evaluation will make up a portion of the assessment data for this lesson.
- Provide students with a **Teamwork and Self-Evaluation** sheet and review the form with the students before they complete them.

Evaluation

You may use some or all of the following to evaluate student's performance:

- Self Reflection/Evaluation Rubric
- Teamwork and Self Evaluation forms
- Presentation of the Challenge Solution(s)
- Research and Design Logs
- Student Response Sheets
- Design Journal

Extensions

1. After the students have worked through the activities, it is useful to extend the learning through career research and extended activities. Career components have been added to the **Research and Design Logs**, but can be extended by other means such as guest speakers, business tours, etc.
2. Extension activities should be included in any student presentations.



Research and Design Log

Name: _____ Date: _____

Define the following terms below. Be sure to write the definitions in your own words.

Sir Isaac Newton -

First Law of Motion -

Second Law of Motion -

Third Law of Motion -

Gravity -

G-force -

Frequency -

Velocity -

Acceleration -

Inertia -

Centripetal Force -

Name: _____ Date: _____

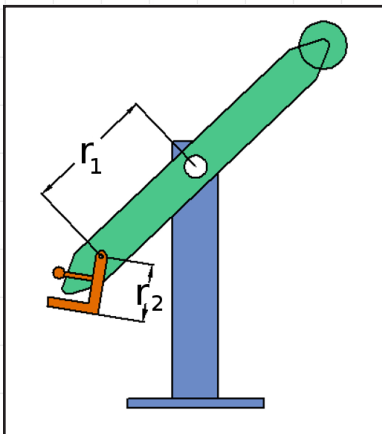
Speeds on Amusement Park Rides



As a Group

Explore

- After discussing Newton's Laws of Motion and g-forces, construct the amusement park ride model for the lesson. The amusement park ride will use 2 motors, a buzzer, 2 LEDs and a push button switch.
- Your K'NEX amusement park ride uses one motor to swing the arm and one motor to rotate the seat. Your first goal is to determine safe rotational speeds for the two motors so your riders remain safe. You will need to develop a program that tests the motors at various speeds (20%, 40%, 60%, 80%, 100%). In order to determine the frequency, or revolutions/second, run each motor speed for 20 seconds and count the number of revolutions (include partial revolutions as decimals). This number will be divided by 20 to get your revolutions/second. Your program can use wait blocks set to 20 seconds or you may use a stopwatch or clock to keep time (or both methods). Your instructor will give you specific guidelines for testing. Since you are testing one motor at a time, the same program can be used to test both motors. **On graph paper**, draw the program you plan to use.

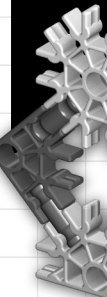


In order for our calculations to work, we need to imagine the ride is an actual size for real riders. If this model were scaled up about 8 times (scale 1:8), the radius of each spinning arm could be the following:

Radius of the swing arm (r_1): **8m**

Radius of the seat arm: (r_2): **2m**

- After completing several exercises as a class, complete the charts on the next page. Pay close attention to the units for each calculation. Use these formulas for calculations:
 - o To determine the **frequency** of the ride (**f**) in revolutions/second, count the number of revolutions in 20 seconds for each motor speed and divide them by 20.
 - o To determine the **circumference** (**c**) of one rotation of the ride, multiply the radius of the ride by 2π to find the answer in m/revolution. **$c = 2\pi r$**
 - o To determine the **velocity** of the ride (**V**), multiply the circumference of one rotation by the frequency in revolutions/second to find the answer in m/sec. **$V = c f$**
 - o To determine the speed in **Kilometers/hour (KPH)**, multiply the velocity of the ride in m/sec by the number of seconds in an hour (3600 sec/hour) and multiply that number by the number of kilometers in one thousand meters 1 km/1000 m. **$KPH = V (3600) (1/1000)$**
 - o To determine the speed in **Miles/hour (MPH)**, convert KPH to MPH using the following formula. **$MPH = Km/hr (1 \text{ mile}/1.609 \text{ km})$**



Swing Arm Data

(r = 8m)

Circumference = _____ m

Motor Speed	Swing Arm Radius (r ₁)	Revolutions per Second (f)	Velocity (V)	KPH	MPH
20%	8 m		m/s		
40%	8 m		m/s		
60%	8 m		m/s		
80%	8 m		m/s		
100%	8 m		m/s		

Seat Arm Data

(r = 2m)

Circumference = _____ m

Motor Speed	Swing Arm Radius (r ₁)	Revolutions per Second (f)	Velocity (V)	KPH	MPH
20%	2 m		m/s		
40%	2 m		m/s		
60%	2 m		m/s		
80%	2 m		m/s		
100%	2 m		m/s		

- On **graph paper**, create 2 graphs for the swing arm and the seat arm using your **KPH** calculation over **Motor Speed Percentages**.



On Your Own

Elaborate and Explain

- Refer to the typical ride speeds provided by your instructor. If you were to use your ride as a Ferris Wheel (using only the swing arm motor) that was appropriate for all ages, what motor speed percentage would you use? Remember that even though you only calculated 5 motor percentages, you can use your graph to estimate KPH for every 10% speed increment and use those as well. Explain why you selected this percentage.
- Develop a program that turns your ride into a heart-pounding, high excitement ride that uses both motors. From class discussion, you learned that constant speed rides usually won't exceed **56-64 KPH** and rides with changing speeds will sometimes hit **130 KPH**. By using both motors, your ride has some of both features as the forces of both arms combine. Which motor speeds would you use for each arm? Explain why you selected these percentages.

Name: _____ Date: _____



As a Group

Getting the Ride In Operation

Explore

- It is now time to develop some programs to get your ride into operation. You will need to develop 2 programs for the following types of rides:
 - o A mild, relaxing Ferris Wheel type ride for all ages. It cannot turn the riders upside down so you will only be using the swing arm motor while the seat stays upright the entire time.
 - o A heart-pounding, high excitement ride that uses both motors.

Use the information from the previous activity to develop your program for safety and fun. Your programs should also include the following:

- o The LEDs should blink.
- o The buzzer should sound.
- o A real ride would run for 1-2 minutes, but for testing purposes, consider a run time of **30 seconds**.
- o It should use the push button switch to start the ride.

There are many ways to develop a program to complete this operation so brainstorm as a group to develop a strategy. **On graph paper**, draw the program you plan to use.

- After completing the activity above, what was the most challenging part of the activity? If this were a real amusement park ride, did you see any problems with the operation of the program? Explain.
- If this was a real ride, it would only be able to seat about **4 people at a time**. Ride capacity and wait times are serious considerations in amusement parks. Amusement parks actually want lines at rides, but not too long that people become angry. If you consider loading time, ride time, and unloading time, how many riders could this ride handle in one hour? As a group, decide these factors.

Loading Time: _____ minutes

Ride Time: _____ minutes

Unloading Time: _____ minutes

=====

Total time per Ride _____ minutes

Approx. Rides/Hour _____

Total Riders/Hour _____

- How could you improve the capacity of this ride to handle more riders/hour? Explain your answer and include sketches on a separate sheet of paper if modifying the ride.

Name: _____ Date: _____



As a Group

Here are several possible design challenges for your group. Use notebook and graph paper to document the activity or activities and fasten them to this sheet.

- Your amusement park ride needs to start and end at a consistent place so riders can load and unload from the ride. You may have noticed that your programs on Student Response Sheet 2 may not have ended consistently every time. Many older amusement park rides have a timer that starts when the ride is started and sounds a buzzer at the end of the ride time. After the buzzer sounds, the ride operator will then manually stop the ride. Want more of a challenge? Use reed switches and magnets to control how the ride stops. Modify your extreme ride to operate in this manner. Chart your programs on graph paper and record your results.
- How many people can you fit on this ride? Right now, it seats about four. Modify your K'NEX amusement park ride to seat as many people as possible. Document your changes on a separate sheet of paper and demonstrate your model to the instructor.
- Rides often start slowly, build up to operating speed, run at that speed for some time, then slow down to gently stop the ride for comfort and safety. Modify your extreme ride to operate in this manner. Chart your programs on graph paper and record your results.
- Extreme rides like these often provide extra thrills for the riders by changing speed or rotation in the middle of the ride. They may even stop the swing arm in the highest position and spin the seat forward and backwards at higher speeds for short periods of time. Add some more excitement to your ride by modifying your program (keeping within safe force and speed limits). Chart your programs on graph paper and record your results.
- **The Ultimate Challenge!** Develop your program to include the following features:
 - o Be able to stop and start the ride at a consistent location manually or automatically for loading and unloading the riders.
 - o The ride starts slow and ends slow for rider comfort and safety.
 - o Add extra thrills for the riders (keeping within safe force and speed limits).
- You are a ride engineer given the challenge of building this ride. How much would this ride cost to build? Determine the cost of the parts required to build the model using a 'Cost per Piece Chart.' Also, determine how many "construction workers" it would take to build the ride, a labor cost per hour, and the total number of hours each employee would be working on the project.
- Determine what it would cost to operate this ride per hour and a price to charge each rider. You must pay ride operators, pay utilities, and pay back the cost of the actual ride.

Self Reflection/Evaluation

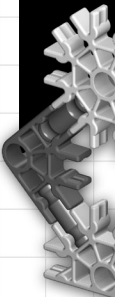
Name: _____ Date: _____

Unit: _____ Model: _____

Complete the Activity Assessment Rubric to provide your impression of how you did with this lesson.

Assessment Rubric			
<i>Circle Responses for each:</i>	Excellent	Good	Acceptable
Research and Design Logs & Worksheets	Student Response Sheets and Design Logs complete with no spelling or grammar errors. All answers on Student Response Sheets are accurate. <input type="text"/> 1-10	Student Response Sheets and Design Logs complete with few spelling or grammar errors. Most answers on Student Response Sheets are accurate. <input type="text"/> 1-8	Student Response Sheets and Design Logs complete with many spelling or grammar errors. Few answers on Student Response Sheets are accurate. <input type="text"/> 1-6
Design & Construction	Your device is very neatly constructed, easy to use, and meets or exceeds expectations outlined in the Design Brief. <input type="text"/> 1-10	Your device is neatly constructed, easy to use, and meets expectations outlined in the Design Brief <input type="text"/> 1-8	Your device has been constructed, is in useable form, and meets the materials criteria listed in the Design Brief. <input type="text"/> 1-6
Design Journals & Presentations	Your Design Journal is complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. It is presented in a neat and orderly fashion. <input type="text"/> 1-10	Your Design Journal is mostly complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows some disorder. <input type="text"/> 1-8	Your Design Journal is missing 1 or more logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows disorganization. <input type="text"/> 1-6
Teamwork/Work Ethic	You worked well with your teammates and interacted well with others. You demonstrated excellent reliability and initiative when working on this challenge. <input type="text"/> 1-5	You worked well with your teammates and interacted well with others. You were reliable and demonstrated initiative when working on this challenge. <input type="text"/> 1-3	You worked well with your teammates and others. You were generally reliability and usually demonstrated initiative when working on this challenge. <input type="text"/> 1
Total Score	<input type="text"/> /35		

Teacher Comments:



Teamwork & Self Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____



As a Group

Teamwork and cooperation are necessary skills required for most jobs since businesses typically have many employees that work together in teams rather than lots of individuals working alone. All employees need to contribute equally, using their skill sets to make a project successful while meeting deadlines. If one person fails to contribute adequately, the business or project can fail.

- **Communication Skills:** How well did your group communicate? How could communications within your group be improved?

- **Work Load:** How was work assigned in your group? Did individuals step up to accept responsibility? Were personal skills considered as work was assigned? For larger groups, is it beneficial to assign someone as a leader?

- **Presentation:** How was the unit presentation developed? How did the group determine responsibilities so no one was left out? What improvements could be made for future presentations?



On Your Own

- **Personal Input:** Do you feel you contributed equally with your group? Did you do too much or not enough? Personal contributions to the group are listed in the *Research and Design Log*, but what could you do to work better in a team?

LESSON #7: PICK IT UP AND PUT IT DOWN

6-8 X



LESSON #7:
PICK IT UP AND PUT IT DOWN

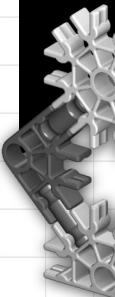
Model: K'NEX Crane



Main Concepts (STEM):

- **Science**
 - Simple Machines and Drive Ratios
- **Technology & Engineering**
 - Crane Design and Structure
- **Mathematics**
 - Computation and Coordinate Systems

Objectives:	Required Materials:	Optional Materials:
<p>Student will be able to:</p> <ul style="list-style-type: none"> • Work effectively both independently and in collaborative teams. • Correctly connect and program the K'NEX interface to control the crane model. • Understand that main parts, function, and types of cranes. • Apply the concepts of simple machines, gear ratios and coordinates systems to the crane construction and operation. • Modify their computer programs to control the crane for specific challenges. 	<p>Teacher will need:</p> <ul style="list-style-type: none"> • K'NEX Interface and software • Computer projector and/or whiteboard • Extension cord (if power is not close to testing area) • Poster board or large table and tape/markers to set up testing area (see lesson notes) • Small paper clips <p>Students will need:</p> <ul style="list-style-type: none"> • K'NEX Interface and components • Computer with K'NEX Computer Control software • K'NEX crane model • Copies of: <ul style="list-style-type: none"> o Research & Design Logs o Student Response Sheets o Challenge Design Briefs o Teamwork & Self-Evaluation forms o Self Reflection/Evaluation Rubrics 	<ul style="list-style-type: none"> • Graph paper • Notebook paper • Colored pencils • Sample K'NEX models (prebuilt crane model, truss examples for lesson) • Calculators • Ping pong balls, plastic practice golf balls & bowls or other items for challenge activities



TEACHER'S NOTES:

- *Students will build the crane model. After the students construct the crane, begin the engagement portion of the lesson. Lesson 7 should take 6-8 class periods, depending on how challenge activities are assigned.*
- *As with previous lessons, students will be asked to construct the model, perform various experiments, chart data, record their thoughts and actions, and develop challenge activities.*
- *The K'NEX crane uses two motors (one to rotate the crane and one to control the chain and hook), one push button switch, two reed switches and three magnets.*

Process

Engagement

1. Keeping in line with the *STEM Exploration* vacation road trip, discuss how the students have passed a construction site on their way to the hotel after their fun day at the amusement park. There is a large crane at the construction site that has attracted their attention and will give them the opportunity to test their programming skills. Discuss the processes used in the lesson with the students:
 - Students will construct the K'NEX crane model for the lesson and complete the *Engagement* activities. The crane uses two motors: one to rotate the crane and one to control the chain and hook.
 - They will be programming their model to run various experiments and competitions.
 - Students will also examine the fundamentals of simple machines again as related to the crane model.
 - They will also examine crane design, truss structures and coordinate systems.
 - They will finish the lesson by completing one or more open-ended challenge activities.
2. Distribute or direct students to the **Research and Design Logs** and **Student Response Sheets** for this unit. Introduce the **Challenge Design Briefs** when the students are ready for the challenge activities and the **Assessment Sheets** at the end of the activity. This will help students focus on the current activities. These pages are provided at the end of each lesson or in the **Resources** section of the Teacher's Guide. Links to editable electronic versions of the Research & Design Logs, Student Response Sheets, Design Briefs, Evaluation/Assessment forms and the Cost Per Piece chart can be accessed by the students from the Start Menu, or you can drag and drop the "STEM Explorations Resources" folder from the software CD onto the desktop or a shared drive.
3. Discuss that the **Research and Design Logs** and **Student Response Sheets** will be used in the same manner as lesson 1.
4. Lesson 7 introduces the students to the concepts of crane operation and the simple machines and drives that are used in the crane design.
5. Have the students discuss different types of cranes they have seen and how they were used. Different types of cranes serve different purposes.
6. Ask the students if they know how tall cranes are assembled and work? Some cranes can actually build themselves as they need to grow taller. To introduce them to this concept, find a video or discussion about cranes such as these examples that show crane assembly:

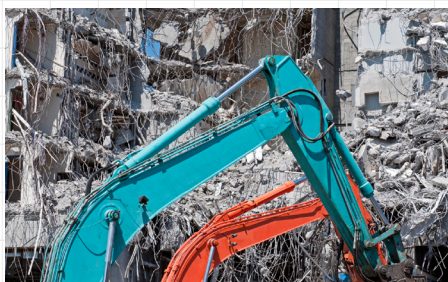
[Tower Crane Assembly](#)

[Constructing a Tower Crane](#)

Exploration

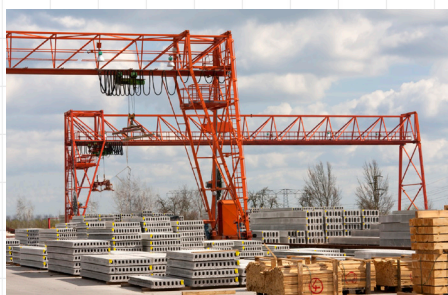
1. Establish student teams (2-3 students per group), and then review the activity and **Student Response Sheet 1**. Allow students time to discuss the activity in their groups.
2. Students should understand the safe operation of the K'NEX interface and electrical concerns. Review the *STEM Explorations User's Guide*, if needed.
3. The students should construct the K'NEX crane model. This model is constructed using two motors (one to rotate the crane and one to control the chain and hook), one push button switch, two reed switches and three magnets.
4. Review the activity and **Student Response Sheet 1** with the class. Discuss how this activity will introduce the students to the types and purposes of different cranes and how they are constructed. They will also examine truss structures, simple machines and drive systems used in the crane model.
5. Review the main types of cranes with the students and display examples:

Mobile Cranes- Mobile Cranes are basically “cranes on wheels” that are able to be transported to where they are needed. They are usually cable controlled or hydraulically powered.



Hydraulic Cranes- Hydraulic cranes use fluid pumped into cylinders to lift heavy objects instead of cables. Think of water flowing through a pipe under pressure. That fluid has the potential of doing a great deal of work. Fluid is channeled into a cylinder and put to work in systems like car brakes, jacks and machines with hydraulic cylinders that do work like cranes.

Overhead Cranes- An overhead crane is a crane with a movable bridge carrying a movable or fixed hoisting mechanism and traveling on an overhead fixed runway structure. They are often found in work yards or in long factory buildings running on beams at the tops of the walls.



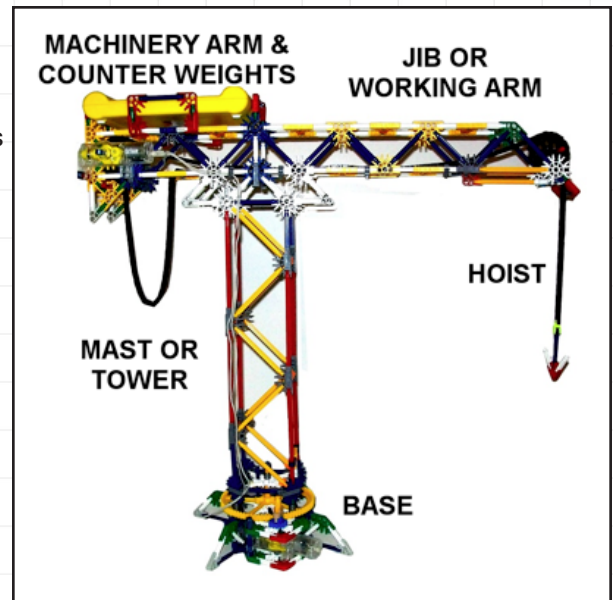
Gantry Cranes- A Gantry Crane differs from an overhead crane in that the wheels of the crane are on the legs, rather than being fixed in one location. Gantry cranes look much like overhead cranes, but are more mobile.

Tower Cranes- A tower crane is a stationary crane with an extremely long vertical mast. Tower cranes are used in construction for large structures such as bridges and hi-rise buildings. Our K'NEX crane model is constructed to represent a tower crane.



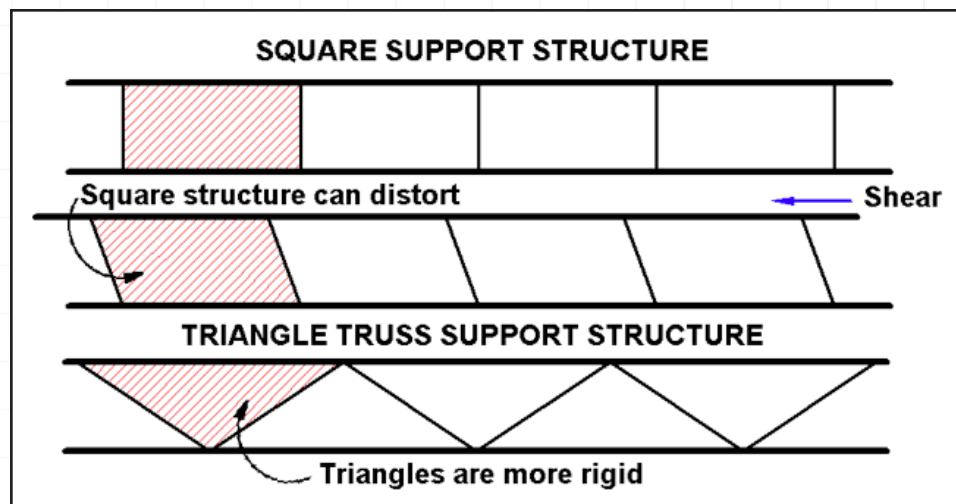
6. Examine the parts of a tower crane with the students:

- The **Base** of the crane is fastened to a large concrete mass that stabilizes the crane.
- The **Mast or Tower** is connected to the base and gives the crane its height.
- On a real crane, the **Slewing Unit** (*not shown*) would be found at the top of the mast where the crane would rotate. The slewing unit consists of the gears and motor for rotation. Our K'NEX model actually rotates at the base.
- At the top of the tower, the horizontal arm splits. Think of this arm in the same manner as a lever. The **Jib or Working Arm** is the arm that supports the work load. On a real tower crane, the hoist would be able to move inward and outward from the mast.
- The **Machinery Arm** holds the crane's motors and electronics and also the counterweights.
- The **Counter Weights** balance the load and keep the crane from falling over. Our K'NEX Control Interface will act as a counter weight for our crane.
- The **Hoist** is the chain or cable and hook that lift the load.



While tower cranes can lift a great deal of mass, they do have their limitations due to their height. Often, as tower cranes grow in height, they will need to be anchored to the building as they grow upward to keep them stable. The concrete mass at the base and the strength in the mast can compensate for the loads they will carry, but without the counter weight mass, they would topple easily. The next item in the lesson will discuss the unique shape of the mast and jib.

7. Ask the students if the triangle shapes that are apparent in the mast and jib serve a purpose. This type of structure is called a truss. A truss is defined as a structure consisting of a triangle or triangle shapes used to span long distance with great strength due to the fact that a triangle ensures the greatest rigidity. Trusses have been used for many years in bridges, roof, and floor structures. Have the students build the 2 structures shown below with K'NEX:



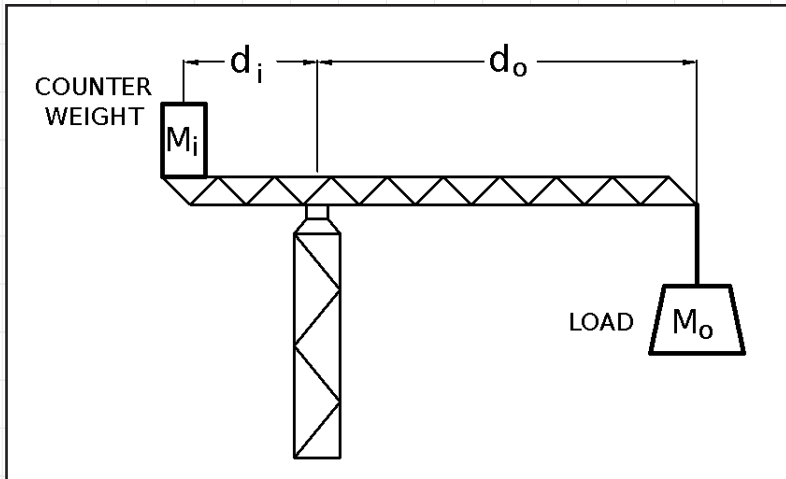
A truss structure is more common on many objects that require a rigid structure using fewer materials. Triangles resist distortion as forces are applied on them. In the square support structure example above, a shearing force applied to the structure will cause the structure to distort. The truss is used for the mast and the arm because they are able to support more weight and resist failure. The manufacturers of these cranes have engineered them to be able to support specific amounts of weight.

8. Compare a 1st class lever to the crane arm with the students and complete some sample calculations to determine counter weights and lifting loads. Since we are determining balancing masses, we can figure out the mechanical advantage using:

$$MA = d_o / d_i$$

d_i = Effort Distance to Fulcrum (counter weight)

d_o = Load Distance to Fulcrum



Example 1:

You need to lift a mass of 100 Kg.
 $D_i = 10$ m; $D_o = 50$ m
 What is your counter weight (M_i)?

$$MA = d_o / d_i$$

$$MA = 50 \text{ m} / 10 \text{ m}$$

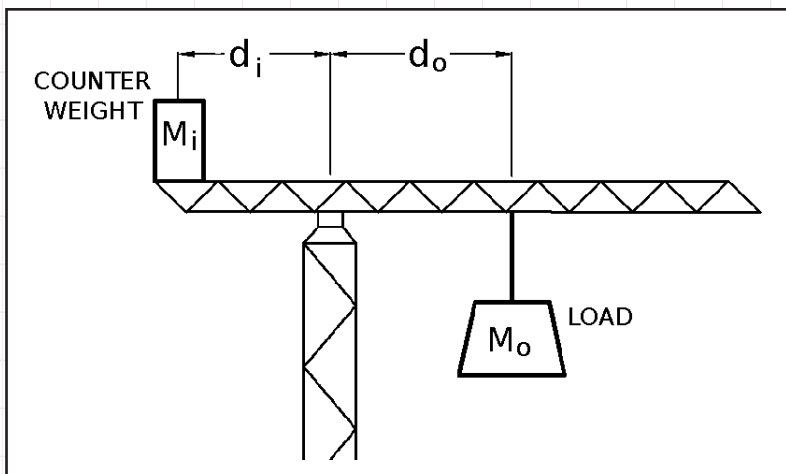
$$MA = 5$$

Multiply the Load by the mechanical advantage:

$$M_i = M_o \times MA$$

$$M_i = 100 \text{ Kg} \times 5$$

$$M_i = 500 \text{ Kg Counter Weight}$$



Example 2:

You need to lift a mass of 100 Kg.
 $D_i = 10$ m; $D_o = 25$ m
 What is your counter weight (M_i)?

$$MA = d_o / d_i$$

$$MA = 25 \text{ m} / 10 \text{ m}$$

$$MA = 2.5$$

Multiply the Load by the mechanical advantage:

$$M_i = M_o \times MA$$

$$M_i = 100 \text{ Kg} \times 2.5$$

$$M_i = 250 \text{ Kg Counter Weight}$$

Since tower cranes are capable of moving the load in and out from the tower (mast), you can see that heavier masses can be lifted closer to the tower (mast). Since counter weights can't be adjusted once the crane is built, limitations are placed on what can be lifted. Remember that the construction of the tower and arm can handle some mass and does not need to rely on a perfectly balanced system. Even though the crane is tall, it is built using truss structures for strength and has a concrete mass at the base. These features alone are able to support a great deal of mass.

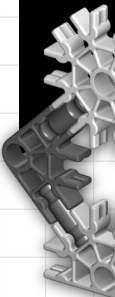
The students will be asked to research typical limits and safety devices used in tower cranes. While the students will not be provided with website links in the lesson, here are some helpful links you may decide to provide:

[How Tower Cranes Work 1](#)

[How Tower Cranes Work 2](#)

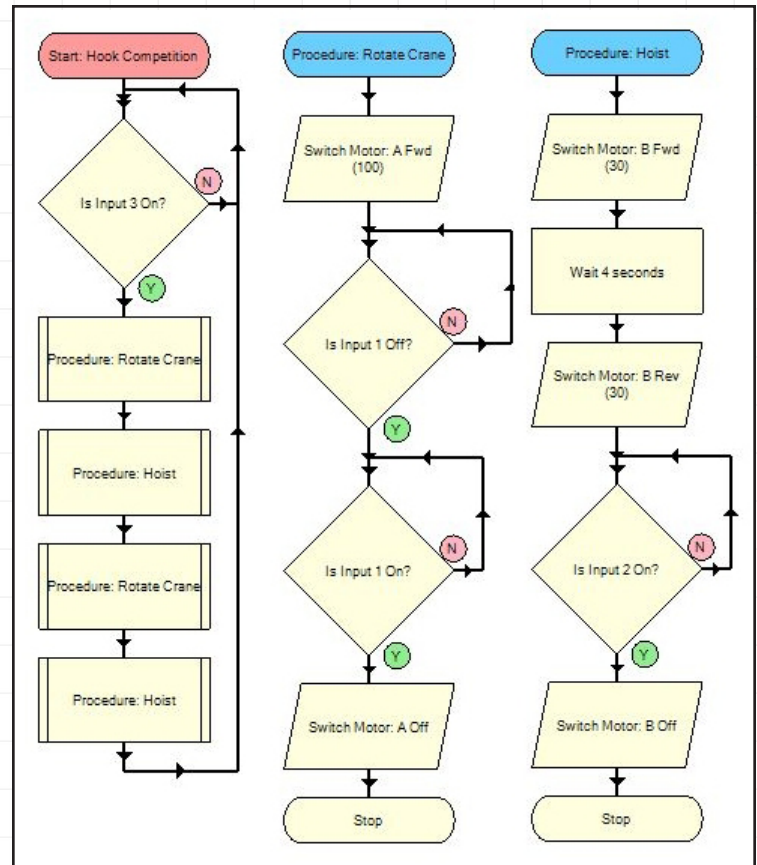
[Stabilizing a Tower Crane](#)

9. Instruct the students to complete **Student Response Sheet 1** and the first seven vocabulary terms found on the **Research and Design Log**.



10. In this activity, the students will test the operation of the crane and examine some of the mechanical systems used. They will also have an opportunity for a class challenge to see which group can pick up the K'NEX box the most times out of 10 attempts. Here is a speed test example:

Component Connections:	
Component:	Location:
Motor 1	Motor A
Motor 2	Motor B
Reed Switch 1	Input 1
Reed Switch 2	Input 2
PB Switch	Input 3



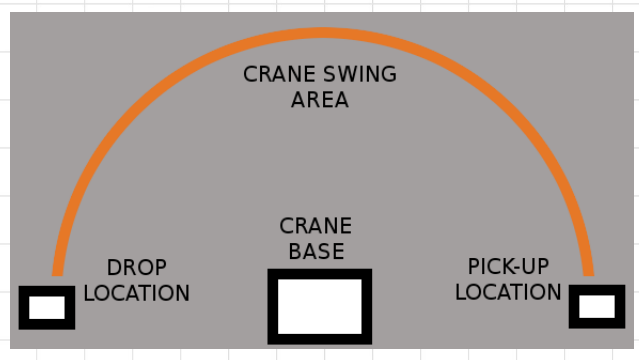
The sample program above uses the push button switch to start the cycle. The base motor (motor A) rotates the crane while procedure "Rotate Crane to Stop" stops the crane when the reed switch is triggered by a magnet. Notice that this same procedure is used for both directions. The "Hoist 30%" procedure is run. Since we are testing various speeds, a wait time has not been used. The crane lowers until the push button switch is pressed. Students may decide to use wait blocks for this operation instead. The hoist then rises until the reed switch is tripped. The base motor then reverses direction and drops the hoist. The program percentages are changed for the other two speed test. You may decide to provide the students with some or the entire program depending on available time and ability level.

TEACHER'S NOTES:

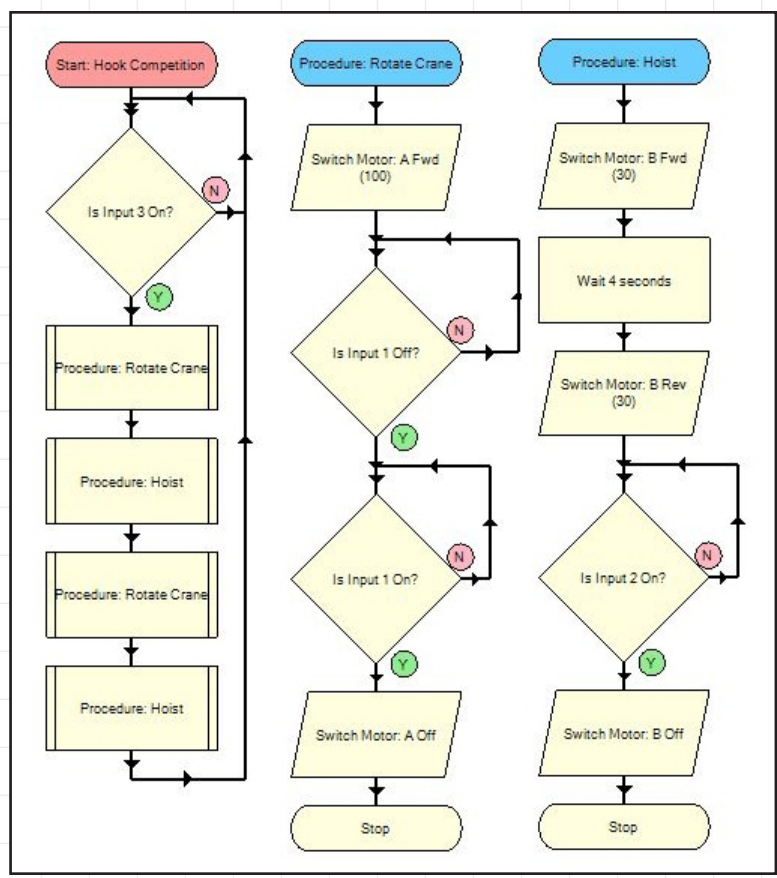
While students are running their speed tests the reed sensor on the hoist may not always trigger due to swinging or an improperly angled magnet, especially at higher speeds. When this occurs, the safety mechanism in the motor may ratchet. The students should be ready to stop the program or manually align the magnet with the switch with their hand to stop the motor.

11. The second challenge in *Student Response Sheet 1* requires the students to use the motor speeds they determined to modify their programs for a class competition. The goal of the competition is to see which team can pick up the K'NEX box the most times out of 10 attempts. The students may be creative with their programming in order to improve their ability to hook the box (i.e. drop the hoist and swing the crane to hook the box better) or stick with a basic "drop and rise" attempt.

Set up the testing area prior to the activity so the students can create their program knowing how the testing area will be designed. This will also let them know how the hook should be angled for the best chance of success. It is recommended that you use masking tape to mark a box where the crane will be placed and where the box will be placed. This can be done on a table, floor area or poster board.



A sample program that could be used for this challenge is shown. Notice that the program is identical to the speed test except that a "Wait" block has been used to replace the push button switch in the *Hoist* procedure to control the drop of the hook. The students will need to test their programs to determine an appropriate wait time in relationship to the speeds they selected for the motors. The push button switch is only used to execute each attempt. Again, you may decide to provide the students with some or the entire program depending on available time and ability level.



Component Connections:

Component:	Location:
Motor 1	Motor A
Motor 2	Motor B
Reed Switch 1	Input 1
Reed Switch 2	Input 2
PB Switch	Input 3

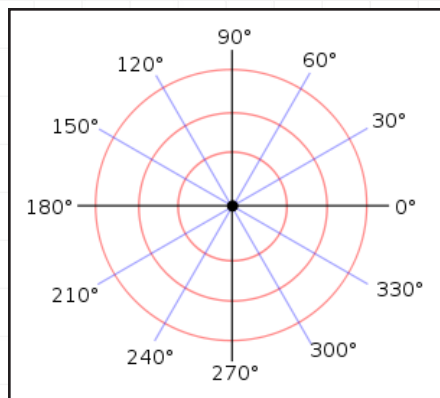
- After the students have had sufficient time to test their cranes and respond to the questions related to the activity on their *Student Response Sheets*, summarize the activity with the class.
- Review **Student Response Sheet 2** with the class and have them complete the remaining vocabulary terms found on the **Research and Design Log**.
- Student Response Sheet 2 will have the students complete a different type of competition with their K'NEX crane model while examining coordinate systems and CNC programming.

15. CNC stands for Computer-Numerical-Control and is used in many manufacturing situations. In a simple form, the students have been working with CNC programming throughout the lessons. CNC occurs when you use a computer to control a machine to complete accurate and/or repetitive operations that would be difficult for a human to complete. CNC is used to control manufacturing machines, robotics, computer printers, and even objects like we have been experimenting with in these lessons.
16. Special motors have been made for accurate CNC applications called Stepper Motors. Stepper motors are designed to rotate a specific degree angle every time they receive a digital pulse (similar to pulses that we discussed in Lesson 2). This is how accurate motion is controlled in machines, like the printer heads in an inkjet printer placing ink in an exact location. CNC machines can use accurate coordinates for movement.
17. Discuss Coordinate Systems with the students. A coordinate system is basically a system that uses geometric coordinates to establish position. A system that the students are most accustomed to using is called a Cartesian coordinate system. A Cartesian coordinate system is defined as a coordinate system for which the coordinates of a point are its distances from a set of perpendicular lines that intersect at the origin of the system. A standard x,y graph is a Cartesian system. There are many other coordinate systems in existence. For example, most CAD (computer-aided-drafting) programs use systems called Absolute, Relative, and Polar Coordinate systems.

Absolute coordinates are determined exactly how students have been graphing points in math class. There is an origin $(0,0)$ and points are found at a distance from that origin and expressed as an x,y location.

Relative Coordinates are expressed as x,y like absolute coordinates, but the origin moves to the location of the point you are drawing from. Most CAD systems distinguish a relative coordinate from an absolute coordinate by adding the @ symbol before the x,y . (i.e. @2,4)

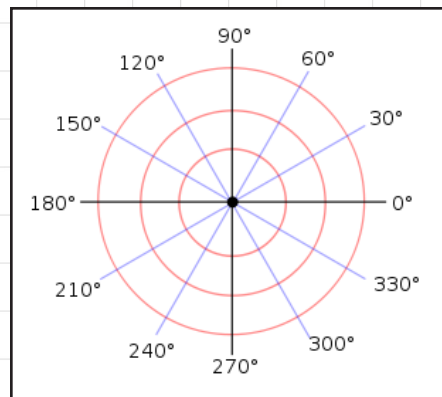
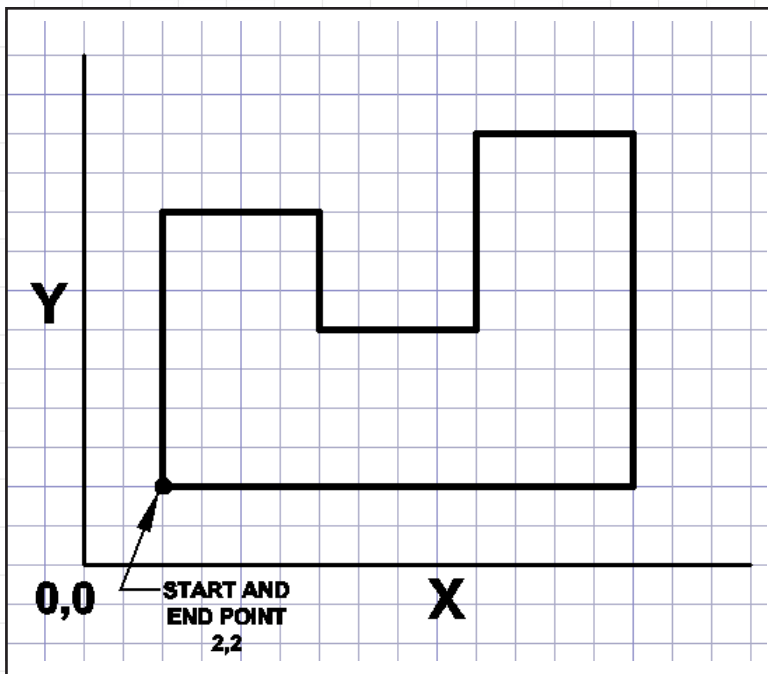
Polar Coordinates are expressed as a length and an angle. You do not need to know the coordinate you are drawing from or drawing to. Most CAD systems distinguish a polar coordinate as @length of line<degree angle. (i.e. @2<0) Polar coordinates are typically measured counter-clockwise with 0 degrees to the right.



TEACHER'S NOTES:

The students will be completing some coordinate system examples on the student response sheet. It is advised that you review the three coordinate systems, explaining the notation, and completing some example coordinate charts with the students. You may also wish to display the polar angle chart for the students as they work through the activity.

Here is an example demonstrating drawing a shape starting from a point 2,2 in all three coordinate systems. The shape is drawn counter-clockwise from the start point.



Absolute Coordinates:

Start:	2,2
To point:	14,2
To point:	14,11
To point:	10,11
To point:	10,6
To point:	6,6
To point:	6,9
To point:	2,9
End point:	2,2

Relative Coordinates:

Start:	2,2
To point:	@12,0
To point:	@0,9
To point:	@-4,0
To point:	@0,-5
To point:	@-4,0
To point:	@0,3
To point:	@-4,0
End point:	@0,-7

Polar Coordinates:

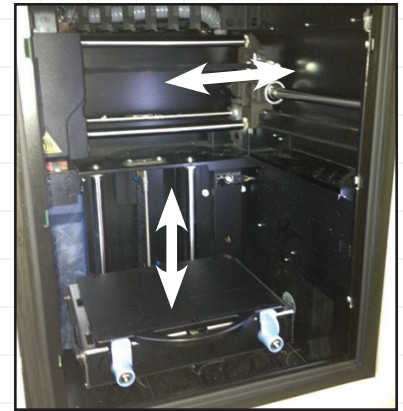
Start:	2,2
To point:	@12<0
To point:	@9<90
To point:	@4<180
To point:	@5<270
To point:	@4<180
To point:	@3<90
To point:	@4<180
Endpoint:	@7<270

TEACHER'S NOTES:

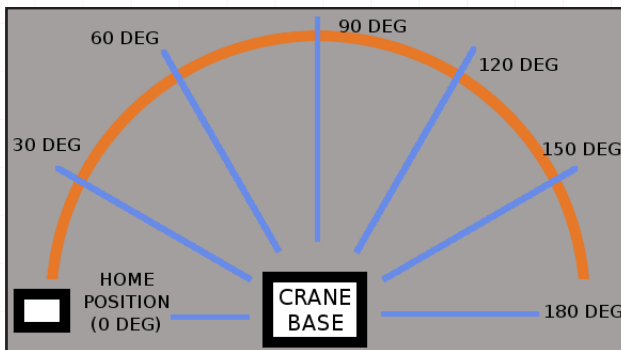
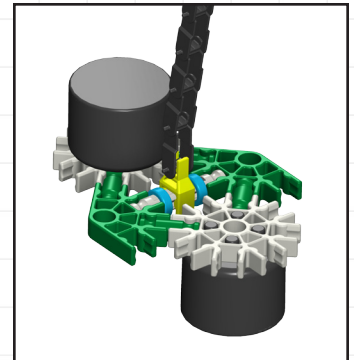
Relative and Polar coordinates can be confusing at first. While Absolute coordinates are referenced from the origin of the grid, Relative coordinates use the point you are drawing from as the origin. While this makes it easier since you do not need to know where you are located related to the origin of the grid, you do need to consider your ending point. In Relative coordinate systems, any point going to the left or down, will be negative. Polar coordinates only need to know the length and angle of the line.

18. Since most machines controlled by CNC work in a 3D workspace, discuss 3-axis coordinates with the students. Not only do they have to consider the X and Y axes, but there is also a Z axis in real space. If you have access to Youtube.com, there are many videos available displaying CNC machines in operation that can be displayed for the students.

The K'NEX crane moves in 3D space, but since it rotates on an axis, it is using a polar coordinate. This activity will allow the students to use degree angles to develop timing for their program.



19. The competition activity for Student Response Sheet 2 will require the students to modify their K'NEX crane model slightly. They will need to remove one of their base magnets and use it to replace the anchor hook. They will still use the one base magnet as a "home" position. The modification only requires the removal of the hook and the gray 1/2 connector block that holds the hook. The goal of this activity is to develop a program that will rotate the crane approximately 30 degrees at a time and lower the hoist to pick up paper clips. The goal of the competition is to see who can collect and hold the most paper clips. The testing area will need to be set up as follows:



On a table or on poster board, you will need to layout a semicircle with markings every 30 degrees and a mark for the center point of the K'NEX crane. You will be placing paper clips on each 30 degree line for the students to attempt to collect with the crane's magnet. Since the K'NEX model does not use stepper motors that could be programmed to stop at exact angles, timing with wait blocks will need to be used.

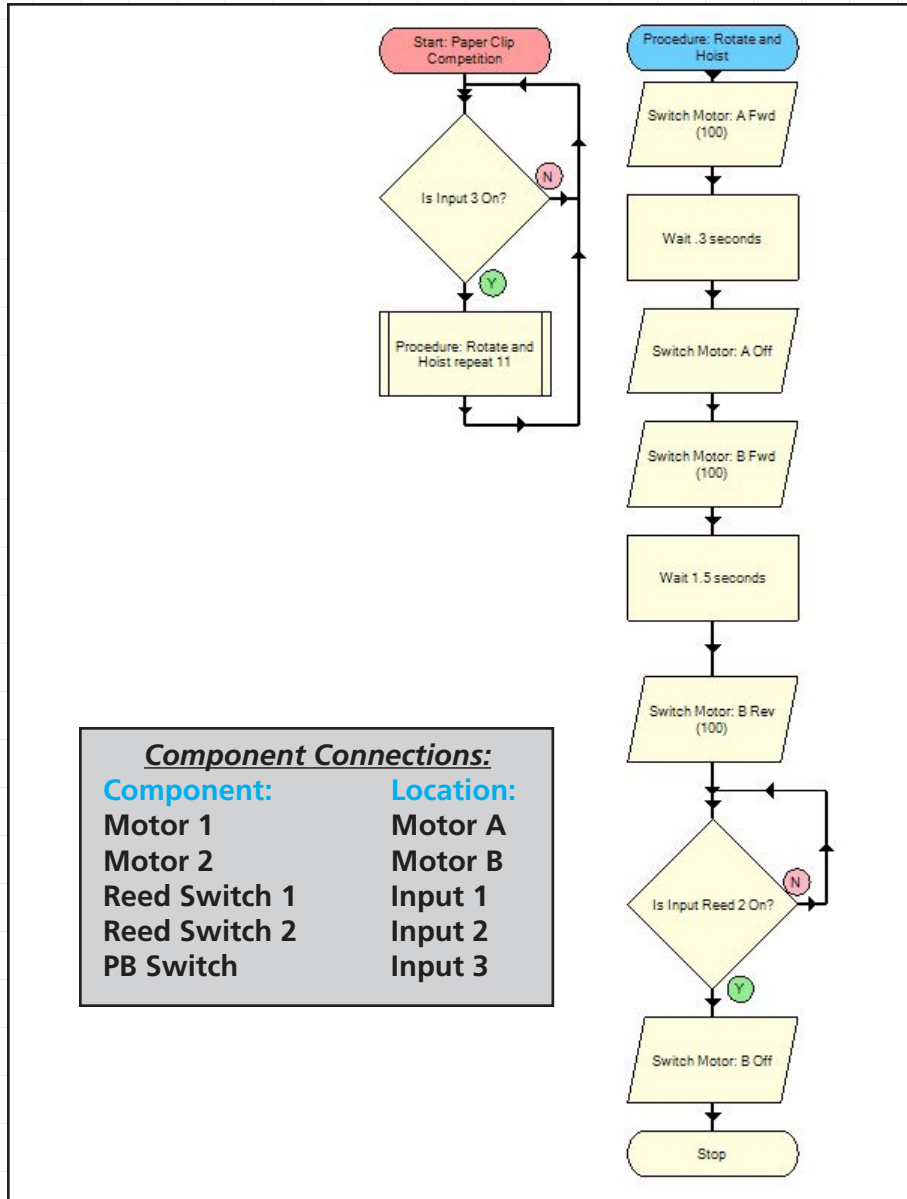


Laying out the testing area can easily be done using a protractor and meter stick. Check for accuracy as the angles are marked.

Several paper clips should be placed on each line to account for variations in where the magnet is dropped and for swing in the chain. You may even want to create a "pile" for more chances.

When developing a program to run this test, the students may need some help with finding appropriate wait times to run the crane. If it seems like they are having trouble developing a program, you may want to suggest this method:

With your crane programmed at the appropriate motor speed, run the crane 180 degrees while timing it with a stop watch. Since we are stopping every 30 degrees in the competition, take the time and divide it by 6. This will give the students a good starting point for their programming. They may still need to fine tune the wait times. For the example program shown below, it took approximately 7 seconds to travel 180 degrees which gave a time of about 1.16 seconds for every 30 degrees. Since the program needs to start and stop, some adjustment needed to be made. The time that worked for the program tested below was 1.2 seconds.



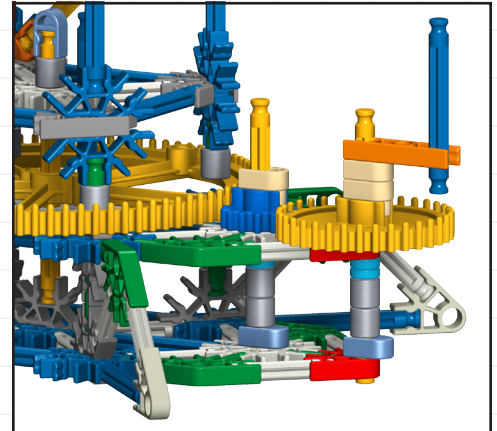
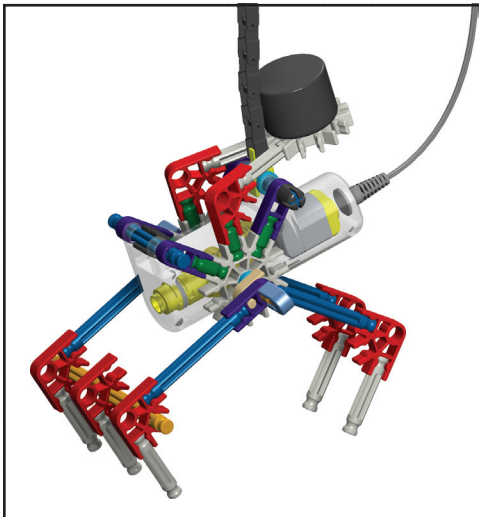
The program displayed is started with the push button switch and then executes the "Rotate 30 Degrees" and "Hoist 30%" procedures in sequence six times. The "Hoist 30%" procedure and "Rotate Crane to Stop" are basically the same procedures used in the previous test. The "Rotate 30 Degrees" procedure is the procedure the students may need to experiment with to get the proper timing.

TEACHER'S NOTES:

The students may experience trouble with the crane rotating exactly the same every time. This could be due to fluctuations in motor performance and resistance in the crane's systems. It is a feature that adds to the fun of the competition.

20. After the students have had sufficient time to complete the paper clip competition and respond to the questions related to the activity on their *Student Response Sheets*, distribute the **Challenge Design Briefs** that will outline several possible challenge activities for you or the students to select from. There are also several opportunities for the students to modify their crane model and compete. A sample program for the *Ultimate Challenge* can be found in the *Answer Sheets*.

Several activities on the Challenge Design Briefs require the students to build a motorized claw to be used on the hoist. This will require the students to remove the motor from the base and substitute it with a hand crank. The claw can be used to simulate popular claw games that are seen in arcades or used to move other objects.



The Ultimate Challenge activity will provide the students with an opportunity to create a gripper-style game where they may try to grab ping pong balls (or whatever other object you may wish to supply them with) from a bowl and move them to another location.

Explanation

1. Throughout the activities in this lesson students have been completing **Student Response Sheets**. Allow sufficient time to complete these sheets as they finish each activity so they can demonstrate they are able to explain what they have discovered. Remind students that some sections of the **Student Response Sheets** are to be completed "**As a Group**" while others are to be completed "**On Your Own.**" They should be formulating thoughts, calculations and definitions from their own words.
2. Decide if you want groups to present their results after each *activity* or *wait until the entire unit is finished* to present their findings. Presentation is an important part of the learning experience since all students may approach these *activities with different thoughts* and ideas. Presentations should include a variety of elements such as descriptions, visual aids and demonstrations.

Elaboration

Students will self-evaluate their challenge solutions based on the criteria provided in the rubric for this activity. Elaboration components are found in the logs and response sheets.

TEACHER'S NOTES:

- Assign the **Self Reflection/Evaluation** rubric to the students so they can self-evaluate their work. The rubric score and your evaluation will make up a portion of the assessment data for this lesson.
- Provide students with a **Teamwork and Self-Evaluation** sheet and review the form with the students before they complete them.

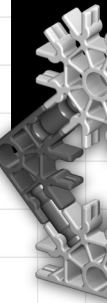
Evaluation

You may use some or all of the following to evaluate student's performance:

- Self Reflection/Evaluation Rubric
- Teamwork and Self Evaluation forms
- Presentation of the Challenge Solution(s)
- Research and Design Logs
- Student Response Sheets
- Design Journal

Extensions

1. After the students have worked through the activities, it is useful to extend the learning through career research and extended activities. Career components have been added to the **Research and Design Logs**, but can be extended by other means such as guest speakers, business tours, etc.
2. Extension activities should be included in any student presentations.





On Your Own

Research and Design Log

Name: _____ Date: _____

Define the following terms below. Be sure to write the definitions in your own words.

Truss -

Base (crane) -

Mast or Tower (crane) -

Slewing Unit (crane) -

Jib or Working Arm (crane) -

Counter Weights (crane) -

Hoist (crane) -

CNC -

Coordinate Systems -

Cartesian Coordinates -

Polar Coordinates -

Name: _____ Date: _____



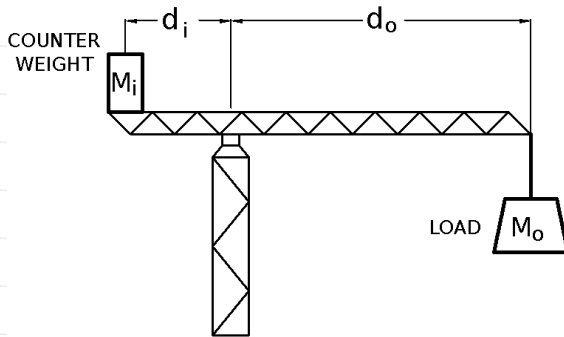
On Your Own

The Tower Crane

Explore

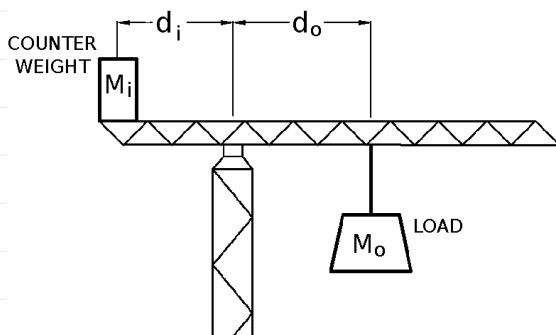
- Before testing your crane, examine some of the physics related to tower cranes. Since a tower crane is limited to how much it can safely pick up due to working arm lengths and counter weights, complete the following practice exercises:

d_i = Effort Distance to Fulcrum (counter weight)
 d_o = Load Distance to Fulcrum
 Mechanical Advantage: $MA = d_o / d_i$
 Counter Weight: $M_i = M_o \times MA$



Example 1:

$M_o = 7,000 \text{ Kg}$
 $d_o = 35 \text{ m}$
 $d_i = 10 \text{ m}$
 $MA = \underline{\hspace{2cm}}$
 $M_i = \underline{\hspace{2cm}} \text{ Kg (counter weight mass)}$



Example 2:

$M_o = 7,000 \text{ Kg}$
 $d_o = 15 \text{ m}$
 $d_i = 10 \text{ m}$
 $MA = \underline{\hspace{2cm}}$
 $M_i = \underline{\hspace{2cm}} \text{ Kg (counter weight mass)}$

- Internet Research: Find some typical sizes and limits for real tower cranes on the internet. If you have trouble finding information, your instructor can help.

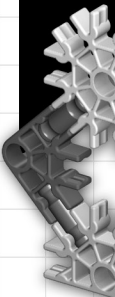
Maximum Unsupported Height: _____

Maximum Reach: _____

Maximum Lifting Power: _____

Counter Weight Mass: _____

- What safety features are used to prevent the operator from overloading the crane?



Elaborate and Explain

- On tower cranes, the counter weight is not adjusted for different loads since the structure of the tower itself can support a certain range of mass without falling, but it does have limits. Notice the location of the load on each example on the previous page. What can be said about the load in relationship to how far out from the tower it is being lifted? Explain.
- You found that tower cranes can only be built so high unsupported. What must engineers do when they want to go higher?
- Review the assembly instruction for the K'NEX crane (the crane does not need to be assembled to answer these questions). There is a gear system at the base of your K'NEX tower crane that is used to rotate the tower. After examining the gears that will be used, determine the following:
 - o What is the gear ratio of the system?
 - o Is the system geared up or geared down? How did you determine this?
 - o For every full rotation of the crane, how many times does the motor rotate? How did you determine this value?



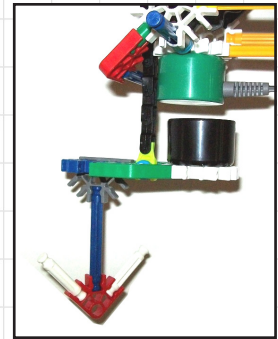
As a Group

Explore

- After reviewing your answers together for the previous questions, construct the crane model for the lesson. The crane uses two motors (one to rotate the crane and one to control the chain and hook), one push button switch, two reed switches and three magnets. The push button is hand held and used to start your program.
- Your K'NEX crane model is designed with a hook to grab a box. In order to keep the hoist from rising too high, there is a reed switch and magnet system that can be programmed to limit the lift. You will also see a reed switch and two magnets at the base to limit rotation. Your first programming challenge is to determine appropriate rotational and hoisting motor speeds. This will also give you the opportunity to practice using the hook to pick up the K'NEX box. Develop a program that will meet the following requirements:
 - o Use the push button switch to start the program for each speed test.
 - o Rotate a full 180 degrees (from magnet to magnet) to pick up the box, and then return to the start position to drop the box.
- Your crane should start in a "home" position (hoist raised and rotated to one magnet position). When the button is pressed, the crane should rotate to the other magnet position, lower the hook to pick up the box, raise the hook to the reed switch limit, rotate back to the "home" position, lower the box, and then raise the hook. You should be able to press the button again to run the next percentage for both motors. Test both motors at 30%, 50% and 70%. It may be easier to develop the program to run one speed only, and then change the percentages for the next speed test. Determine which percentage works best for each motor. **On graph paper**, draw the program you plan to use.

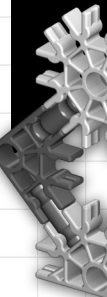
Elaborate and Explain

- While you only tested 3 percentages for each motor, you may select and test different speeds to “fine tune” your program. Also, you may find that different percentages work better for each motor.
 - o Which percentage worked best for the base rotation?
 - o Which percentage worked best for the hoist?
- You may have experienced problems with the hoist reed switch registering correctly every time to stop the motor. If you experienced this problem, how did you overcome it? This may have occurred more at higher speeds. Are there any other difficulties with the model or program that make this activity a challenge? Was hooking the box difficult? If so, how could you modify the program to help this? Explain.



Explore

- Class Competition! Now that you have determined the best motor speeds and have considered how to improve hooking the box, modify your program so that you can see which group can pick up the box the most times out of 10 tries. The program and activity should follow these guidelines:
 - o Use the push button switch to start the program for each attempt. You will start and end at the “home” position (at one base magnet and hoist raised).
 - o Rotate a full 180 degrees (from magnet to magnet) to pick up the box, and then return to the start position to drop the box (you can manually help unhook the box, but you cannot help hook the box).
 - o The push button switch can only be used to start each attempt. You must determine appropriate “wait” times to drop and raise the hook. **On graph paper**, draw the program you plan to use.
- Record your results and the results of all the other groups in the space below.
- So who won? Were there any differences with each group’s programming?
- What would your group do differently if you were to do this challenge again?



Name: _____ Date: _____

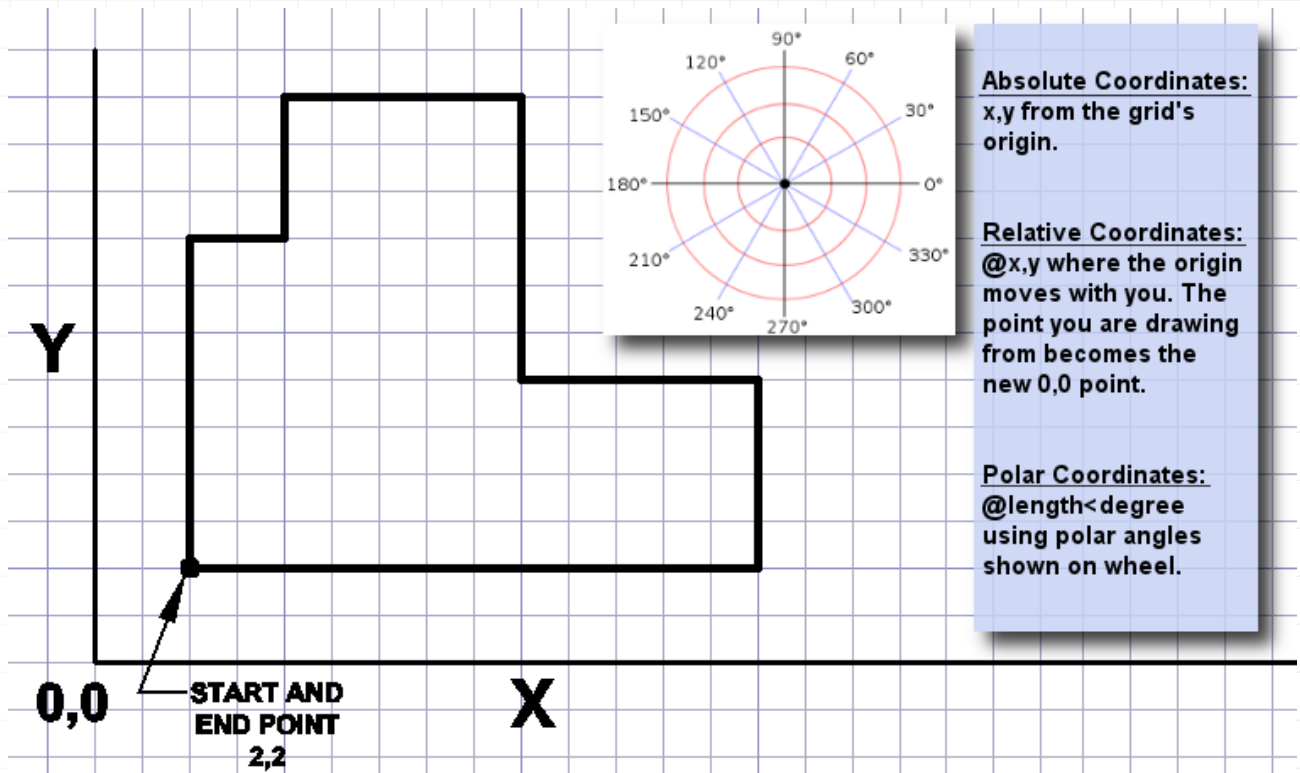


CNC and Coordinate Systems

On Your Own

Explore

- In class discussion, you talked about coordinate systems and CAD (computer-aided-drafting). Below, you will see a drawing on a normal x,y grid with the origin at the lower left corner (0,0). The starting and ending point of the drawing is 2,2. Write down the coordinates needed to draw the shape in each CAD coordinate system. *The shape is drawn counter clockwise from the 2,2 point.*



Absolute Coordinates		Relative Coordinates		Polar Coordinates	
From Point:	2,2	From Point:	2,2	From Point:	2,2
To Point:	14,2	To Point:	@12,0	To Point:	@12<0
To Point:		To Point:		To Point:	
To Point:		To Point:		To Point:	
To Point:		To Point:		To Point:	
To Point:		To Point:		To Point:	
To Point:		To Point:		To Point:	
To Point:	2,2	To Point:	@0,-7	To Point:	@7<270

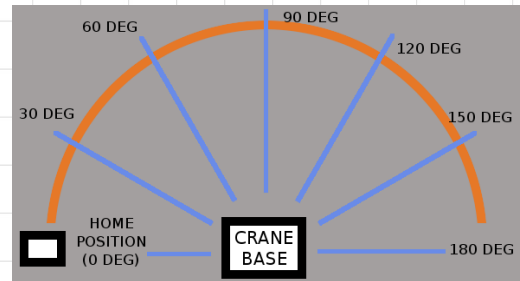


As a Group

Observe

- Review your answers to the coordinate exercise on the previous sheet as a group and check for understanding.
- **Class Competition!** You will be modifying your crane hoist to use a magnet in place of the hook to see how many paper clips can be picked up from specific locations. Remove one magnet from the tower base (keep one for finding a “home” position) and modify the hoist so you can use the magnet instead. Your instructor can help if you have trouble with the modifications.

- Develop your program for the competition. Use the motor speeds that worked well for your first activity again for this program. Paper clips will be placed at even intervals of 30 degrees around a half circle (180 degrees). Your goal is to develop a program using wait blocks so the hoist is dropped at every interval in order to collect and hold as many paper clips as possible. While you could try to guess at the proper timing, it would be better to logically try to calculate your intervals since they are evenly spaced. Your instructor can provide some helpful ideas. Your program must do the following:

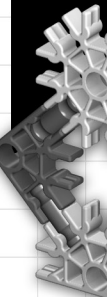


- o Start using the push button switch from the “home” position.
- o Automatically complete the sequence of stopping at each interval, dropping and raising the magnet, and then move to the next location.
- o When it reaches the last location, it should return to the home position where the paper clips can be counted.

Your instructor will determine how many tries you have to obtain the highest score. **On graph paper,** draw the program you plan to use.

Observe

- Record your results and the results of all the other groups.
- Who won? Were there any differences with each group’s programming?
- What could your group have done differently if you were to do this challenge again? Did you notice any inconsistencies with your model?



Challenge Design Brief

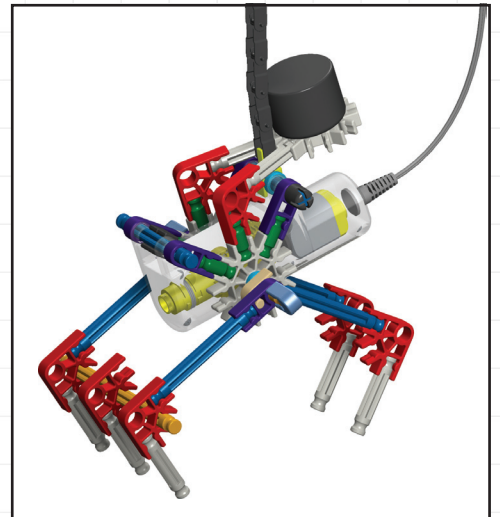
Name: _____ Date: _____



As a Group

Here are several possible design challenges for your group. Use notebook and graph paper to document the activity or activities and fasten them to this sheet.

- Modify the anchor hook to be able to “pick things up and put them down” without the operator needing to assist with the hooking and unhooking. Create a program that would be able to pick up and place the K’NEX box or other object of your choice at different levels (meaning pick it up from the surface and place it on a box or stack of books). Chart your program on graph paper and record your results.
- Modify your crane to now use a hand crank for the base and a motorized claw for the hoist. For this activity, you will no longer be using the reed switch at the base since it is now manually rotated. Create a program that will allow you to use the push button switch to lower the claw, grab the K’NEX box, and then place it at another location. Depending on how you create the program, you may need to program in wait times to allow the crane to be hand-cranked to the next position. You can also use the push button for all operations. There are many ways to create this program. Chart your program on graph paper and record your results.
- **The Ultimate Challenge!** Modify the crane to use the gripper and hand crank as described above. In arcades, you will see gripper games where you can move the claw over a prize and try to grab it. Your instructor will provide you with the objects you will try to “win”. Your goal will be to develop the program to lower and grip with only one push button press, and then release the prize over a box or bowl.
- You are a construction engineer given the challenge of building this crane on site. How much would it cost to build the crane? Determine the cost of the parts required to build the model using a ‘Cost per Piece Chart.’ Also, determine how many “construction workers” it would take to build the crane, a labor cost per hour, and the total number of hours each employee would be working on the project.



Self Reflection/Evaluation

Name: _____ Date: _____

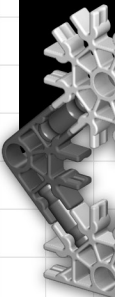
Unit: _____ Model: _____

Complete the Activity Assessment Rubric to provide your impression of how you did with this lesson.

Assessment Rubric			
<i>Circle Responses for each:</i>	Excellent	Good	Acceptable
Research and Design Logs & Worksheets	Student Response Sheets and Design Logs complete with no spelling or grammar errors. All answers on Student Response Sheets are accurate. <input type="text"/> 1-10	Student Response Sheets and Design Logs complete with few spelling or grammar errors. Most answers on Student Response Sheets are accurate. <input type="text"/> 1-8	Student Response Sheets and Design Logs complete with many spelling or grammar errors. Few answers on Student Response Sheets are accurate. <input type="text"/> 1-6
Design & Construction	Your device is very neatly constructed, easy to use, and meets or exceeds expectations outlined in the Design Brief. <input type="text"/> 1-10	Your device is neatly constructed, easy to use, and meets expectations outlined in the Design Brief <input type="text"/> 1-8	Your device has been constructed, is in useable form, and meets the materials criteria listed in the Design Brief. <input type="text"/> 1-6
Design Journals & Presentations	Your Design Journal is complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. It is presented in a neat and orderly fashion. <input type="text"/> 1-10	Your Design Journal is mostly complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows some disorder. <input type="text"/> 1-8	Your Design Journal is missing 1 or more logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows disorganization. <input type="text"/> 1-6
Teamwork/Work Ethic	You worked well with your teammates and interacted well with others. You demonstrated excellent reliability and initiative when working on this challenge. <input type="text"/> 1-5	You worked well with your teammates and interacted well with others. You were reliable and demonstrated initiative when working on this challenge. <input type="text"/> 1-3	You worked well with your teammates and others. You were generally reliability and usually demonstrated initiative when working on this challenge. <input type="text"/> 1
Total Score	<input type="text"/> /35		

Teacher Comments:

PICK IT UP AND PUT IT DOWN



Teamwork & Self Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____



As a Group

Teamwork and cooperation are necessary skills required for most jobs since businesses typically have many employees that work together in teams rather than lots of individuals working alone. All employees need to contribute equally, using their skill sets to make a project successful while meeting deadlines. If one person fails to contribute adequately, the business or project can fail.

- **Communication Skills:** How well did your group communicate? How could communications within your group be improved?

- **Work Load:** How was work assigned in your group? Did individuals step up to accept responsibility? Were personal skills considered as work was assigned? For larger groups, is it beneficial to assign someone as a leader?

- **Presentation:** How was the unit presentation developed? How did the group determine responsibilities so no one was left out? What improvements could be made for future presentations?

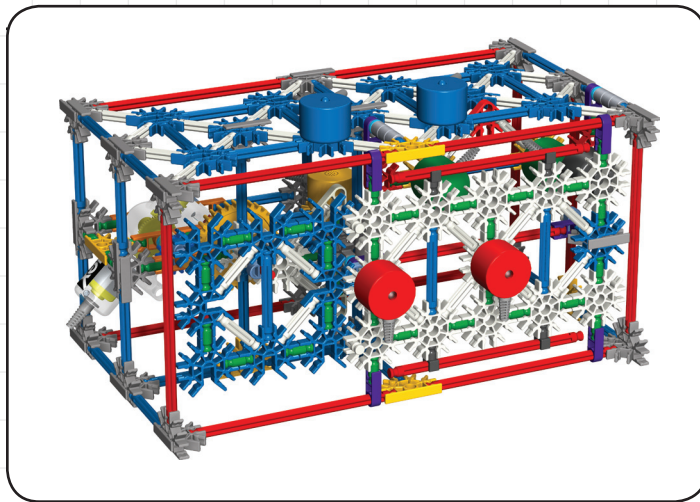


On Your Own

- **Personal Input:** Do you feel you contributed equally with your group? Did you do too much or not enough? Personal contributions to the group are listed in the *Research and Design Log*, but what could you do to work better in a team?

LESSON #8: A SAFE COMBINATION

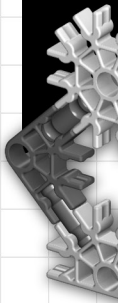
5-7 X



Main Concepts (STEM):

- **Science**
 - Logical Thinking and Problem Solving
- **Technology & Engineering**
 - Digital Design
- **Mathematics**
 - Binary and Boolean Computation

Objectives	Required Materials:	Optional Materials:
<p><i>Student will be able to:</i></p> <ul style="list-style-type: none"> • Work effectively both independently and in collaborative teams. • Correctly connect and program the K'NEX interface to control the safe model • Understand the difference between analog and digital. • Apply the concepts binary number systems and Boolean logic. • Modify their computer programs to control the safe for specific challenges. 	<p><i>Teacher will need:</i></p> <ul style="list-style-type: none"> • K'NEX Interface and software • Computer projector and/or whiteboard • Extension cord (if power is not close to testing area) <p><i>Students will need:</i></p> <ul style="list-style-type: none"> • K'NEX Interface and components • Computer with K'NEX Computer Control software • K'NEX safe model • Copies of: <ul style="list-style-type: none"> o Research & Design Logs o Student Response Sheets o Challenge Design Briefs o Teamwork & Self-Evaluation forms o Self Reflection/Evaluation Rubrics 	<ul style="list-style-type: none"> • Graph paper • Notebook paper • Colored pencils • Sample K'NEX models (prebuilt safe model) • Calculators



TEACHER'S NOTES:

- *Students will use build the safe model. After the students construct the safe, begin the engagement portion of the lesson. Lesson 9 should take 5-7 class periods, depending on how challenge activities are assigned.*
- *As with previous lessons, students will be asked to construct the model, perform various experiments, chart data, record their thoughts and actions, and develop challenge activities.*
- *The K'NEX safe uses one motor, two push button switches, two reed switches, one magnet, one buzzer and two LEDs.*

Process

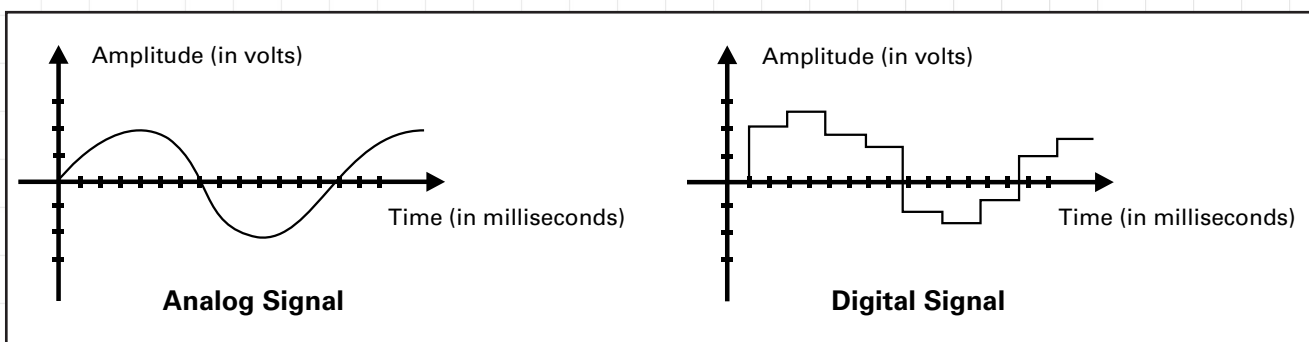
Engagement

1. Keeping in line with the *STEM Exploration* vacation road trip, discuss how the students have now reached the hotel and find a digital safe in their room to lock up their valuables. Discuss the processes used in the lesson with the students:
 - Students will construct the K'NEX safe model for the lesson and complete the *Engagement* activities. The safe uses two push button switches that act as the combination lock to open the safe.
 - They will be programming their model to run various experiments and to develop a combination to allow access to their safe.
 - Students will also examine the fundamentals of digital and analog electronics, binary number systems and Boolean logic. These concepts are the fundamentals for all computer programming.
 - They will finish the lesson by completing one or more open-ended challenge activities.
2. Distribute or direct students to the **Research and Design Logs** and **Student Response Sheets** for this unit. Introduce the **Challenge Design Briefs** when the students are ready for the challenge activities and the **Assessment Sheets** at the end of the activity. This will help students focus on the current activities. These pages are provided at the end of each lesson or in the **Resources** section of the Teacher's Guide. Links to editable electronic versions of the Research & Design logs, Student Response Sheets, Design Briefs, Evaluation/Assessment forms and the Cost Per Piece chart can be accessed by the students from the Start Menu, or you can drag and drop the "STEM Explorations Resources" folder from the software CD onto the desktop or a shared drive.
3. Discuss that the **Research and Design Logs** and **Student Response Sheets** will be used in the same manner as lesson 1.
4. Lesson 8 introduces the students to the concepts of a digital programmable safe and computer logic.
5. The students have already been exposed to digital logic through the previous lessons. They have seen input and output devices that are either on or off and motors that do not vary voltage, but use the percentage of on and off time to vary speed. Ask them what the term "digital" means to them. They are called "the children of the digital age", but do they know what that means? A computer is a digital device while a dimmer light is an analog device. You will review these concepts at a later time.
6. To help introduce the students to the concepts of digital electronics, here is an interesting website for the student with some brief information:

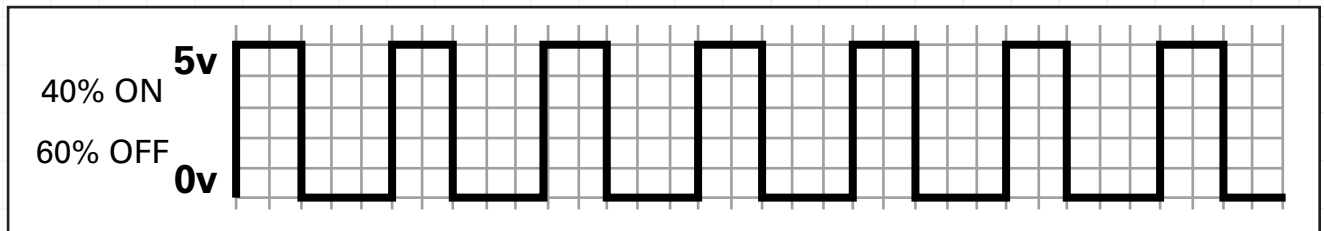
[Digital Electronics](#)

Exploration

1. Establish student teams (2-3 students per group), and then review the activity and **Student Response Sheet 1**. Allow students time to discuss the activity in their groups.
2. Students should understand the safe operation of the K'NEX interface and electrical concerns. Review the *K'NEX STEM Explorations User's Guide*, if needed.
3. The students should construct the K'NEX safe model. This model is constructed using one motor, two push button switches, two reed switches, one magnet, one buzzer and two LEDs.
4. Discuss how this activity will introduce the students to digital electronics concepts and binary number systems. These are the concepts used in computer systems.
5. In Lesson 2, the students were introduced to the quantities of electricity and examined the effects of *Pulse Width Modulation* in order to control motor speed as opposed to varying the amount of voltage. Review the concepts of analog and digital electronics with the students:
 - o **Analog Electronics**- Analog electrical systems are systems with a continuously variable electrical signal, in contrast to digital electronics where signals usually take only two different levels (typically 5 volts and 0 volts). The term "analog" describes the proportional relationship between a signal and a voltage or current that represents the signal. Analog means "proportional". For example, in order to make a light bulb brighter or dimmer, we can vary how much voltage is delivered to the light bulb. If the lights on a car's dashboard can handle a maximum voltage of 12 volts, we can adjust the voltage to 2-3 volts, which would make them dim, all the way up to 12 volts, which would make them very bright. The same effect can be used to control motors and other devices.
 - o Before the mid 1990's, everything was analog. Today, many electrical devices are still analog. While many devices are now computer controlled, most simple electrical devices in your house like toasters, blenders, lighting systems and fans require varying electrical quantities like voltage and current in order to operate at different speeds and settings. Most of these devices are controlled by switches that vary the amount of resistance to the device (i.e. a volume control knob). Higher resistance means less electric to the device while lower resistance means more electricity to the device. Most radio signals that you listen to on traditional radios are analog. Radio signals are slowly being replaced by HD (Hybrid Digital) radio that requires different radio tuners. In 2009, television broadcasts were required to change from analog to digital signals in the U.S. Below is an example of an analog signal and a digital signal. Notice the square feature of the digital signal.



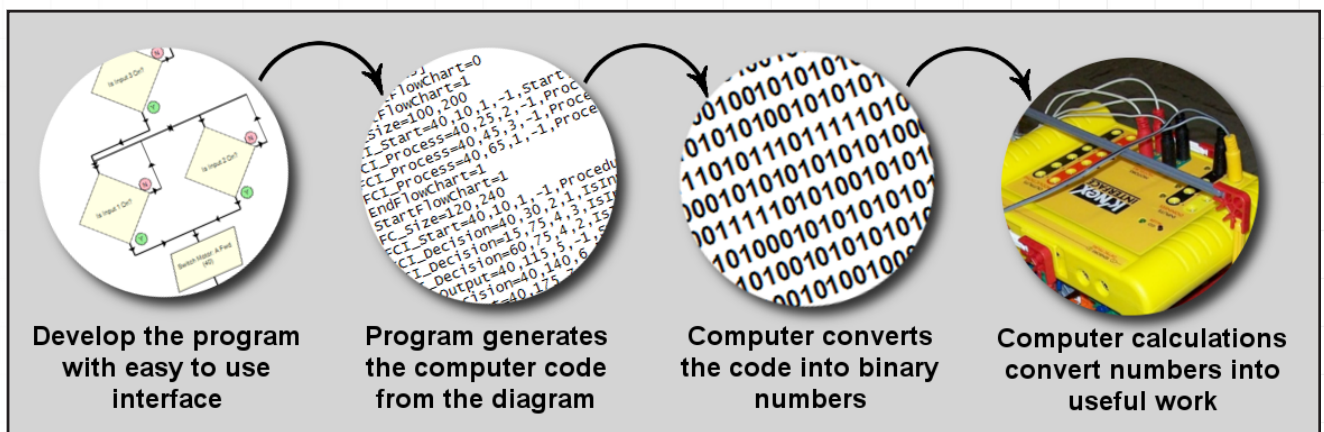
- o **Digital Electronics-** Digital electronics only use two values, rather than a varying level like analog electronics. Most computer applications use values of 0 and 5 volts. Zero volts would be considered "off" while 5 volts would be considered "on". Have the students think of items controlled by computers. Digital signals are sent in patterns and series of "on" and "off" pulses, much like the example pulse width modulation used to control the motor in Lesson 2:



The advantages of digital signals over analog signals are that digital signals do not degrade or become distorted as they are transmitted. They can also take up much less airwave space. This is an important consideration in an age where everyone is using the airwaves for cell phones, laptops and increased digital T.V. and radio stations. When trying to think of the concept of digital transmission, compare it to old Morse code. In Morse code, long and short beeps could represent various letters and numbers. In digital signals, all pulses are the same length in time, but vary by on and off. In the mid 1980s when computers began showing up in homes, a computer could process digital codes at about 16 million times per second (16 MHz). While that may sound fast, today's computers process data at billions of times per second (GHz). Computers have become so fast that they are actually being slowed down by the electrical data flowing through the wires. This is why fiber optic systems are becoming more widely used over longer distances. Nothing travels faster than the speed of light and light pulses can be used to represent digital data as well as electricity. Compare this to blinking a flashlight or laser pointer as opposed to turning an electrical switch on and off. The light will travel faster than the electricity flowing through the wire.

In lesson 2, we tested the motor output and found that it only pulsed on 20% of the time for 20% motor speed. This was a digital signal since voltage stayed the same and was only on or off. If we would treat that motor like a traditional analog motor, we would lower the voltage to 20%.

6. Complete the *first two* vocabulary terms on the **Research and Design Log** and the *first page* of **Student Response Sheet 1** to help with student understanding. This will allow the students to focus on this portion of the lesson before discussing binary number systems.
7. Examine the **binary number system** with the students. You may distribute page 2 of **Student Response Sheet 1** now or at the end of the binary discussion if you have not done so already. A *binary number system* is a base-2 number system. In the case of digital electronics, those numbers are 0 (off) and 1 (on). All numbers and letters are represented by a binary number in computer programs. Computers convert the data we input to binary code, complete computations, and then convert the data into something that can be used or we can understand.



TEACHER'S NOTES:

Ask the students the following questions:

- "Have you ever typed a school project on the computer and saved the file, uploaded a file to the Internet, or attached a file to an email?"
- "Have you ever looked at how large that file is on the computer?"
- "What are the units used to measure the size of a computer file?"

Computers use the following terms to represent digital data:

- **Bit** - A computer bit is a binary digit. It is the smallest unit- a "0" or "1".
- **Byte** - Since bits are too small to do much with; they are usually assembled into groups of 8 called a byte. A byte contains enough information to represent a character, like a letter.
- **Kilobyte (KB)** - A kilobyte is 1,024 bytes. Due to binary counting, it doesn't work out to be quite 1,000 bytes as you would expect.
- **Megabyte (MB)** - A megabyte is 1,024 kilobytes (about 1 million bytes).
- **Gigabyte (GB)** - A gigabyte is 1,024 megabytes (about 1 billion bytes). Today's computer storage systems are measured in gigabytes, or even terabytes, of storage space.

For the examples in this lesson, we will work with binary numbers and convert them to decimal numbers that the students are familiar with. Below, you will see the decimal equivalent for each binary place in an **8-bit** (also known as a byte) binary number:

Decimal	128	64	32	16	8	4	2	1
Binary	1	0	1	0	1	0	1	0

In the example above, you will see that the far right space represents a decimal number of 1. Each place to the left then doubles. In order to calculate the decimal equivalent of the binary number above (10101010), you would add the decimal number for each binary "1". The answer would be $128 + 32 + 8 + 2 = 170$. Below are a few more examples:

- Binary 01 = Decimal 1
- Binary 10 = Decimal $2 + 0 = 2$
- Binary 11 = Decimal $2 + 1 = 3$
- Binary 100 = Decimal $4 + 0 + 0 = 4$
- Binary 101 = Decimal $4 + 0 + 1 = 5$
- Binary 1010 = Decimal $8 + 0 + 2 + 0 = 10$
- Binary 11001 = Decimal $16 + 8 + 0 + 0 + 1 = 25$
- Binary 11111111 = Decimal $128 + 64 + 32 + 16 + 8 + 4 + 2 + 1 = 255$

Review *binary addition* with the students. Explain that addition in a base-2 system is different than addition in the base-10 system that we use daily. In a binary system, $1 + 1$ should equal 2, which is really displayed as 10. In any column that adds to 2, the column is set to "0" and the 1 is carried. If a column adds to 3, the column is set to "1" and the 1 is carried (binary 3 is 11). See the examples below with decimal equivalencies displayed:

$$\begin{array}{r} 1001 \quad (9) \\ + 1101 \quad (13) \\ \hline 10110 \quad (22) \end{array}$$

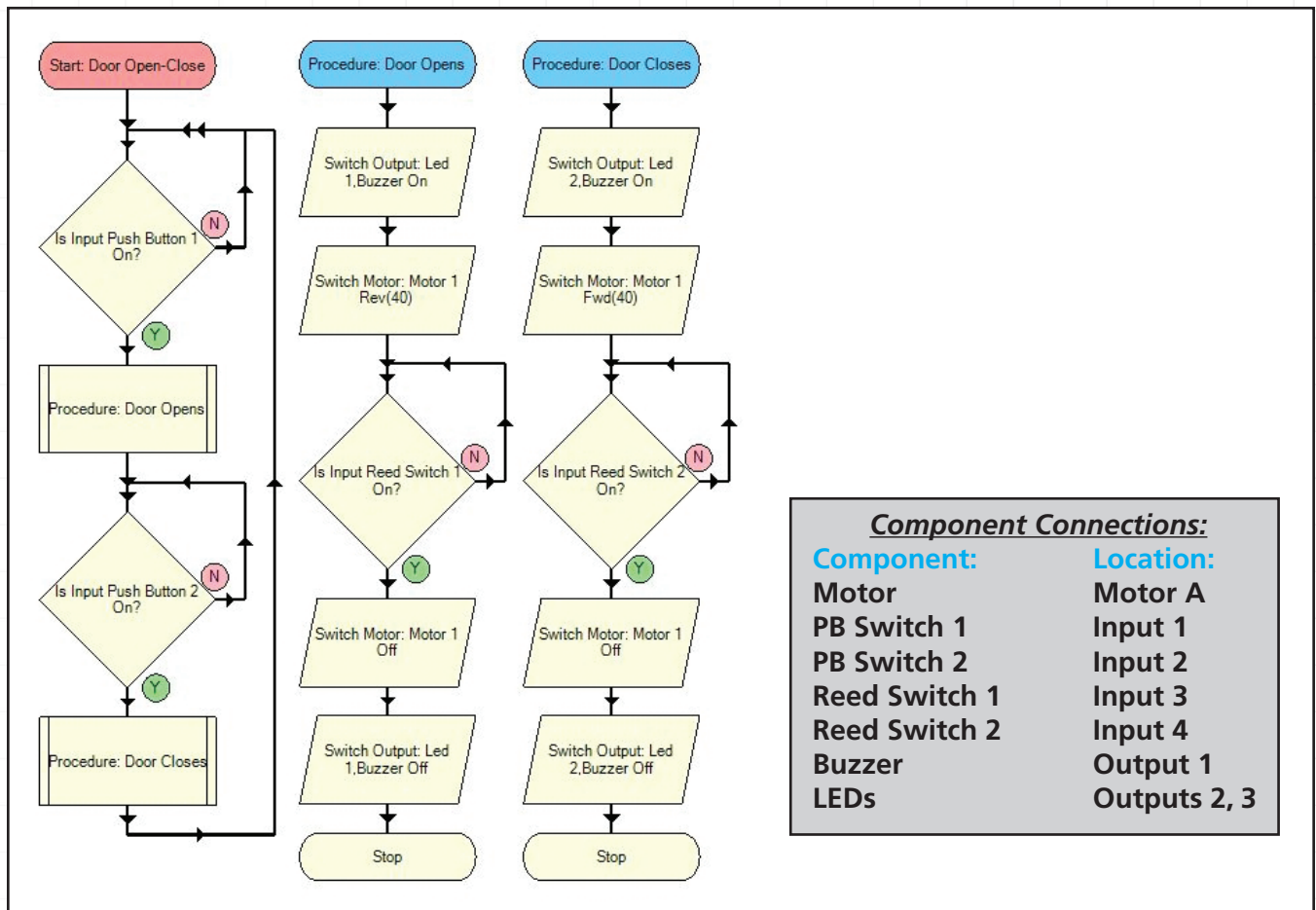
$$\begin{array}{r} 111 \quad (7) \\ + 111 \quad (7) \\ \hline 1110 \quad (14) \end{array}$$

$$\begin{array}{r} 1011 \quad (11) \\ + 1110 \quad (14) \\ \hline 1110 \quad (25) \end{array}$$

8. Instruct the students to complete **Student Response Sheet 1, page 2** and vocabulary terms *three through seven* found on the **Research and Design Log**.

In this activity, the students will examine the digital components of their safe to understand the operation; complete some sample binary problems; and determine an appropriate operating speed for their safe's motor while completing a simple "open and close" program for the safe.

Depending on available time and student ability level, you may wish to provide students with a flow chart of the first steps of their program to get them started. The students will need to develop and diagram the program they will use for the test. Here is a sample program that could be used for this activity:



The door is assumed closed at the beginning of the program. The program above uses the push button switches as inputs 1 and 2 and the reed switches for inputs 3 and 4. The buzzer is output 1 with the LEDs as outputs 2 and 3. The LED used in the "Door Opens" procedure is wired to glow green while the LED in the "Door Closes" procedure is wired to glow red (to signify opening and closing). The motor speed is set to 40% for smooth opening and closing.

TEACHER'S NOTES:

Since the motor is connected to the door through the use of a crank that can swing 360 degrees, it is not necessary to reverse the motor direction for each operation. It can continue on the same direction to complete both procedures.

9. After the students have had sufficient time to test their safe and respond to the questions related to the activity on their Student Response Sheets, summarize the activity with the class.
10. Review **Student Response Sheet 2** with the class. They should also complete the remaining vocabulary on the **Research and Design Log**. Because of time constraints and the complexity of the material, the following discussion on Boolean logic is **optional**. If you decide not to complete the Boolean portion of the unit, the students will not need to complete the final four vocabulary terms on the *Research and Design Log* nor the second and third pages of *Student Response Sheet 2*. **You may decide to skip the Boolean section, present all the material to the students, or assign it as a research project.** If skipping the logic block section, proceed to step #12.
11. You may review the principles of *Boolean Logic* with the students. Boolean logic was developed by George Boole in the 1840s. Boolean logic is a form of algebra where values are reduced to being either *true* or *false* and is the fundamental math used in computer systems to control output (as *binary systems* work with on or off). Even though Boolean logic was developed long before computers came into existence, it is the perfect math to use in computer systems. Boolean logic is used to answer programming questions as well as calculations. Boolean logic is also used in 3D computer drafting to join or cut two different 3D objects. Examples of these applications will be shown later.

Computer processors are made up of millions to billions of *Logic Gates*. A logic gate is an elementary building block in digital circuits that typically have 1-2 inputs and 1 output. Logic gates follow the rules of Boolean math. There are a variety of Boolean logic gates that can be examined, but for the purpose of this introductory lesson, we will focus on *three* types:

- **Inverter or NOT Gate** – This is the simplest type of gate that can be used. A NOT gate simply takes the input (1 or 0) and inverts, or flips it.
“The output is NOT the same as the input”.
- **AND Gate** – An AND gate will only provide a true output (1) if both inputs are true. Otherwise, the output is always false (0).
“The output will be true if input A AND B are true”.
- **OR Gate** – An OR gate will provide a true output (1) if *at least* one of the two inputs is true (1).
“The output will be true if input A OR B is true”.

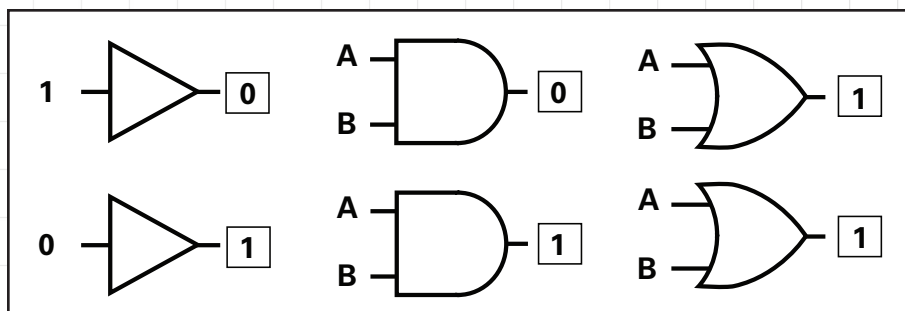
A	B	Q
1	0	
0	1	
0	0	0
0	1	0
1	0	0
1	1	1
0	0	0
0	1	1
1	0	1
1	1	1

A
Q

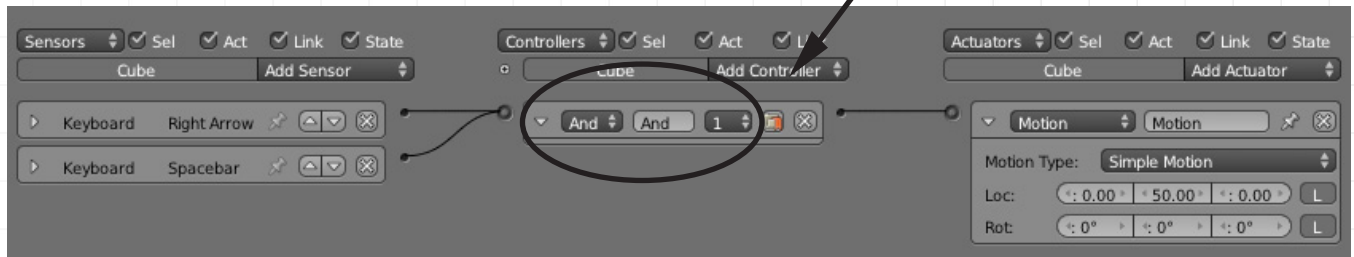
A
Q

A
Q

These basic logic blocks form the mathematical basis for computer computations. By combining gates in specific ways, they can add, subtract, multiply and divide numbers. They are the basic blocks in a calculator. Look at the examples above in regards to input and output states. “A” and “B” represent *Inputs* while “Q” represents the *Output* of the gate. “Q” is typically used on logic gates as the output rather than “O” since it looks too much like a zero. If you look at the *And* gate example, zeros on both inputs will produce a zero on the output. The other 3 example input combinations show the resulting output. Review several examples with the students to demonstrate understanding:

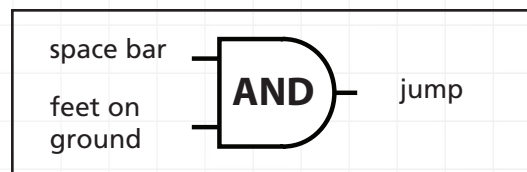


Computer game development software uses Boolean logic blocks to perform operations. Here is an example of a game command logic block from a 3D design and game development program called *Blender*. The example shown is designed to make a character run 50 m/s when the space bar and the right arrow keys are pressed at the same time. Notice that an “*And*” controller in the middle is connected to both keyboard input sensors. This means that the motion of 50.00 will only be applied when both buttons are pressed. If the controller is set to “*Or*” instead of “*And*”, the force would be applied when either button is pressed.



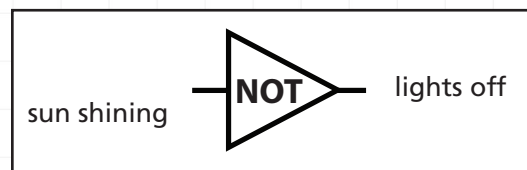
Review these text examples with the students where these logic blocks could be used:

- When developing a computer game, a character needs to be able to jump when the space bar is pressed, but he should only be able to jump when his feet are on the ground. What type of logic block is needed?



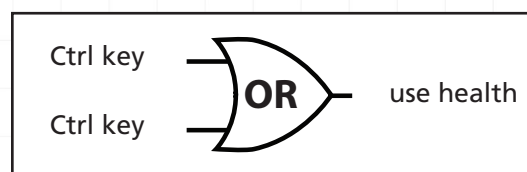
The AND gate will not allow the output to occur unless both inputs are true (or at a 1 value).

- When the sun is shining, the dusk-to-dawn lights should be off.



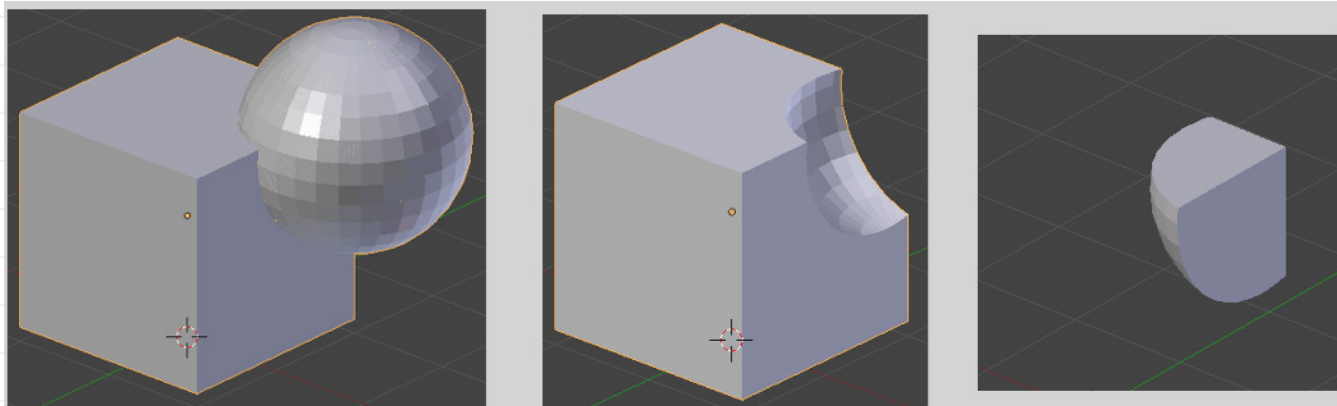
The NOT gate flips the value of the input. If the sun is shining (1), the lights are off (0).

- When designing a computer game, the player should be able to use either “Ctrl” key to use health.



The OR gate will provide a true (1) output if either input is true (1).

Boolean logic is also useful for Computer-aided drafting applications (CAD). In 3D design programs, Boolean logic is used to join and cut 3D shapes. Below is a sample from the Blender 3D design software program where Boolean operations are being used to affect a cube and sphere shapes that overlap one another.



Boolean Union:

The two shapes are joined together into one object.

(Like an AND gate: both shape A and B)

Boolean Subtraction:

The one shape is used to cut the other.

(Like an OR gate: one or the other shape is removed)

Boolean Difference:

A shape is created that represents the area that was shared by both.

(Like a NOT gate: not A or B, but shared)

For more information about logic blocks, here is a website with more information that the students could use for research:

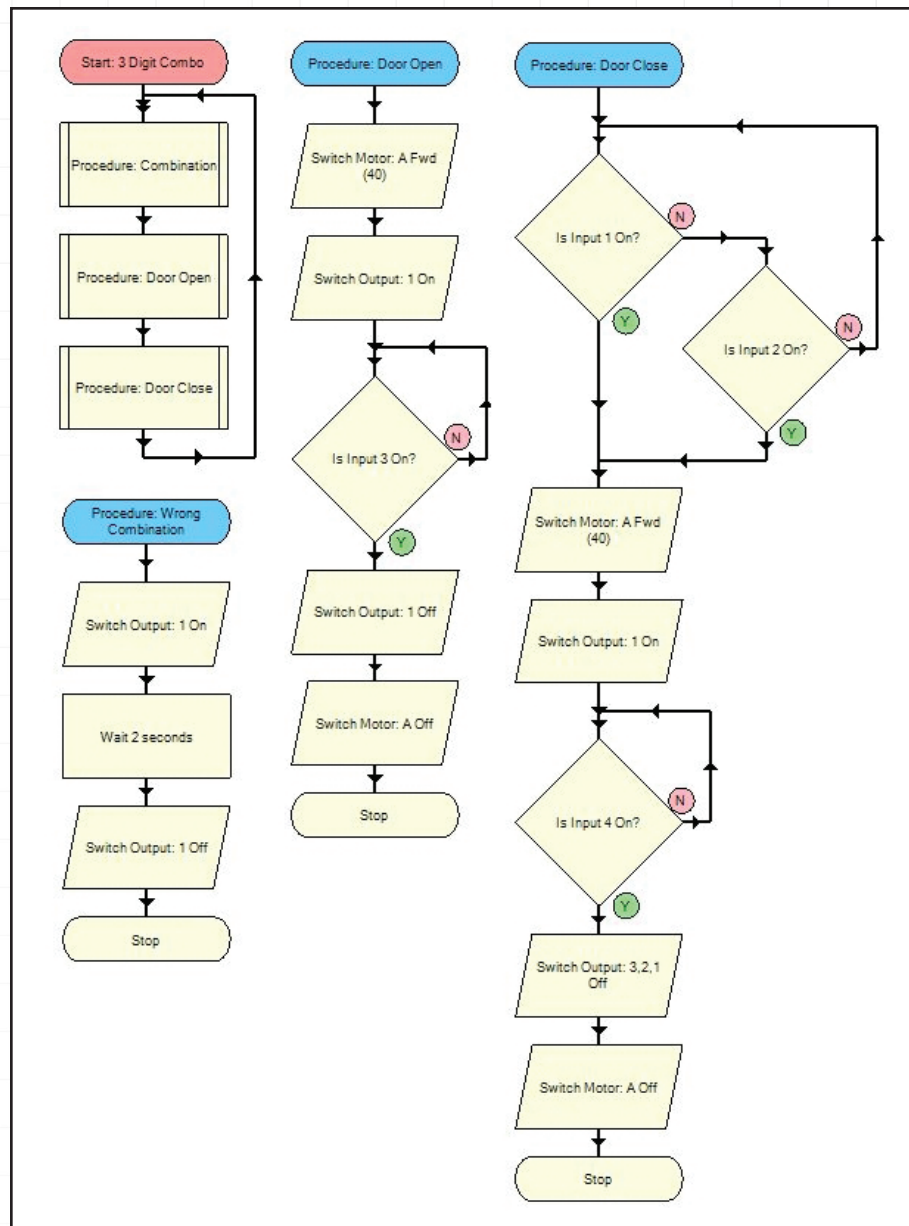
[How Boolean Logic Works](#)


- The students will also develop a more complex program for the safe during Student Response Sheet 2. In order to have the students focus on programming a combination lock for the safe, they will not be using the LEDs for this exercise to keep the program simpler. Discuss that their program may require more elaborate “branch” logic, meaning, the program will branch in several directions rather than a straight downward program as most programs have been up to this point. They will be required to develop a 3-digit combination for their lock this time and can use any combination they wish, but both buttons must be used. If a wrong combination is pressed, the buzzer should sound. They should also be able to use any button to close the gate.

The program shown uses the following connections:

Component Connections:	
Component:	Location:
Motor	Motor A
PB Switch 1	Input 1
PB Switch 2	Input 2
Reed Switch 1	Input 3
Reed Switch 2	Input 4
Buzzer	Output 1
LEDs	Outputs 2, 3

Depending on available time and student ability level, you may wish to provide students with a flow chart of the first steps of their program to get them started. The students will need to develop and diagram the program they will use for the test.



- 
13. After the students have had sufficient time to test their combination programs and respond to the questions related to the activity on their *Student Response Sheets*, distribute the **Challenge Design Briefs** that will outline several possible challenge activities for you or the students to select from.

Explanation

1. Throughout the activities in this lesson students have been completing **Student Response Sheets**. Allow sufficient time to complete these sheets as they finish each activity so they can demonstrate they are able to explain what they have discovered. Remind students that some sections of the **Student Response Sheets** are to be completed **“As a Group”** while others are to be completed **“On Your Own.”** They should be formulating thoughts, calculations and definitions from their own words.
2. Decide if you want groups to present their results after each *activity* or *wait until the entire unit is finished* to present their findings. Presentation is an important part of the learning experience since all students may approach these *activities with different thoughts* and ideas. Presentations should include a variety of elements such as descriptions, visual aids and demonstrations.

Elaboration

Students will self-evaluate their challenge solutions based on the criteria provided in the rubric for this activity. Elaboration components are found in the logs and response sheets.

TEACHER’S NOTES:

- Assign the **Self Reflection/Evaluation** rubric to the students so they can self-evaluate their work. The rubric score and your evaluation will make up a portion of the assessment data for this lesson.
- Provide students with a **Teamwork and Self-Evaluation** sheet and review the form with the students before they complete them.

Evaluation

You may use some or all of the following to evaluate student’s performance:

- Self Reflection/Evaluation Rubric
- Teamwork and Self Evaluation forms
- Presentation of the Challenge Solution(s)
- Research and Design Logs
- Student Response Sheets
- Design Journal

Extensions

1. After the students have worked through the activities, it is useful to extend the learning through career research and extended activities. Career components have been added to the **Research and Design Logs**, but can be extended by other means such as guest speakers, business tours, etc.
2. Extension activities should be included in any student presentations.





Research and Design Log

Name: _____ Date: _____

Define the following terms below. Be sure to write the definitions in your own words.

Analog Electronics -

Digital Electronics -

Binary Number System -

Bit -

Byte -

Kilobyte (KB) -

Megabyte (MB) -

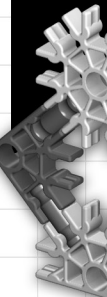
Optional Vocabulary:

Boolean Logic -

NOT Gate -

AND Gate -

OR Gate -



Name: _____ Date: _____



As a Group

A Digital Safe

Explore

- After discussing digital electronics, construct the safe model for the lesson. The safe will use one motor, two push button switches, two reed switches, one magnet, one buzzer and two LEDs. Note that these are all digital devices. The input and output devices only register “on” and “off” while the motor is controlled through a digital pulse (*as discussed in lesson 2*).
- Your K’NEX safe model uses one motor to drive the door, two push buttons to operate the door (*and later to set a combination*), two reed switches to limit door travel, a buzzer and two LEDs. Your first test is to develop a program to test the following:
 - o Determine an adequate motor speed to safely operate the door.
 - o Use one push button to open the door and one push button to close the door.
 - o Use the reed switches to limit door travel.
 - o Have one LED light green when opening and one LED light red when closing.
 - o Have the buzzer sound when the door is moving.

On graph paper, draw the program you plan to use.

Elaborate and Explain

- Answer the following questions as a group:
 - o What motor speed did you decide worked best? Why did you select this speed?
 - o In Lesson 5, you learned about *cams* and *cranks*. Which one of these devices is used to open the door on your safe? Explain your choice.
 - o Does the direction of the motor rotation affect the operation of the door or can it rotate either direction (or all the way around). What makes this possible?
 - o The safe is an example of a digital device. List at least 5 other devices that are digital. (*Hint: controlled by a computer*)
 - o Traditional radio is considered analog because of varying electrical signals. List at least 5 other devices that are considered analog. (*Hint: variable speed or brightness*)



On Your Own

Explore

- In your class discussion, you talked about binary number systems and how to convert binary numbers to decimal numbers you work with everyday. Using the diagram below, convert the following binary numbers to decimal:

Decimal	128	64	32	16	8	4	2	1
Binary	1	0	1	0	1	0	1	0

Binary	Decimal
11011	
101010	
00011	
11001101	

Binary	Decimal
10000110	
10111011	
1011	
1110101	

- Since your values can never be greater than 1, remember that numbers need to be carried differently. Complete the following binary addition problems plus complete their decimal equivalents.

1.

Binary	Decimal
111	
+111	+

2.

Binary	Decimal
10011	
+11010	+

3.

Binary	Decimal
101010	
+101111	+

4.

Binary	Decimal
11111111	
+11100011	+

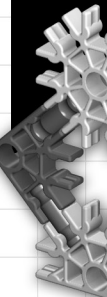
- An 8-bit binary number is a byte. A Kilobyte (KB) is 1,024 bytes. How big is the *program file* you just created to control the safe? Go to the computer where you saved the .go file and find out the size of the file. How large is the file?
- Find someone in class that has a USB flash drive or other storage device. What is the capacity of that drive? Looking at the size of the safe program file- how many files that size could you save on that drive? Explain your answer.



As a Group

Elaborate and Explain

- Discuss your individual findings as a group and come to some common conclusions.

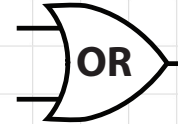
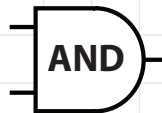
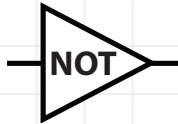




On Your Own

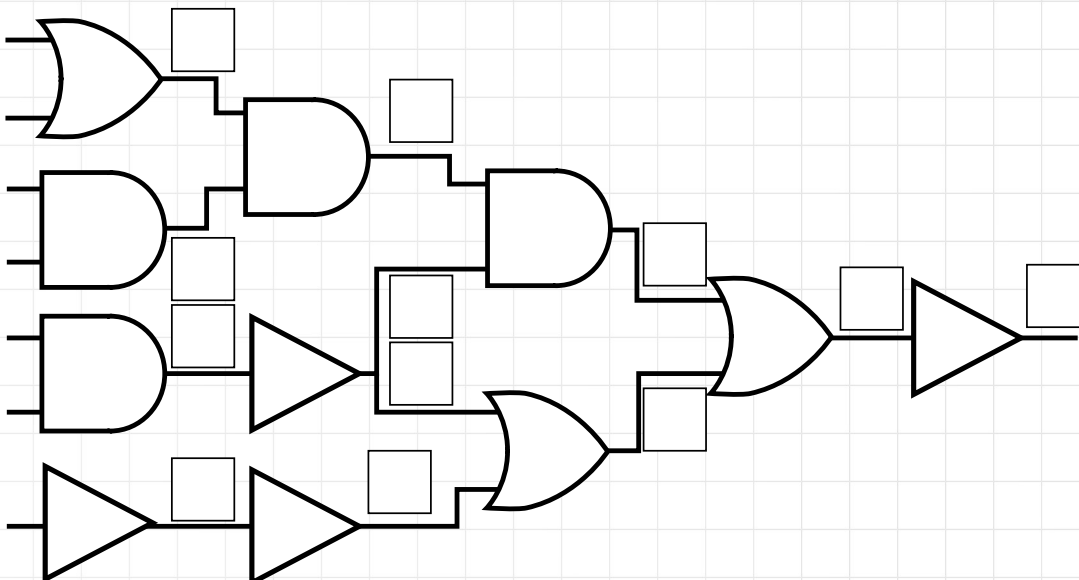
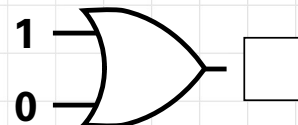
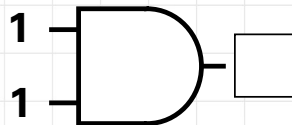
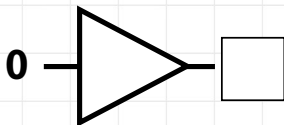
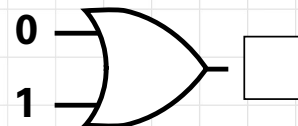
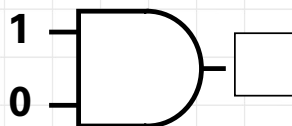
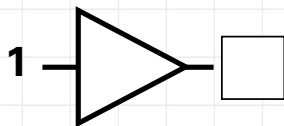
Observe

- While you did not necessarily use Boolean logic gates to write your combination program, computer logic was used to execute your commands. From your class discussion on Boolean logic, review the Boolean logic gates below and complete the exercises.



<p>Inverter or NOT Gate - This is the simplest type of gate that can be used. A NOT gate simply takes the input (1 or 0) and inverts, or flips it. <i>"The output is <u>NOT</u> the same as the input"</i>.</p>	<p>AND Gate - An AND gate will only provide a true output (1) if both inputs are true. Otherwise, the output is always false (0). <i>"The output will be true if input <u>A AND B</u> are true"</i>.</p>	<p>OR Gate - An OR gate will provide a true output (1) if at least one of the two inputs is true (1). <i>"The output will be true if input <u>A OR B</u> are true"</i>.</p>
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- Complete the following logic gate examples. Print your answers in the boxes



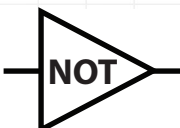
- Computer game designers use logic gate expressions of "NOT", "AND" and "OR" to complete actions in the game. Complete the following logic examples by drawing in the correct logic gate in the space provided.

Statement	Inputs	Gate Type	Output
When developing a computer game, a character needs to be able to fall when he walks off an edge, but he should only be able to fall when gravity is present in the game.	Walk off edge		Fall
	Gravity		

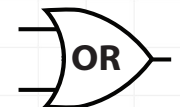
Statement	Inputs	Gate Type	Output
Develop a game for both right-handed and left-handed people. The running command can be the "up arrow" or the "W" key.	Up arrow		Run
	W key		

Statement	Inputs	Gate Type	Output
If it is raining, the baseball game cannot be played today.	Rainy day		Play a baseball game

- Develop three of your own logic statements in the blocks below.

Statement	Inputs	Gate Type	Output
			

Statement	Inputs	Gate Type	Output
			

Statement	Inputs	Gate Type	Output
			



As a Group

- Discuss your individual Boolean results as a group.

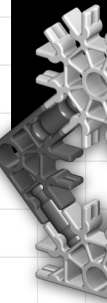
Name: _____ Date: _____



As a Group

Here are several possible design challenges for your group. Use notebook and graph paper to document the activity or activities and fasten them to this sheet.

- Modify your combination safe program so that it automatically closes after a certain amount of time instead of using a push button to close. Chart your program on graph paper and record your results.
- Add the LEDs into your combination program. Develop a way to make one blink green for correct combinations and one blink red for wrong combinations. Chart your program on graph paper and record your results.
- A 3-digit combination is very easy to guess. Especially when the program tells you when you hit a wrong button. Add more digits to your program. Try for a 5-6 digit number. Chart your program on graph paper and record your results.
- **The Ultimate Challenge!** Develop your program that combines the above features:
 - o Automatic closing after a certain amount of time.
 - o LEDs that blink to indicate correct and wrong combinations.
 - o 5-6 digit combination.Chart your program on graph paper and record your results.
- You are a safe designer working for a contractor building a new bank. Determine the cost of the parts required to build the model using a 'Cost per Piece Chart.' Also, determine how many "construction workers" it would take to build the safe, a labor cost per hour, and the total number of hours each employee would be working on the project.



Self Reflection/Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____

Complete the Activity Assessment Rubric to provide your impression of how you did with this lesson.

Assessment Rubric			
<i>Circle Responses for each:</i>	Excellent	Good	Acceptable
Research and Design Logs & Worksheets	<p>Student Response Sheets and Design Logs complete with no spelling or grammar errors. All answers on Student Response Sheets are accurate.</p> <p><input type="text"/> 1-10</p>	<p>Student Response Sheets and Design Logs complete with few spelling or grammar errors. Most answers on Student Response Sheets are accurate.</p> <p><input type="text"/> 1-8</p>	<p>Student Response Sheets and Design Logs complete with many spelling or grammar errors. Few answers on Student Response Sheets are accurate.</p> <p><input type="text"/> 1-6</p>
Design & Construction	<p>Your device is very neatly constructed, easy to use, and meets or exceeds expectations outlined in the Design Brief.</p> <p><input type="text"/> 1-10</p>	<p>Your device is neatly constructed, easy to use, and meets expectations outlined in the Design Brief</p> <p><input type="text"/> 1-8</p>	<p>Your device has been constructed, is in useable form, and meets the materials criteria listed in the Design Brief.</p> <p><input type="text"/> 1-6</p>
Design Journals & Presentations	<p>Your Design Journal is complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. It is presented in a neat and orderly fashion.</p> <p><input type="text"/> 1-10</p>	<p>Your Design Journal is mostly complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows some disorder.</p> <p><input type="text"/> 1-8</p>	<p>Your Design Journal is missing 1 or more logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows disorganization.</p> <p><input type="text"/> 1-6</p>
Teamwork/Work Ethic	<p>You worked well with your teammates and interacted well with others. You demonstrated excellent reliability and initiative when working on this challenge.</p> <p><input type="text"/> 1-5</p>	<p>You worked well with your teammates and interacted well with others. You were reliable and demonstrated initiative when working on this challenge.</p> <p><input type="text"/> 1-3</p>	<p>You worked well with your teammates and others. You were generally reliability and usually demonstrated initiative when working on this challenge.</p> <p><input type="text"/> 1</p>
Total Score	<p><input type="text"/> /35</p>		

Teacher Comments:

Teamwork & Self Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____



As a Group

Teamwork and cooperation are necessary skills required for most jobs since businesses typically have many employees that work together in teams rather than lots of individuals working alone. All employees need to contribute equally, using their skill sets to make a project successful while meeting deadlines. If one person fails to contribute adequately, the business or project can fail.

- **Communication Skills:** How well did your group communicate? How could communications within your group be improved?

- **Work Load:** How was work assigned in your group? Did individuals step up to accept responsibility? Were personal skills considered as work was assigned? For larger groups, is it beneficial to assign someone as a leader?

- **Presentation:** How was the unit presentation developed? How did the group determine responsibilities so no one was left out? What improvements could be made for future presentations?



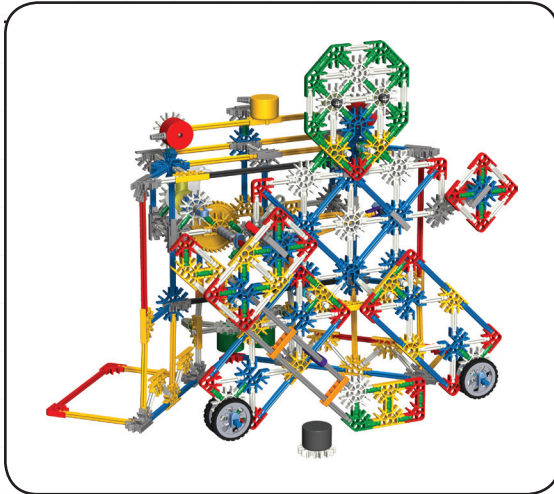
On Your Own

- **Personal Input:** Do you feel you contributed equally with your group? Did you do too much or not enough? Personal contributions to the group are listed in the *Research and Design Log*, but what could you do to work better in a team?



LESSON #9: A HOCKEY GAME AT THE HOCKEY GAME

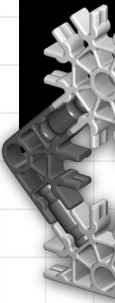
Model: K'NEX Hockey Goalie



Main Concepts(STEM):

- **Science**
 - Stroboscopic Effect, Visual Perception
- **Technology & Engineering**
 - Engineering Design
- **Mathematics**
 - Measurement, Scale

Objectives	Required Materials:	Optional Materials:
<p>Student will be able to:</p> <ul style="list-style-type: none"> • Work effectively both independently and in collaborative teams. • Correctly connect and program the K'NEX interface to control the safe model. • Understand the difference between analog and digital. • Apply the concepts binary number systems and Boolean logic. • Modify their computer programs to control the safe for specific challenges. 	<p>Teacher will need:</p> <ul style="list-style-type: none"> • K'NEX Interface and software • Computer projector and/or whiteboard • Extension cord (if power is not close to testing area) <p>Students will need:</p> <ul style="list-style-type: none"> • K'NEX Interface and components • Computer with K'NEX Computer Control software • K'NEX hockey goalie model • Copies of: <ul style="list-style-type: none"> o Research & Design Logs o Student Response Sheets o Challenge Design Briefs o Teamwork & Self-Evaluation forms o Self Reflection/Evaluation Rubrics 	<ul style="list-style-type: none"> • Graph paper • Notebook paper • Colored pencils • Sample K'NEX models (prebuilt safe model) • Calculators



TEACHER'S NOTES:

- *Students will build the hockey goalie model. After the students construct the hockey goalie, begin the engagement portion of the lesson. Lesson 9 should take 5-7 class periods, depending on how challenge activities are assigned.*
- *As with previous lessons, students will be asked to construct the model, perform various experiments, chart data, record their thoughts and actions, and develop challenge activities.*
- *The K'NEX hockey goalie uses one motor, two reed switches, three magnets, one buzzer and two LEDs.*

Process

Engagement

1. Keeping in line with the STEM Exploration vacation road trip, discuss how the students are now on their way home from a fun vacation and stop to see a hockey game. At the ice rink, they find an arcade hockey game in the game room. Discuss the processes used in the lesson with the students:
 - Students will construct the K'NEX hockey goalie model for the lesson and complete the Engagement activities. The hockey goalie uses two reed switches to register a goal for the game when the puck (magnet) passes the goalie. They will be programming their model to run various experiments and to play an actual game.
 - Students will also examine the mechanical systems used on the model.
 - They will finish the lesson by completing one or more open-ended challenge activities.
2. Distribute or direct students to the **Research and Design Logs** and **Student Response Sheets** for this unit. Introduce the **Challenge Design Briefs** when the students are ready for the challenge activities and the **Assessment Sheets** at the end of the activity. This will help students focus on the current activities. These pages are provided at the end of each lesson or in the **Resources** section of the Teacher's Guide. Links to editable electronic versions of the Research & Design Logs, Student Response Sheets, Design Briefs, Evaluation/Assessment forms and the Cost Per Piece chart can be accessed by the students from the Start Menu, or you can drag and drop the "STEM Explorations Resources" folder from the software CD onto the desktop or a shared drive.
3. Discuss that the **Research and Design Logs** and **Student Response Sheets** will be used in the same manner as previous lessons.
4. During Lesson 9, students will examine the mechanical systems of the K'NEX hockey goalie and experiment with the crank system used to move the goalie. They will also focus on creating a functional game program while examining the qualities of a good game design.
5. All of the students have probably played computer and arcade-style games to some degree. Ask them what makes a computer game exciting to play while holding their attention? Why are some games successful while others fail? If they were game designers, what should they consider in order to design a successful game?
6. To help introduce the students to the concepts of good game design that are considered by game design professionals, review the following websites:

[What Makes a Game Good 1](#)

[What Makes a Game Good 2](#)



Exploration

1. Establish student teams (2-3 students per group), and then review the activity and **Student Response Sheet 1**. Allow students time to discuss the activity in their groups.
2. Students should understand the safe operation of the K'NEX interface and electrical concerns. Review the *STEM Explorations User's Guide*, if needed.
3. The students should construct the K'NEX hockey goalie model. This model is constructed using one motor, two reed switches, three magnets, one buzzer and two LEDs.
4. Review the activity and **Student Response Sheet 1** with the class. Discuss how this activity will introduce the students to computer game design and will also review the mechanical systems used in the hockey goalie model. They will be recalling some of their knowledge of simple machines as they examine the crank system used to move the goalie.
5. Since the students will be developing a functional arcade-style game, it is important to discuss the qualities of a good game. While many of the students may play hours of computer games weekly, they may give little consideration as to what makes a game successful. In the *Engagement* section, the students probably offered many ideas about what they think makes a game good, but what do the professionals consider? Commercial computer games you buy nowadays typically take one to three years of development with teams of anywhere between 10 and 50 people working on the project. Budgets easily reach in the millions of dollars. All these people are highly experienced: programmers, art designers, sound technicians, sales professionals, etc. If these professionals do not consider what makes a game successful, the game will fail.

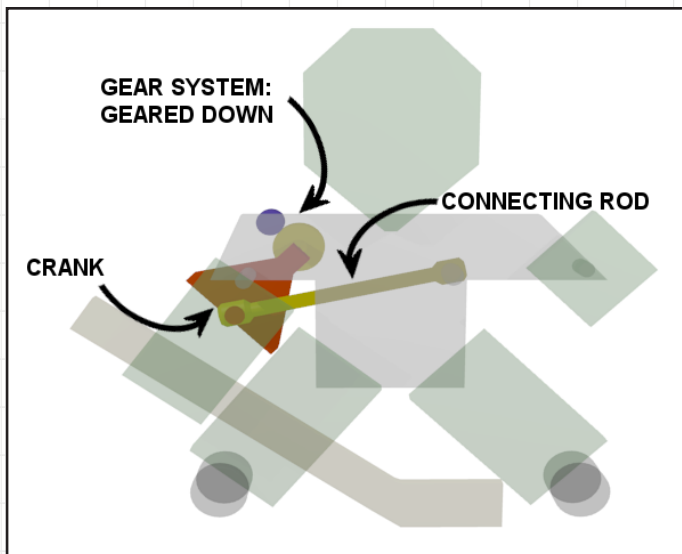
Below are some of the considerations of a good game:

- **Who is your audience?** The challenge level of the game should match the audience level.
- **Do you have good instructions?** Players may become frustrated if they do not know what to do.
- **Do your graphics and design match the game?** Players expect good quality graphics and design in today's games.
- **A balancing act.** Decisions and their effects need to be balanced. When a decision is made, the player should see the effect. For example, if you score a goal and the game increases speed, it should be an appropriate increase and not make the game too difficult too quickly.
- **Who is in control?** The player should feel like they are in control of the game and not the other way around, but surprises can be good.
- **Game objects.** The player needs to be able to control objects and resources in the game, but only enough to balance play. For example, in a simple slap shot hockey game like your K'NEX Hockey game, students will only control the hockey stick and puck.
- **How long should the game last?** Is the game meant to last for a short period of time (minutes) or a longer length of time (hours). Your K'NEX hockey game should only last a few minutes at most.
- **What is the goal of the game?** Every game needs to have a goal that is well defined at the beginning of the game. If it is a longer game, there may be smaller goals along the way.

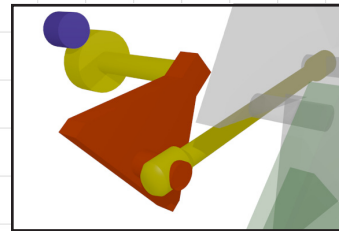
While these considerations apply to the development of a game, the same thought process could be used for a variety of scientific, engineering, and manufacturing design situations.

6. Examine the mechanical systems of the hockey goalie with the students. The mechanics of the hockey goalie are very simple with only one motor, two gears and a crank system to move the goalie back and forth in front of the goal. The first challenge for the students will be to determine how fast the goalie should move and how hard it is to score at the different speeds. The students will also be asked to answer several questions about the mechanics of the system.

- Review gear ratios with the students. The hockey goalie uses 2 gears to step down the motor speed. Review the concepts of gearing discussed in lesson 5 if a refresher is needed.
- Review the concepts of rotational motion and linear (translational) motion. The hockey goalie converts the rotational motion of the motor to a linear (translational) motion for the goalie. Tell the students to focus on the mechanical system in the goalie model. These are the features they find:



- A set of gears used to reduce the speed from the motor (gear down).
- A long arm acting as a crank.
- A connecting rod used to connect the crank to the goalie. The connecting rod converts the rotational motion to linear motion.



- The students will be asked to calculate the gear ratio and linear movement of the goalie.

As with previous lessons, the students will count the gear teeth to determine the gear ratio of the system and a sample output force. *Review these concepts from Lesson 5 as you feel necessary.* They will also examine the crank arm to determine how force is transferred to the goalie. *It is recommended that you review the following example with the students to calculate force and mechanical advantage in the system:*

Gear System:

For this example, the gear teeth information given does not match the actual K'NEX model. That information will need to be provided by the students for their actual Student Response Sheet questions.

Input Gear: 10 teeth (T_{smaller}) (blue gear in above images)

Output Gear: 30 teeth (T_{larger}) (yellow gear in above images)

Gear Ratio: ($T_{\text{larger}} / T_{\text{smaller}}$):1

30/10:1

3:1 ratio, geared down (speed is reduced by a factor of three while the input force is increased by a factor of three)

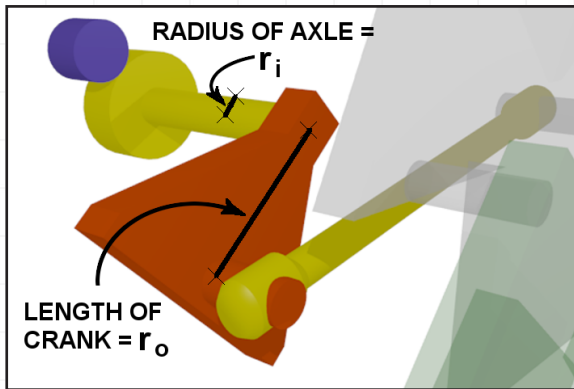
While actual input force from the motor would be difficult to calculate due to inconsistencies in motor construction and chosen motor speed percentages, an input force of **10 N** will be used for this example. Since this system is geared down, force is multiplied by 3 (the mechanical advantage as well). If the system was geared up, force would be multiplied by 1/3.

Input Force (F_i): 10 N

Output Force (F_o): 10 N x 3 = 30 N

From this example, the gear system of the goalie model would increase the force to 30 N while decreasing speed to 1/3 of the input.

Crank System:

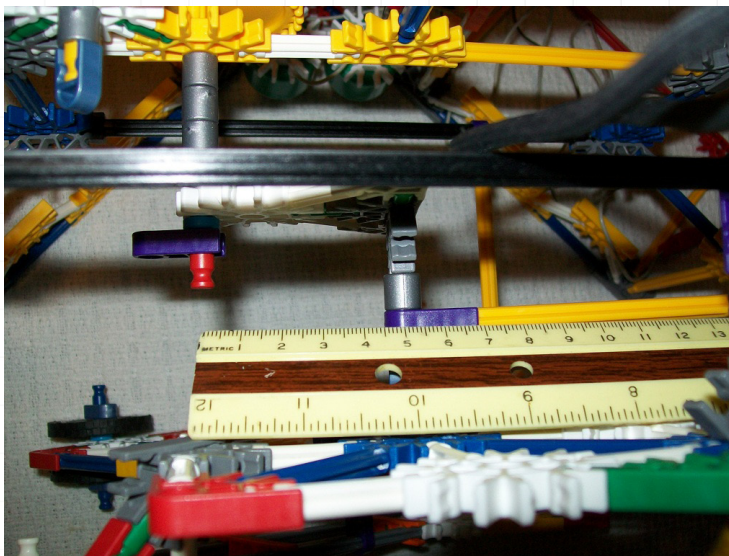


The gear system delivers force to the crank axle which revolves the crank. By using the radius of the axle (r_i) and the length of the crank arm (r_o), students can determine how much force is being delivered from the gear system (input force to the crank- F_i), they can also calculate the output force (F_o) to the goalie. They could use the following formulas from past lessons and replacing d (distance) with r (radius):

$$F_o = (F_i \times r_i) / r_o$$

The students will be asked to measure the axle and crank sizes to determine the sample force in the system. The following procedures could be used for these calculations:

The students should first measure the **crank axle radius** (*diameter/2 would be easiest since the measurement is small*) and the crank length with a metric ruler as accurately as possible.



To obtain the crank axle radius, measure the axle diameter (6 mm or .006 m) and divide by two for a radius of **3 mm, or .003 m.**

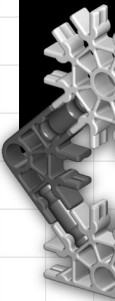
To obtain the crank length, measure the crank axle-connecting rod axle distance. This ruler is showing a measurement of approximately **50 mm, or .05 m.**

Calculate how much **Output Force** is available to move the goalie. Remember that the force coming from the gear system is **30 N** in this example.

$$F_o = (F_i \times r_i) / r_o$$
$$F_o = (30 \text{ N} \times .003 \text{ m}) / .05 \text{ m}$$
$$F_o = 0.09 \text{ Nm} / .05 \text{ m}$$
$$F_o = 1.8 \text{ N}$$

TEACHER'S NOTES:

You may find it helpful to have a loose crank sub assembly available for the students to measure. They may find it difficult to obtain accurate measurements from the assembled goalie model. The students could also remove the goalie from the model temporarily for easier measuring.



From this sample problem, lead a discussion of how force has been reduced from the motor input of 10 N down to an output force of 1.8 N through the two systems. While the gears reduce speed, the very small diameter crank axle to the larger crank arm flips the entire advantage. Since $Work = Force \times Distance$ and $Work In = Work Out$, distance would need to see an increase in order to balance this equation. Since students will not be calculating work, you may decide how much of this concept you wish to discuss.

Mechanical Advantage of the Entire System:

Since the students know the mechanical advantage of the gear system is 3, they can calculate the mechanical advantage of the crank system knowing the input force on the crank is 30N and the output force is 1.8N.

$$\begin{aligned} \text{Crank MA} &= F_o / F_i \\ \text{Crank MA} &= 1.8 \text{ N} / 30 \text{ N} \\ \text{Crank MA} &= 0.06 \end{aligned}$$

The total mechanical advantage of the entire system (*gears and crank*) can be calculated:

$$\begin{aligned} \text{Total MA} &= \text{MA of Gears} \times \text{MA of Crank} \\ \text{Total MA} &= 3 \times 0.06 \\ \text{Total MA} &= 0.18 \end{aligned}$$

The total mechanical advantage could also be calculated using the input force of the motor (10 N) and the final output force of the crank (1.8 N). This method would not require calculating the mechanical advantage of the crank system since it is only using the initial and final forces of the entire system:

$$\begin{aligned} \text{Total MA} &= F_o / F_i \\ \text{Total MA} &= 1.8 \text{ N} / 10 \text{ N} \\ \text{Total MA} &= 0.18 \end{aligned}$$

Either method could be used to determine the total mechanical advantage of the system. Select the method you wish to use with the students or demonstrate both to them.

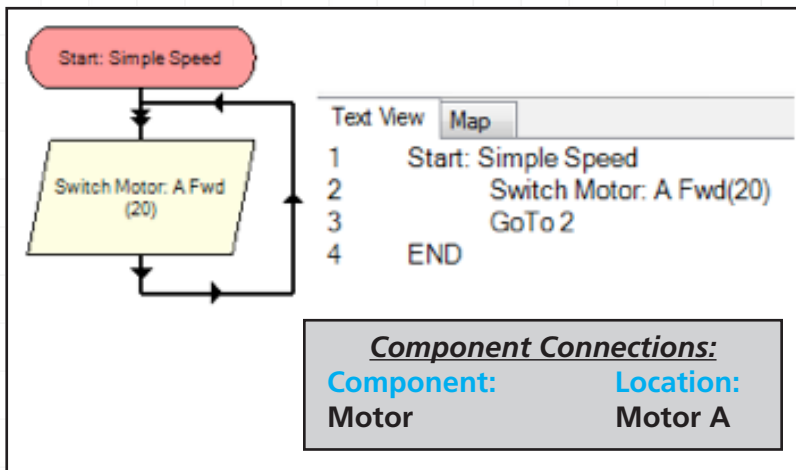
Again, this will demonstrate that force is sacrificed to distance in the K'NEX hockey goalie. *The students will be completing an exercise similar to this one on the Student Response Sheets using data gathered from the goalie model so it is recommended that sample problems are reviewed with them prior to completing the activity.*

The students will also be asked to determine how far the goalie travels by using the crank distance and how many oscillations are made for each motor revolution. Oscillation may be a new term for the students and is defined as "to move or swing side-to-side rhythmically". Another term for this type of motion is *reciprocal* motion.

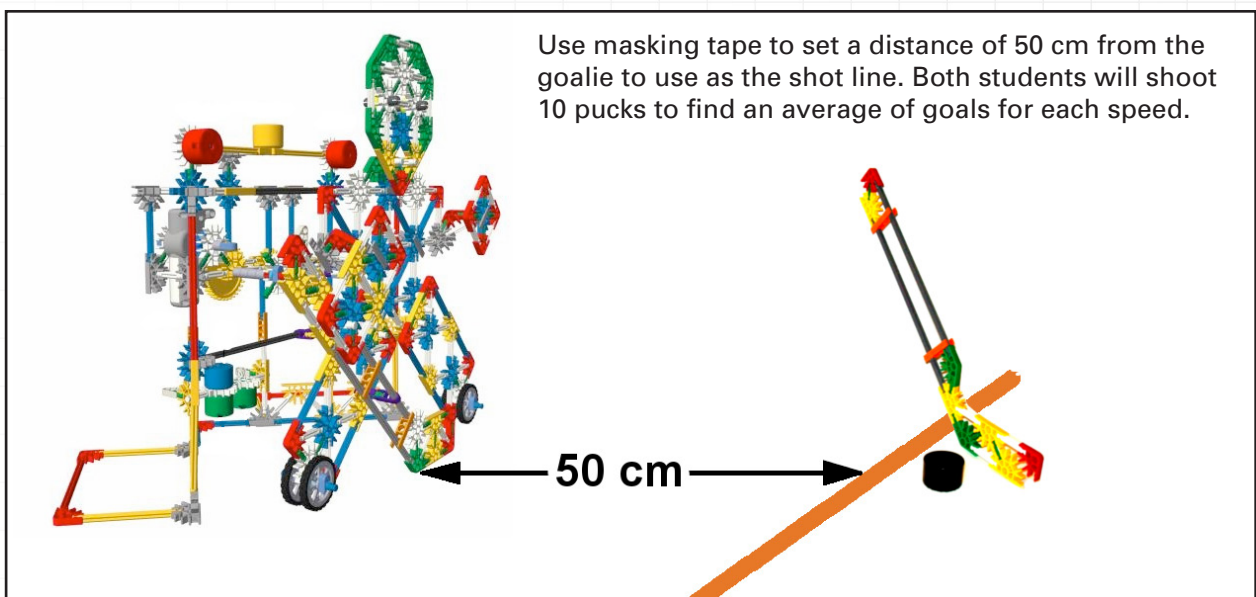
TEACHER'S NOTES:

Complete some sample calculations with the students so they are comfortable with determining forces and mechanical advantage for the K'NEX goalie model. It may also be helpful to display the formulas for the students as they work on the Student Response Sheets.

10. In the first activity, the students will also determine the best motor speeds to use for the hockey game. As with previous lessons, they will need to develop a program that will operate the motor at 20%, 40%, 60%, 80% and 100%. The groups will select 2 members that will shoot a puck 10 times at each speed to determine the percentage of goals scored. The results will be graphed and averaged so appropriate speeds can be selected. Since the amount of time it will take to shoot 10 pucks each will vary, it would be difficult to set a time limit for the motor to run. A simple program like this could be utilized:



This speed test will loop at 20% until the K'NEX interface is turned off. After both students shoot 10 pucks to determine the number of goals, adjust the program for the next motor percentage.



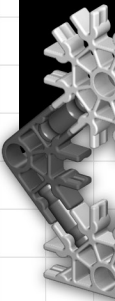
Use masking tape to set a distance of 50 cm from the goalie to use as the shot line. Both students will shoot 10 pucks to find an average of goals for each speed.

TEACHER'S NOTES:

If the students can connect to the computer while testing, they can avoid creating a program to run the goalie. Use the computer to control the interface directly.

11. Instruct the students to complete **Student Response Sheet 1** and the first four vocabulary terms found on the **Research and Design Log**.

12. After the students have had sufficient time to test their hockey goalie and respond to the questions related to the activity on their *Student Response Sheets*, summarize the activity with the class.



13. Review **Student Response Sheet 2** with the class. Students should also complete the remaining vocabulary on the **Research and Design Log**. Now that the students have determined the motor speeds that could work well for an actual arcade hockey game, they will be planning out the actual game and developing the K'NEX hockey goalie programming. Keep in mind that your students may have very different opinions as to what motor speeds work well for their model. Some may like speeds that allow many goals to be scored while others may like a greater challenge.
14. In the first activity, the students reviewed the concepts that make a good game. They will now develop a *Computer Game Design Document* to go with the game they plan to make. While this game is not a true computer game because it is not played on a computer screen and has physical actors (the goalie, pucks, hockey stick), it is controlled by a computer program with sounds, lights and actions. A game design document is a written description of a software product, that a software designer writes in order to give a software development team an overall guidance of the architecture of the software project. Basically stated, it describes the game in enough detail that the reader will understand the game. Review the typical parts of a game design document with the students:
- **The Game Genre.** Describe the type of game being made. While games can be classified differently, they may fit into one of several categories, or *genres*:
 - *Arcade Games.* Reaction speed or accuracy is the most important aspect of the game. These are usually shorter playing games that are easier to make.
 - *Puzzle Games.* Clever thinking is the most important aspect. Maze games and “board-type” games like chess.
 - *Strategy, Adventure and Role Playing Games.* Most of these games control a character through a scene or events.
 - *Shooter Games.* Shooter games usually fall under 1st-person and 3rd-person. 1st-person shooter games need a 3D scene to make the player feel like they are part of the action. 3rd-person games do not need to be 3D and borrow aspects from adventure games. Most of these games usually have a storyline.
 - *Sport/Racing Games.* There are a lot of sport and racing games out there and can be difficult to make exciting. Controls can also be difficult to develop.
 - *Simulation Games.* These games are used to give you the controls like the “real thing”. Flight simulator and hunting are the most popular types. These can be difficult to make because you must make the game operate like the real life experience.
 - **The Design Brief.** This is where students develop the name for their game and a short description to catch the player’s attention.
 - **Game Objects.** This is where the objects and actors in the game are listed with a brief description of what they do in the game.
 - **Game Sounds.** All the sounds and music used in a game are listed along with the times when they are heard.
 - **Game Controls.** All controls used for the game and how they are used are listed.
 - **Game Flow.** This is a written description of how the game flows. Describes where the player starts and how they move through the game.
 - **Game Levels.** Used to describe the number of levels for the game.

Here is a game design document for a simple *Space Invaders* type game.

Game Name: Space Intruders

Game Genre: Arcade

Design Brief:

Space Intruders is a little arcade/action game where you must destroy all alien intruders as they march toward the bottom of the screen. Your ship moves across the bottom of the screen and can fire lasers up toward the alien intruders.

Game Objects:

For this game, there will be four game objects:

- Your ship- it moves across the bottom of the screen using the arrow keys and can fire lasers using the space bar.
- Barriers- the barriers just sit there and protect you from alien shots. The barriers disappear after several alien shots.
- Alien ship- these ships automatically march down toward the bottom of the screen, shooting randomly. When they are hit by your laser shot, they explode.
- Life gem- these gems appear randomly throughout the game and if you are able to shoot one, your health is increased.

Game Sounds:

A background music track is used to enhance game play. There is also a sound for your laser shot and one for the alien shot. A sound is also played for the health gem.

Game Controls:

- Esc to exit the game
- Arrow keys to move
- Space bar to shoot

Game Flow:

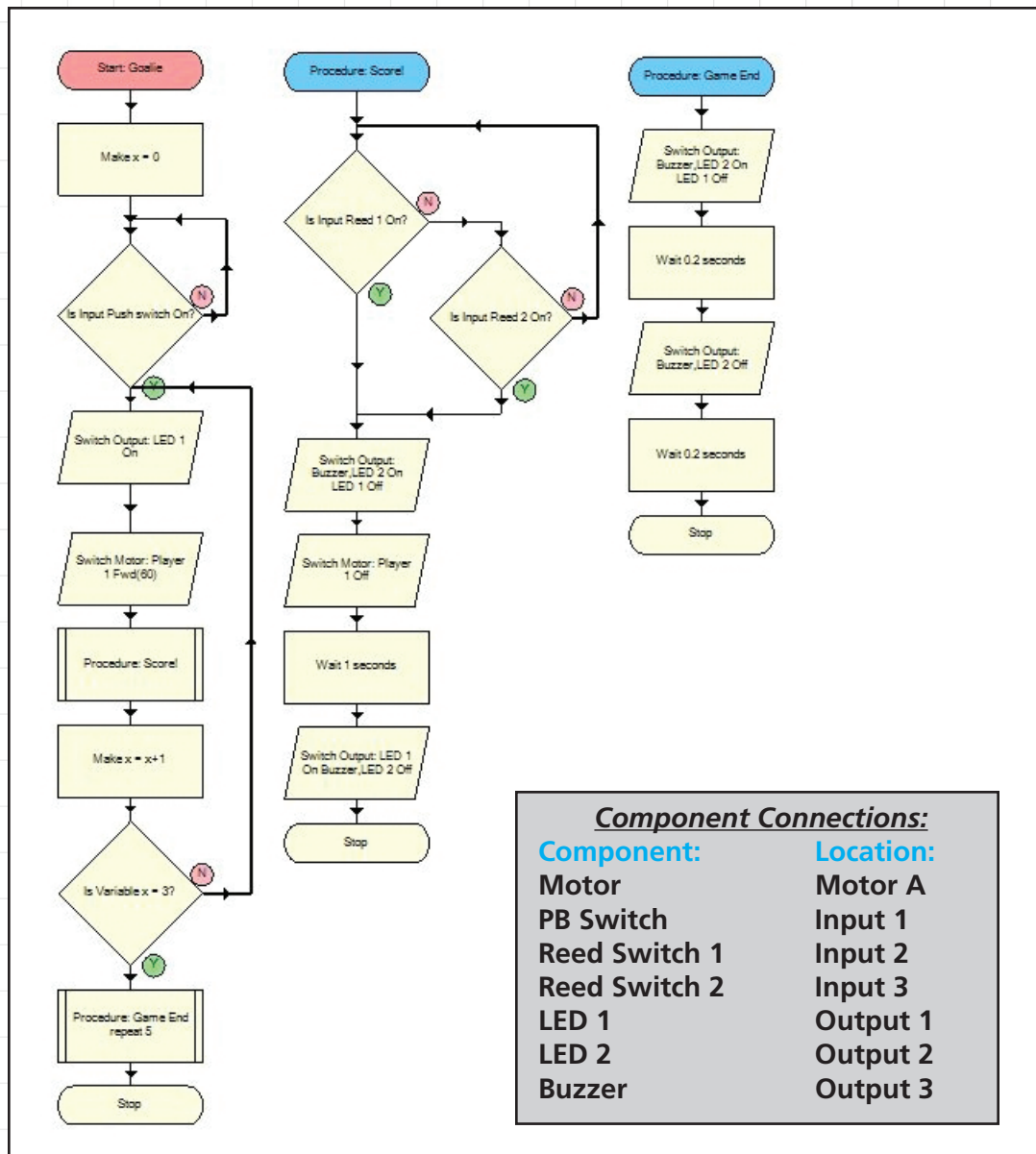
The game starts at a welcome screen with instructions, and then moves to level 1. The game starts immediately. If you receive too much damage, the game is over. If you clear the alien invaders, you move to the next level where game play is faster.

Game Levels:

There are only 3 levels in this game. If the player makes it through all three levels, a victory screen is displayed with a high score chart.

The students will be completing a game design document for their hockey goalie game.

15. The students will also develop a simple game program to control the hockey goalie model. For this activity, they will develop a one-level game that will end after three goals are scored. One LED will signal that the game is ready to be played. With each score, the buzzer will sound and the other LED will signal a goal. At the end of the game, they must program the buzzer and LEDs to flash several times to indicate that the game is over. A component connection chart is displayed here. While there are several ways to program the game to meet these requirements, this is a program that introduces the students to variables used in the K'NEX programming:



The program shown uses the push button switch to begin the program and to start the program again after a goal has been scored. This allows the player time to remove the puck from the reed switch before game play resumes. The procedure *Score* senses the puck (magnet) that triggers one of the reed switches. At that time, the motor stops, the one LED goes off while the buzzer and other LED turn on for 3 seconds. If the game can continue, the push button switch can be pressed and the process starts again.

This program introduces the concept of a **variable** to the K'NEX programming. Just like variables in other mathematical settings, the students can set a value and change that value as needed. You will see the variable block show up three times in the program on the previous page. At the beginning of the program, the students *Make* the variable $x=0$. This is the initial value. When a goal is made, the students *Make* the variable $x=x+1$. Every time a goal is scored, this variable will increase 1 in value. The students then ask the question "*Is Variable $x=3$?*" If not, the program loops back up to the beginning. If $x=3$, the program then moves to the *End Game* procedure. In order to keep the procedure simple so that it only flashes the LED and sounds the buzzer once, the procedure is set to repeat 3 times. The students plan the variables in advance as they write the program.

TEACHER'S NOTES:

Why use variables in the K'NEX program?

If the students want to make their game so that it ends at 5 goals instead of 3, all they would need to do is change the question to "Is Variable $x=5$?". Variables are used in most computer games to keep track of lives, ammo, timing of events, and scoring.

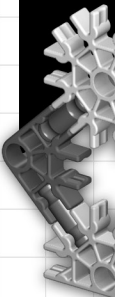
Depending on available time and student ability level, you may wish to provide students with a flow chart of the first steps of their program to get them started. The students will need to develop and diagram the program they will use for the test.

16. The students will also need to respond to several questions related to the model and programming in this section.

After the students have had sufficient time to test their game programs and respond to the questions related to the activity on their *Student Response Sheets*, distribute the **Challenge Design Briefs** that will outline several possible challenge activities for you or the students to select from.

Explanation

1. Throughout the activities in this lesson students have been completing **Student Response Sheets**. Allow sufficient time to complete these sheets as they finish each activity so they can demonstrate they are able to explain what they have discovered. Remind students that some sections of the **Student Response Sheets** are to be completed "**As a Group**" while others are to be completed "**On Your Own.**" They should be formulating thoughts, calculations and definitions from their own words.
2. Decide if you want groups to present their results after each *activity* or *wait until the entire unit is finished* to present their findings. Presentation is an important part of the learning experience since all students may approach these *activities with different thoughts* and ideas. Presentations should include a variety of elements such as descriptions, visual aids and demonstrations.



Elaboration

Students will self-evaluate their challenge solutions based on the criteria provided in the rubric for this activity. Elaboration components are found in the logs and response sheets.

TEACHER'S NOTES:

- Assign the **Self Reflection/Evaluation** rubric to the students so they can self-evaluate their work. The rubric score and your evaluation will make up a portion of the assessment data for this lesson.
- Provide students with a **Teamwork and Self-Evaluation** sheet and review the form with the students before they complete them.

Evaluation

You may use some or all of the following to evaluate student's performance:

- Self Reflection/Evaluation Rubric
- Teamwork and Self Evaluation forms
- Presentation of the Challenge Solution(s)
- Research and Design Logs
- Student Response Sheets
- Design Journal

Extensions

1. After the students have worked through the activities, it is useful to extend the learning through career research and extended activities. Career components have been added to the **Research and Design Logs**, but can be extended by other means such as guest speakers, business tours, etc.
2. Extension activities should be included in any student presentations.



On Your Own

Research and Design Log

Name: _____ Date: _____

Define the following terms below. Be sure to write the definitions in your own words.

Translational Motion -

Oscillation -

Reciprocal Motion -

Connecting Rod -

Game Design Document -

Genre -

Game Design Brief -

Game Objects -

Game Controls -

Game Flow -

Game Levels -

Name: _____ Date: _____

The Hockey Goalie



As a Group

Explore

- After discussing game design and the mechanical systems of this model, construct the hockey goalie model for the lesson. The goalie will use one motor, two reed switches to register goals, three magnets (pucks), one buzzer and two LEDs. For this first activity, you will only be using the motor and pucks to determine appropriate motor speeds.

- **The Gear System:** Determine the gearing ratio of the system. The goalie uses 2 gears in the system. Count the gear teeth and determine the following:

o **Input Gear # of Teeth:** _____ T **Output Gear # of Teeth:** _____ T

o What is the gear ratio of the system? Use the following formula: $(T_{\text{larger}} / T_{\text{smaller}}):1$

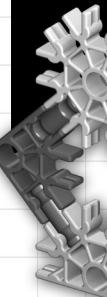
Gear Ratio: _____:1

o Is this system geared up or down? How did you determine this?

o **Calculate the output force of the gear system.** In previous lessons and during class discussion, you determined the force of a gear system. If the motor provides an input force (F_i) of **10 N**, what would be the output force on the second gear and axle? How did you determine this?

Gear System Output Force: _____ N

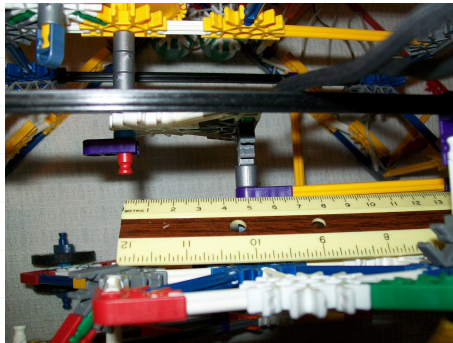
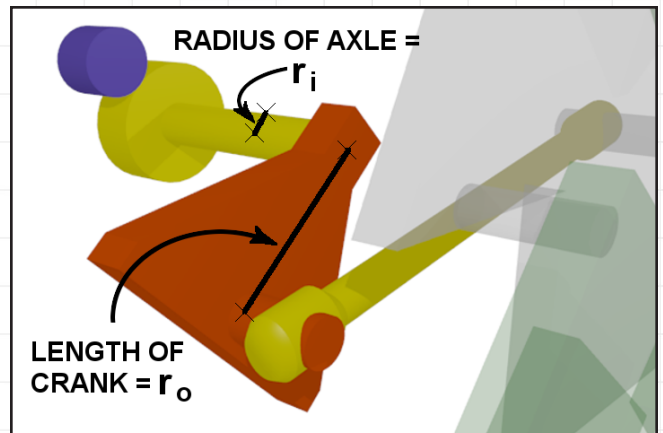
o If the motor spins 60 times per minute (1 time per second), how many times will the goalie oscillate per minute? Explain your answer.



- **The Crank System:** In your class discussion, you determined that the *output force* from the gear system is used as the *input force* (F_i) of the crank system. You will also need to determine the radius of the crank axle and the length of the crank arm in order to determine output force.

To obtain the crank axle radius, measure the axle diameter and divide by two for a radius (r_i).

To obtain the crank length, measure the crank axle to connecting rod axle distance (r_o).



Measure as accurately as possible and convert to meters (i.e. 5 mm = .005 m). Your instructor can help you if you are having trouble with measurements. The picture to the left shows a measurement being taken of the crank length.

- o **Calculate the output force of the crank system.** During class discussion, you determined the output force of a crank system. Use the information you gathered above to determine the crank's output force and the following formula: $F_o = (F_i \times r_i) / r_o$

Crank System Output Force: _____ N

- o **Calculate the mechanical advantage of the entire system.** During class discussion, you determined that the overall mechanical advantage of the hockey goalie was determined by using the Input Force (F_i) from the *motor* and the Output Force (F_o) of the *crank*. Another way to say this is that the motor provides an input amount of force (F_i) that is transferred through the gears and then the crank to produce a final force output (F_o). You could also use the mechanical advantage of each system and multiply them for a total mechanical advantage. Use one of the following formulas:

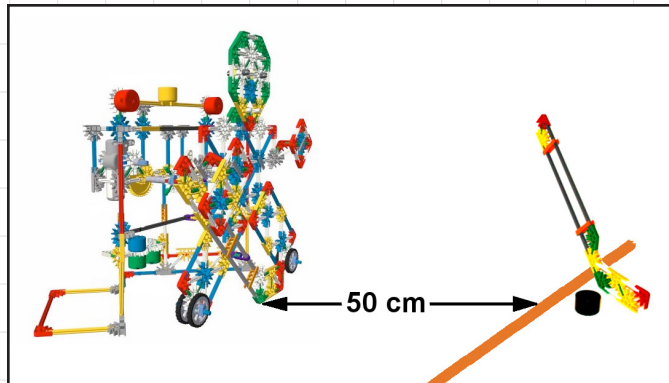
$$MA = F_o / F_i \quad \text{- or -} \quad \text{Total MA} = MA \text{ of Gears} \times MA \text{ of Crank}$$

Total Mechanical Advantage: _____

- What observation can your group make relating to input and output forces and distances? What happens in each part of the system?

- It is now time to determine the best speeds to use for the hockey game. Write a program to test each motor speed (20%, 40%, 60%, 80%, and 100%) to determine which speeds allow for "appropriate" scoring. You do not want it to be too easy or too hard to score goals. Since you do not know how long the motor should run at each speed, create a simple program that runs the motor continually until the interface is shut off or, if possible, run the interface directly from the computer control program.

Set up your testing area by using masking tape to mark a shot line 50 cm from the goalie. Select 2 members from your group to shoot 10 pucks from the line for each motor speed. Record the number of goals scored for each player in the bar graph below, and then average the number of scored goals on the second bar graph.



Goals Scored	9										
	8										
	7										
	6										
	5										
	4										
	3										
	2										
	1										
		Player 1	Player 2	Player 1	Player 2	Player 1	Player 2	Player 1	Player 2	Player 1	Player 2
	20%		40%		60%		80%		100%		

Goals Scored	9									
	8									
	7									
	6									
	5									
	4									
	3									
	2									
	1									
		20%		40%		60%		80%		100%



On Your Own

Elaborate and Explain

- Examine the data you collected on pages 1 and 2. By looking at the length of the output arm (the length of the crank), how does this relate to how much the goalie moves side to side, or oscillates?

- Look at your mechanical advantage and input/output forces. While the gearing system increased the force in that part of the system, what happened to it in the crank part of the system? Explain.

- Examine your average goals scored for each percentage. Think about how easy it should be to score goals for the arcade game. Should the game be easy or hard? Should it start out easy and become harder as the game is played? What speeds would you use for different difficulties? Explain your answers.



As a Group

- Discuss your individual observations as a group and determine which motor speeds you would use for a game that becomes more difficult at three levels of play. Explain how you determined these speeds as a group.

Name: _____ Date: _____

A 3-Goal Arcade Hockey Game



As a Group

Explore

- It is now time to develop an actual hockey game for your goalie model. For this game, we will only program one motor speed and the game will end after 3 goals. Your programs should also include the following:
 - o Use the push button switch to start the game. It may also be helpful to program the game so the push button switch starts the game back up after each goal so pucks can be cleared from the goal before continuing.
 - o Use one LED to signal that it is safe to shoot the puck.
 - o Sound the buzzer and light the other LED at scored goals.
 - o Signal with the LED and buzzer that the game is over after 3 goals.
- Before developing your program, write a *Game Design Document* for your hockey game.

Game Name: _____

Game Genre: _____

Design Brief:

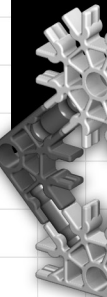
Game Objects:

Game Sounds:

Game Controls:

Game Flow:

Game Levels:



- There are many ways to develop your programs to complete these operations. Brainstorm as a group to develop a programming strategy. This program would work well with variables. On graph paper, draw the programs you plan to use.
- After completing the activity, what was the most challenging part? What programming changes or additions could make this game operate better? Are there any changes to the model that would improve the game? Explain.
- Look at your program on the computer. Is it designed as neatly as possible or are there confusing connectors running in odd directions? Part of the design cycle for any product or program is refinement and improvement. After years of modifying any popular software program, it becomes difficult to follow the code because so many people work on the program and add their parts. It can become a confusing mess! On graph paper, see if your group can clean up your program in any way and improve it on the computer. Show your instructor the before and after results.



On Your Own

- There are quite a few systems and subsystems in action in the hockey game. List as many systems as you can identify.
- Remember past discussions on Dependent Variables, Independent Variables, and Constants. List several examples that you identified as you completed experiments with this model.

Dependent Variables:

Independent Variables:

Constants:

- If you wanted to change the game so that it would end at 6 goals instead of 3 goals, what simple change could be made in your program?



As a Group

- Discuss your individual observations as a group.

Challenge Design Brief

Lesson #9: A Hockey Game at the Hockey Game

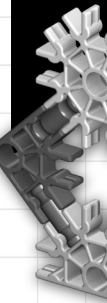
Name: _____ Date: _____



As a Group

Here are several possible design challenges for your group. Use notebook and graph paper to document the activity or activities and fasten them to this sheet.

- Modify your program so that the goalie changes speed after each goal is scored or after a certain amount of time. Create a new design document on notebook paper to match your new game. Chart your program on graph paper and record your results.
- There are three periods in a real hockey game. Modify your program so that the goalie stops and a special buzzer sounds and LEDs flash to signify the end of a period. Create a new design document on notebook paper to match your new game. Chart your program on graph paper and record your results.
- Modify your program to increase the number of goals that can be scored and add at least one other special feature to your game. Create a new design document on notebook paper to match your new game. Chart your program on graph paper and record your results.
- **The Ultimate Challenge!** Develop your program that combines the above features:
 - o Goalie changes speed after scores or period endings.
 - o Use different buzzers and LEDs for goals, ending of periods, and game end.
 - o Change how many goals can be scored and add one other special feature.
 - o Create a new design document on notebook paper to match your new game and chart your program on graph paper and record your results.
- You are an arcade game designer working on a new arcade hockey game. Determine the cost of the parts required to build the model using a 'Cost per Piece Chart.' Determine how many "manufacturing workers" it would take to build the game, a labor cost per hour, and the total number of hours each employee would be working on the project. Also, determine how much money could be made per hour from people playing the game at an arcade. You will need to determine a cost per play and how many games could be played per hour.



Self Reflection/Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____

Complete the Activity Assessment Rubric to provide your impression of how you did with this lesson.

Assessment Rubric			
<i>Circle Responses for each:</i>	Excellent	Good	Acceptable
Research and Design Logs & Worksheets	<p>Student Response Sheets and Design Logs complete with no spelling or grammar errors. All answers on Student Response Sheets are accurate.</p> <p><input type="text"/> 1-10</p>	<p>Student Response Sheets and Design Logs complete with few spelling or grammar errors. Most answers on Student Response Sheets are accurate.</p> <p><input type="text"/> 1-8</p>	<p>Student Response Sheets and Design Logs complete with many spelling or grammar errors. Few answers on Student Response Sheets are accurate.</p> <p><input type="text"/> 1-6</p>
Design & Construction	<p>Your device is very neatly constructed, easy to use, and meets or exceeds expectations outlined in the Design Brief.</p> <p><input type="text"/> 1-10</p>	<p>Your device is neatly constructed, easy to use, and meets expectations outlined in the Design Brief</p> <p><input type="text"/> 1-8</p>	<p>Your device has been constructed, is in useable form, and meets the materials criteria listed in the Design Brief.</p> <p><input type="text"/> 1-6</p>
Design Journals & Presentations	<p>Your Design Journal is complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. It is presented in a neat and orderly fashion.</p> <p><input type="text"/> 1-10</p>	<p>Your Design Journal is mostly complete with all logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows some disorder.</p> <p><input type="text"/> 1-8</p>	<p>Your Design Journal is missing 1 or more logs, worksheets, design briefs, evaluations, program diagrams, sketches and rubrics. Presentation shows disorganization.</p> <p><input type="text"/> 1-6</p>
Teamwork/Work Ethic	<p>You worked well with your teammates and interacted well with others. You demonstrated excellent reliability and initiative when working on this challenge.</p> <p><input type="text"/> 1-5</p>	<p>You worked well with your teammates and interacted well with others. You were reliable and demonstrated initiative when working on this challenge.</p> <p><input type="text"/> 1-3</p>	<p>You worked well with your teammates and others. You were generally reliability and usually demonstrated initiative when working on this challenge.</p> <p><input type="text"/> 1</p>
Total Score	<p><input type="text"/> /35</p>		

Teacher Comments:

Teamwork & Self Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____



As a Group

Teamwork and cooperation are necessary skills required for most jobs since businesses typically have many employees that work together in teams rather than lots of individuals working alone. All employees need to contribute equally, using their skill sets to make a project successful while meeting deadlines. If one person fails to contribute adequately, the business or project can fail.

- **Communication Skills:** How well did your group communicate? How could communications within your group be improved?

- **Work Load:** How was work assigned in your group? Did individuals step up to accept responsibility? Were personal skills considered as work was assigned? For larger groups, is it beneficial to assign someone as a leader?

- **Presentation:** How was the unit presentation developed? How did the group determine responsibilities so no one was left out? What improvements could be made for future presentations?



On Your Own

- **Personal Input:** Do you feel you contributed equally with your group? Did you do too much or not enough? Personal contributions to the group are listed in the *Research and Design Log*, but what could you do to work better in a team?



On Your Own

Research and Design Log

Name: _____ Date: _____

Unit: _____ Model: _____

Unit Vocabulary. Be sure to write the definitions in your own words.

Name: _____ Date: _____

Unit: _____ Model: _____

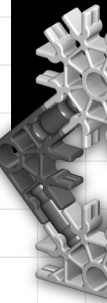
In the space below, list what you have learned through this unit as well as the tasks you have completed. Please be detailed and write in complete sentences.

The following Internet or paper resources were used:

While working through the activity, what problems did you encounter and how were they solved?

What contributions did you make for your own success or the success of the team?

Find a career related to this lesson. Write a brief job description and the education needed.

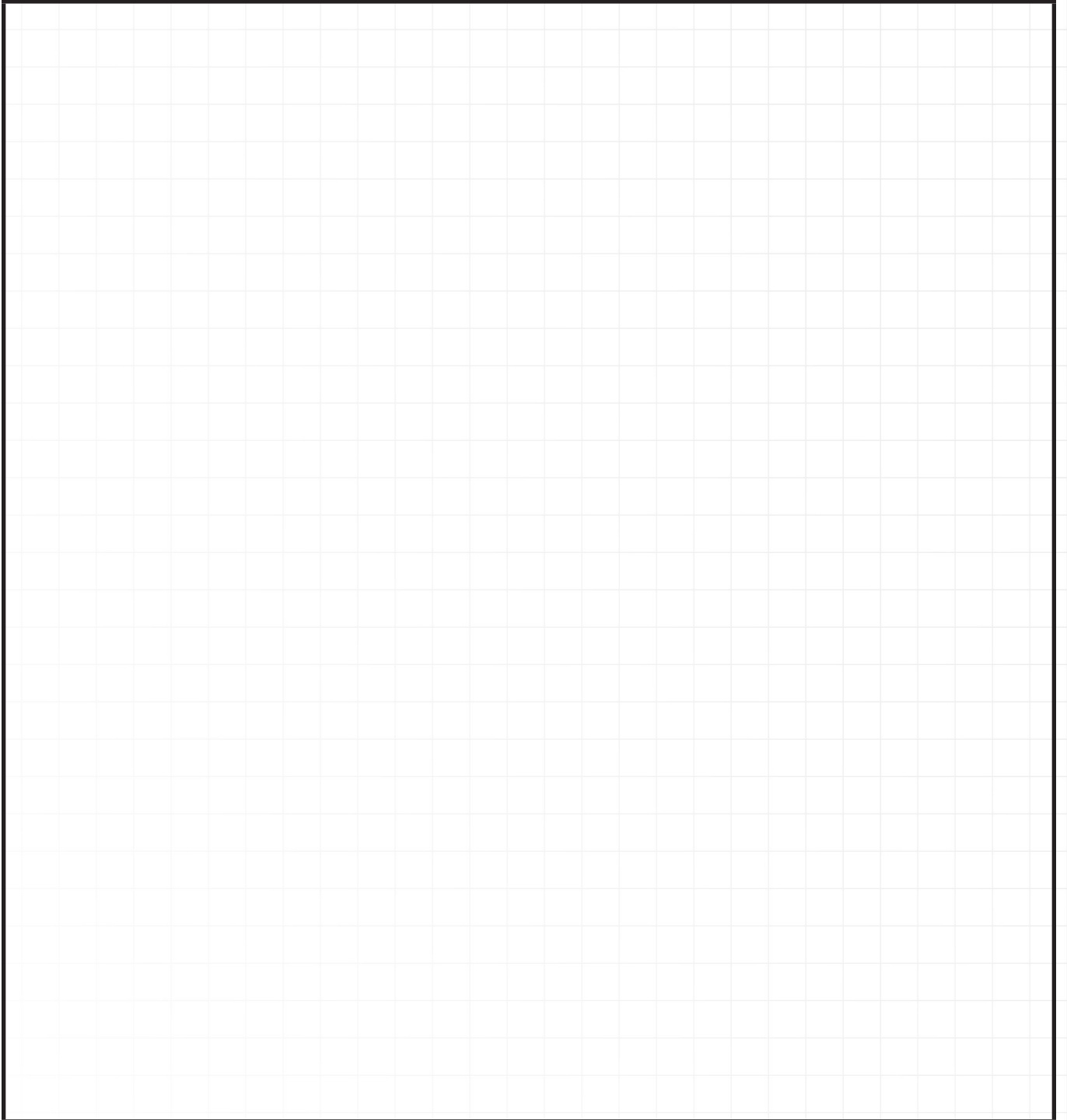


Name: _____ Date: _____

Unit: _____ Model: _____

Brainstorming & Design Sketch Area

Print and use the space below to complete any sketches, graphs, or computer program flow charts that were useful in completing this unit and not included on the Student Response Sheets. This is a good place to record any group brainstorming sessions.

A large rectangular area filled with a light gray grid pattern, intended for students to draw sketches, graphs, or flowcharts. The grid covers most of the page's width and height, leaving margins for text and headers.

Self Reflection/Evaluation

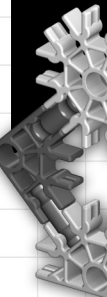
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Unit: _____ Model: _____

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Total Score	<input type="text"/> /35		

Teacher Comments:



Teamwork & Self Evaluation

Name: _____ Date: _____

Unit: _____ Model: _____



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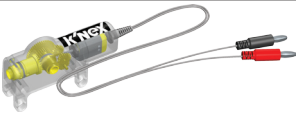
















- **Presentation:** How was the unit presentation developed? How did the group determine responsibilities so no one was left out? What improvements could be made for future presentations?

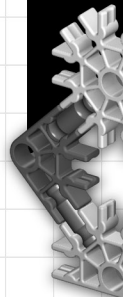




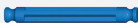




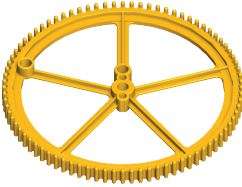














On Your Own

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Cost Per Piece Chart

	ITEM	COST	QTY	TOTAL
ELECTRONIC COMPONENTS				
	LED	\$ _____	X ____ =	\$
	BUZZER	\$ _____	X ____ =	\$
	PUSH BUTTON SWITCH	\$ _____	X ____ =	\$
	REED SWITCH	\$ _____	X ____ =	\$
	MAGNET	\$ _____	X ____ =	\$
	MOTOR	\$ _____	X ____ =	\$
CONNECTORS				
	PURPLE	\$ _____	X ____ =	\$
	ORANGE	\$ _____	X ____ =	\$
	LIGHT GREY	\$ _____	X ____ =	\$
	RED	\$ _____	X ____ =	\$
	GREEN	\$ _____	X ____ =	\$
	YELLOW	\$ _____	X ____ =	\$
	DARK GREY	\$ _____	X ____ =	\$
	BLUE	\$ _____	X ____ =	\$
	WHITE	\$ _____	X ____ =	\$
	BLACK	\$ _____	X ____ =	\$
	CYAN	\$ _____	X ____ =	\$
	ORANGE	\$ _____	X ____ =	\$
	NEON GREEN	\$ _____	X ____ =	\$
	METALLIC BLUE	\$ _____	X ____ =	\$
	TAN	\$ _____	X ____ =	\$
	BLACK	\$ _____	X ____ =	\$

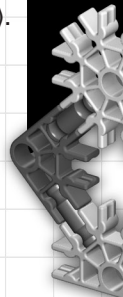


	ITEM	COST	QTY	TOTAL
RODS				
	GREEN	\$ _____	X ____ =	\$
	WHITE	\$ _____	X ____ =	\$
	BLUE	\$ _____	X ____ =	\$
	YELLOW	\$ _____	X ____ =	\$
	RED	\$ _____	X ____ =	\$
	LIGHT GRAY	\$ _____	X ____ =	\$
	BLACK	\$ _____	X ____ =	\$
GEARS AND OTHER SPECIALTY PARTS				
	GEAR (5 INCH) - YELLOW	\$ _____	X ____ =	\$
	GEAR (FOR CHAIN) - BLACK	\$ _____	X ____ =	\$
	GEAR (LARGE) - YELLOW	\$ _____	X ____ =	\$
	GEAR (SMALL) - BLUE	\$ _____	X ____ =	\$
	SPOKED HUB	\$ _____	X ____ =	\$
	TIRE	\$ _____	X ____ =	\$
	STRING	\$ _____ /per foot	X ____ =	\$
	SPACER - CYAN	\$ _____	X ____ =	\$
	SPACER - GREY	\$ _____	X ____ =	\$
	WIRE CLIP	\$ _____	X ____ =	\$
	CHAIN LINK	\$ _____	X ____ =	\$
	SMALL WHEEL	\$ _____	X ____ =	\$
	SNAP-CAP	\$ _____	X ____ =	\$
	HEAD - NEON GREEN	\$ _____	X ____ =	\$
	HEAD - NEON RED	\$ _____	X ____ =	\$

Glossary of Terms

The terms that are included are defined as they apply to the lessons included in the Teacher's Guide. Some of the terms may have more detailed definitions when used in other applications.

1st Class Lever	A lever where the fulcrum is between the effort (force) and the load.
2nd Class Lever	A lever where the fulcrum is located at one end of the lever and the effort is at the other end. The load is located between the fulcrum and effort.
3rd Class Lever	A lever where the fulcrum is located at one end and the load is located at the other end. The force is applied between the two.
Acceleration	The increase in the velocity of an object.
Ampere	Unit of measure for electrical current.
Analog Electronics	Analog electrical systems are systems with a continuously variable signal, in contrast to digital electronics where signals usually take only two different levels.
AND Gate	In Boolean logic, an AND gate will only provide a true output (1) if both inputs are true. Otherwise, the output is always false (0).
Base (crane)	Lowest part of a tower crane that is fastened to a large concrete mass that stabilizes the crane.
Belt Drive	A loop of flexible material used to link two or more rotating shafts mechanically over pulleys.
Binary Number System	A base-2 number system. In the case of digital electronics, those numbers are 0 (off) and 1 (on).
Bit	A computer bit is a binary digit. It is the smallest unit- a "0" or "1".
Block and Tackle	A mechanism consisting of ropes and one or more pulley-blocks that are used for lifting or pulling heavy objects.
Boolean Logic	Boolean logic is a form of algebra where values are reduced to being either true or false.
Byte	Bits are usually assembled into groups of 8 called a byte. A byte contains enough information to represent a character, like a letter.
Cam	A projection on a rotating part in machinery, designed to push on another part while rotating. It is used to convert rotary motion to linear or reciprocal motion.
Cartesian Coordinates	A coordinate system for which the coordinates of a point are its distances from a set of perpendicular lines that intersect at the origin of the system.
Centripetal Force	A force that acts on a body moving in a circular path and is directed toward the center around which the body is moving.
Chain Drive	A device is used to link two or more sprockets on rotational shafts over a distance.
Circuit	A group of electrical components that perform a task. A basic circuit includes a power source, conductors, control device, and a load.
Circumference	Distance around a circle. Calculated as $2 \times \pi \times r$ (radius) or as $\pi \times d$ (diameter).
CNC	CNC stands for Computer Numerical Control. This identifies a system that uses a computer to control a machine using accurate motors and sensors to do work.
Conductor	A material with low resistance that allow electricity to flow easily.
Connecting Rod	A rod that transmits motion or power from one moving part to another in a machine.
Constant	Any variable that is kept the same, unchanged during an experiment.
Coordinate Systems	Systems that use geometric coordinates to establish position.
Counter Weights (crane)	Heavy weights used on tower cranes to balance the load and keep the crane from falling over.
Crank	A device for transmitting rotary motion, consisting of a handle or arm attached at right angles to a shaft.
Current	The "amount" of electricity. Current is measured in Amperes or Amps.
Decision Block	A K'NEX Computer Control Software symbol used to ask a question using feedback from an input or the value of a variable. Answers are "yes" or "no".



Dependent Variable	The variable that will be measured during an experiment. Also called the responding, or measured variable.
Differential	A device that splits the engine torque two ways, allowing each output to spin at a different speed.
Digital Electronics	Digital electronics only uses two values, rather than a varying level like analog electronics.
Efficiency	An expression of performance. Efficiency = work output/work input X 100 (percent).
Energy Loss	Losses in a system (mechanical, electrical, fluid, thermal). These losses affect the efficiency of the system.
Feedback	Provides monitoring of the system. (examining results, program self-monitoring through decision blocks)
First Law of Motion	An object at rest will remain at rest unless acted on by an unbalanced force. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an unbalanced force.
Flow Line	A K'NEX Computer Control Software symbol used to connect symbols together to operate the flow chart.
Force	A push or pull that has both magnitude and direction.
Force Transformers	A machine or device that can change input values of force, movement or rate into different output values.
Frequency	The rate at which something occurs or is repeated over a particular period of time.
Fulcrum	A turning or pivot point on a lever.
Game Controls	The part of a game design document where all controls used in the game are listed along with their functions.
Game Design Brief	The part of a game design document where the name for your game and a short description is given to catch the player's attention.
Game Design Document	A written description of a software product that a software designer writes in order to give the software development team guidance as to the architecture of the software project.
Game Flow	The part of a game design document where a description of the game play is given.
Game Levels	The part of a game design document where the levels and difficulty of each level are listed.
Game Objects	The part of a game design document where all objects and actors used in the game are listed along with their descriptions.
Gantry Crane	A Gantry Crane differs from an overhead crane in that the wheels of the crane are on the legs, rather than being fixed in one location.
Gear	A toothed wheel that works with one or more other toothed wheels used to control the speed and force in a machine.
Gear Down	An expression used to indicate that the speed of an output gear is slower than the input gear.
Gear Ratio	The ratio of the rates that gears turn in a system.
Gear Tooth	The projection on the circumference of a wheel (gear) that interacts with the teeth on another gear to create rotation.
Gear Up	An expression used to indicate that the speed of an output gear is faster than the input gear.
Genre	A category of artistic composition, as in music or literature, characterized by similarities in form, style, or subject matter. In game design, it is the category of the game type.
G-force	The unit of force equal to the force exerted by gravity; used to indicate the force to which a body is subjected when it is accelerated.
Gravity	The force that attracts a body toward the center of the earth or toward any other physical body having mass.
Hoist (crane)	The chain or cable and hook that lift the load on a crane.

Pulley	A wheel with a grooved rim around which a cord passes. It acts to change the direction of a force applied to the cord and/or multiply the applied force.
Pulse Width Modulation	Varying the amount of electrical energy sent to a load or other device by changing the length of time a pulse is left on compared to when it is off.
Reciprocal Motion	A repetitive up-and-down or back-and-forth motion.
Reed Switch	A type of switch where the contacts are closed by the use of a magnet.
Resistance	The opposition to the flow of electricity. Measured in Ohms.
Screw	An inclined plane that wraps around itself. Used to hold things together or raise and lower objects.
Second Law of Motion	Acceleration is produced when a force acts on a mass. The greater the mass (of the object being accelerated) the greater the amount of force needed (to accelerate the object).
Simple Machines	Simple machines are tools that make work easier and have few or no moving parts. They also use energy to do work.
Sir Isaac Newton	A famous scientist and mathematician that developed laws dealing with motion and gravity.
Slewing Unit (crane)	Found at the top of the mast where the crane would rotate. The slewing unit consists of the gears and motor for rotation.
Sprocket	A wheel with teeth used to mesh with a chain in a chain drive system.
Start Block	A K'NEX Computer Control Software symbol required at the beginning of the flow chart or procedure.
STEM	Science, Technology, Engineering and Mathematics integrated curriculum.
Stop Block	A K'NEX Computer Control Software symbol used to end a flow chart or procedure.
Third Law of Motion	For every action there is an equal and opposite re-action.
Tooth or Cogged Belt	A belt drive system where the belt has teeth to act like a chain drive.
Torque	A force-like quantity in a rotational system. Torque = (Force) X (Lever Arm Length). Expressed in Newton-Meters (Nm).
Tower Crane	A tower crane is a stationary crane with an extremely long vertical mast. Tower cranes are used in construction for large structures such as bridges and hi-rise buildings.
Translational Motion	Linear motion or motion along a straight line, such as an axis.
Truss	A structure consisting of a triangle or triangle shapes used to span long distance with great strength due to the fact that a triangle ensures the greatest rigidity.
Variable	Any measurable characteristic or attribute, such as motor speeds, program wait times or distances.
Velocity	The speed of something in a given direction.
Voltage	The "pressure" under which electricity flows. Measured in Volts.
Watt	Unit of measure for electrical power.
Wedge	Made up of two inclined planes or at least one slanted side, it is used to push two objects apart. The planes meet to form a sharp edge and move to do work.
Wheel and Axle	A simple machine where a larger wheel, or cylinder, is mounted on a smaller cylinder called the axle. A wheel and axle can be used in a machine to multiply force or distance.
Work	The product of the force applied to an object along its direction of movement and the distance the object moves while force is applied. Work = Force X Distance. Expressed in Newton-Meters (Nm).

LESSON #1: IS THE CAR READY?

Research and Design Log Vocabulary:

Efficiency – An expression of performance. Efficiency = work out/work in X 100 (percent).

Variable – Any measurable characteristic or attribute.

Independent Variable – Any variable that is deliberately changed. Sometimes called the controlled, manipulated, or changed variable.

Dependent Variable – The variable that will be measured. Also called the responding, or measured variable.

Constant – Any variable that is kept the same, unchanged.

K'NEX Program Start Block – Symbol required at the beginning of the flow chart or procedure.

K'NEX Program Output Block – Symbol used to turn an output (sound or LED) or motor ON or OFF.

K'NEX Program Process Block – Symbol used for operations like “wait” for a time delay, “procedure” to call up a procedure sub-routine, or “make” to set up a variable.

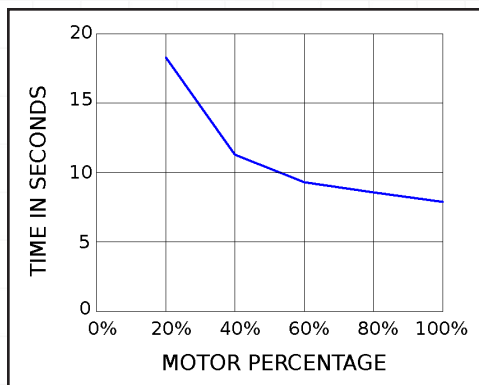
K'NEX Program Decision Block – Symbol used to ask a question using feedback from an input or the value of a variable. Answers are “yes” or “no”.

K'NEX Program Stop Block – Symbol used to end a flow chart or procedure.

K'NEX Program Flow Line – Used to connect symbols together to operate the flow chart.

Student Response Sheet 1

- When graphing time, you should obtain data similar to the one displayed:



If efficiency was equal at every test, the graphed line would be straight (as displayed from 60%-100%). As the motor speed drops, it appears as though motor performance is greatly reduced, especially from 40% down to 20%. According to this graph, performance is equal or almost equal at 60%, 80% and 100%, meaning the K'NEX motors operate most efficiently at higher speeds.

- Motor percentage is an *Independent Variable*, measured or mean time is a *Dependent Variable*, and the one meter distance, the car, interface, power cord and test surface are examples of Constants.
- Inaccuracy in the time test could be caused by many factors. Some of them could be:
 - Human error (while obtaining the actual time).
 - Inconsistencies in the 2 motors (i.e. not exactly equal output).
 - Slipping on the testing surface or uneven surface.
 - Swivel wheel not properly aligned or catch on uneven test surface, friction in the system.
 - Power cord not allowing free movement.

Student Response Sheet 2

- By using a solid axle, both wheels would spin at the same rate, causing excess friction. Wheels would try to drag and slip while cornering causing excess wear and heat on the tires, loss in fuel economy, excess wear on the mechanical parts like bearings and axles from pressure to name a few.
- A differential works by allowing both wheels to drive, but allowing for different rates on each wheel. A disadvantage of a basic differential is that if one wheel loses traction, no power remains for the other wheel (one tire on ice). Limited slip differentials are now used on most cars that sense slipping and balance torque.

- Any program can be used that allows the students to program different percentages to each motor. The simple one-speed control program listed in the lesson notes for the speed test can be used by changing the motor percents. For the results below, the motors were programmed at 20% and 100%, but student results will vary. Some students may even try zero or reverse the direction on a motor causing the car to “spin on a dime”. While this would be an interesting effect (*and actually used in Lesson #2*), they will not be able to measure a diameter touse for their calculations.

```

Text View  Map
1  Start: Simple Speed Start-Stop
2  Is Input 1 On? GoTo 3 else GoTo 2
3  Switch Motor: B Fwd(20),A Fwd(100)
4  Wait 2 seconds
5  Is Input 1 On? GoTo 6 else GoTo 5
6  Switch Motor: B Off,A Off
7  Stop
8  END

```

At 20% and 100% motor outputs, a loop of approximately 1 meter (100 cm) was made by the car’s outer wheel. Since the car’s measurement between wheels is approximately 10 cm, the inner diameter would be 80 cm (10 cm removed from radius would be double for the diameter).

- Inner Diameter: **80 cm**
 - Outer Diameter: **100 cm**
 - Inner Circle Circumference: **251 cm** (rounded to nearest cm)
 - Outer Circle Circumference: **314 cm** (rounded to nearest cm)
- If the K’NEX car wheel diameter is **4.5 cm**, it would have a circumference of approximately **14.1 cm**, so divide each circle circumference by 14.1 do find revolutions.
 - Number of Revolutions for Inner Wheel: **17.8 revolutions**
 - Number of Revolutions for Outer Wheel: **22.3 revolutions**
 - From the results above, a solid axle would not allow the wheels to turn at the different rates, causing friction, tire sliding and excess wear. In effect, a solid axle is only good for straight motion.
 - According to the above calculations, the outer wheel needs to make approximately **4.5** more revolution than the inner wheel (*22.3 revolutions – 17.8 revolutions*)
 - From our answer above, the outer wheel needs to cover approximately **63 cm** more than the inner wheel. This can be confirmed 2 ways:

Outer Circumference – Inner Circumference: (*314 cm – 251 cm = 63 cm*)

Revolution X Wheel Circumference: (*4.5 rev X 14.1 cm = 63.45 cm*)

By marking this difference on a meter stick, the students can see this is a substantial difference.

Challenge Design Brief

- Since the design brief challenges are very open ended, there are no specific answers as results will vary. Since most of the challenges relate to the varying speed test, these are some of the results the students may encounter:
 - Adding mass will affect the times at all percentages, but may amplify the inefficiency at lower percentages due to the power loss effect we saw on the original test.
 - Removing the swivel wheels may help keep the car on a straighter track, but may add to the friction and affect efficiency. Much of this will be dependent on the construction of the car model and friction in the wheels.
 - Using only one motor will reduce power and affect time, as with removing the swivel wheels.
 - Reversing the direction of the motors and changing the car into “front wheel drive” should not cause much effect, but this will be dependent on many factors like the ones discussed above.
- The last challenge would probably be the most interesting one for the students as they are given some open-ended design options. This challenge could also be used for competition if time is available.

LESSON #2: CRUISE CONTROL- KEEPING YOUR CAR SAFE

Research and Design Log Vocabulary:

Conductor – Materials with low resistance that allow electricity to flow easily.

Insulator – Materials with high resistance that limit the flow of electricity.

Resistance – The opposition to the flow of electricity. Measured in Ohms.

Voltage – The “pressure” under which electricity flows. Measured in Volts.

Current – The “amount” of electricity. Measured in Amperes or Amps.

Power – The rate of electrical energy being converted into work. Measured in Watts.

Ampere – Unit of measure for electrical current.

Ohm – Unit of measure for electrical resistance.

Watt – Unit of measure for electrical power.

Load – The device doing work in an electrical circuit.

Pulse Width Modulation (PWM) – Varying the amount of electrical energy sent to a load or other device by changing the length of time a pulse is left on compared to when it is off.

Student Response Sheet 1

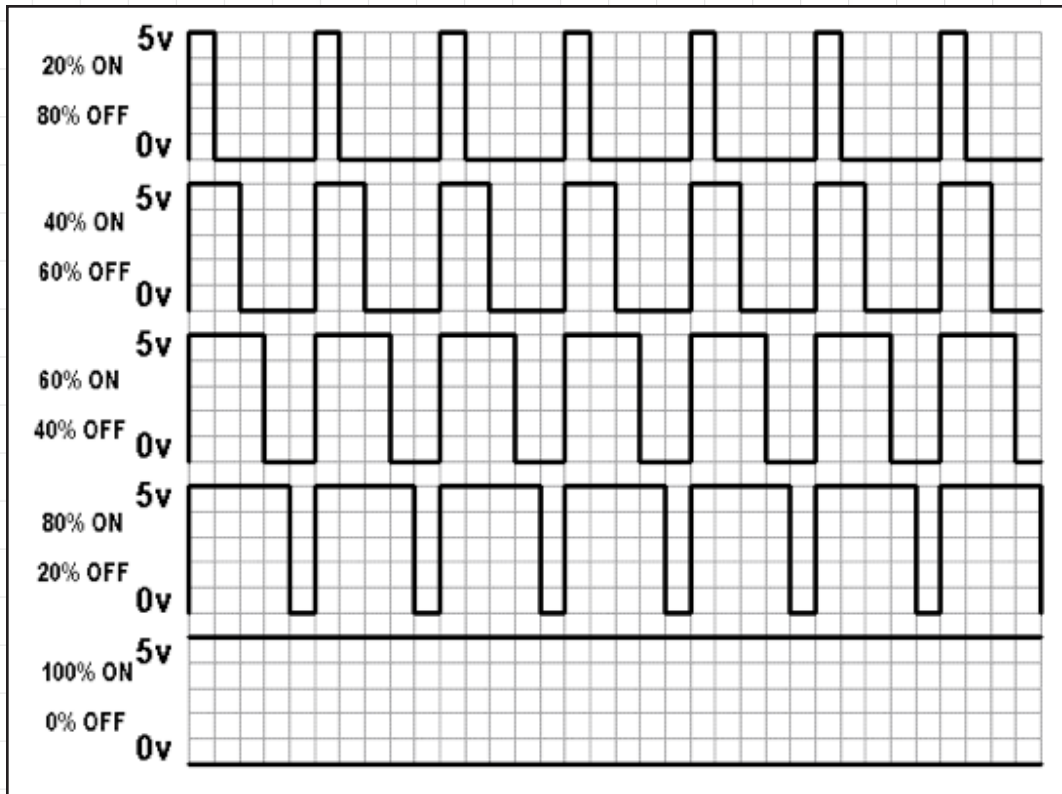
- When developing programs for the tabletop car model, the students may try a variety of different approaches to the challenge. Exact answers to this challenge would be difficult to provide. A good approach to evaluating this activity would be to compare the groups’ results and their programs through class discussion for pros and cons.
- Review the answers given in the Elaborate and Explain section to see how the activity could be improved.

Student Response Sheet 2

- There are several devices that fall under the categories below:
 - o Power Source - The K’NEX Computer Control Interface, power cord from wall outlet
 - o Control Device - Push button switch, power switch on K’NEX interface
 - o Conductor - wires for motors, switches, buzzer
 - o Load - motors, buzzer
- The voltage and current reading were provided in the lesson, but you may use provide your students with your own set of readings through demonstration. The formula used to calculate resistance is $R=E/I$ and the formula for power is $P=IE$

Motor Speed	Voltage (E)	Current (I)	Resistance (R)	Power (P)
20%	1.05 volts	0.05 amps	21.00 ohms	0.05 watts
40%	2.11 volts	0.11 amps	19.18 ohms	0.23 watts
60%	3.16 volts	0.16 amps	19.75 ohms	0.51 watts
80%	4.22 volts	0.22 amps	19.18 ohms	0.93 watts
100%	5.27 volts	0.27 amps	19.52 ohms	1.42 watts

- A example of graphing the pulse width of the various percentages:



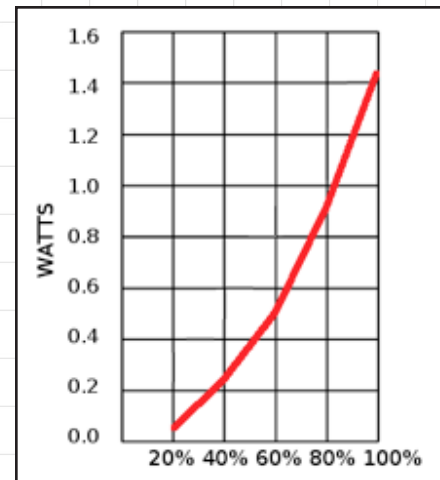
- By using the electrical formulas, the electrical quantities will be very consistent- not what we may have seen in the lesson 1 tests. This is telling us that, even though there is loss of speed at lower voltages, it is not affecting the power consumption of the motor in the same way.

On a related note, this is an advantage of using electric motors over gasoline engines in cars. Gasoline engines are less efficient at different speeds as opposed to electric motors.

These results could differ if we were to test the motor under a stronger load (mass of the car affecting the power consumption), but this would be difficult to do with our wiring.

Many devices have the electrical requirements printed on them in an easy-to-find location. The example provided below supplies information from a laptop computer power supply:

- o 18.5 volts
- o 3.5 amps
- o 5.28 ohms (calculated)
- o 64.75 watts (calculated)





Student Response Sheet 3

- When developing programs for the collision car model, the students may try a variety of different approaches to the challenge. Exact answers to this challenge would be difficult to provide. A good approach to evaluating this activity would be to compare the groups' results and their programs through class discussion for pros and cons.
- Review the answers given in the Elaborate and Explain section to see how the activity could be improved.

Challenge Design Brief

- Since the design brief challenges are very open ended, there are no specific answers as results will vary. Most of the challenges relate to changing the programming and/or the car model. Several of these challenges allow an excellent opportunity for competition.
- The last challenge introduces a car cost calculation activity that is similar to ones that will appear in several future lessons. This could be used in a variety of ways:
 - o Using the K'NEX parts pricing as provided on the Cost per Piece Chart will help the students understand the pricing of the model.
 - o If role playing an actual engineering project, a budget figure should be provided that students are required to meet.
 - o The challenge can be used to enable students to examine how many resources are actually used in a project like the one presented.

LESSON #3: BEGINNING THE JOURNEY

Research and Design Log Vocabulary:

Force – A push or pull. Expressed in **Newtons** (N).

Newton – The Newton is the SI unit for force; it is equal to the amount of net force required to accelerate a mass of one kilogram at a rate of one meter per second squared.

Torque – A force-like quantity in a rotational system. Torque = (Force) X (Lever Arm Length). Expressed in **Newton-Meters** (Nm).

Work – The product of the force applied to an object along its direction of movement and the distance the object moves while force is applied. Work = Force X Distance. Expressed in **Newton-Meters** (Nm).

Newton-Meter (Nm) – Unit of measurement for work. Force (Newton) X Distance (meter).

Mechanical Advantage – The ratio of the force produced by a machine to the force applied to it.

Simple Machines – Simple machines are tools that make work easier and have few or no moving parts. They also use energy to do work.

Reed Switch – A type of switch where the contacts are closed by the use of a magnet.

Pulley – A wheel with a grooved rim around which a cord passes. It acts to change the direction of a force applied to the cord and/or multiply the applied force.

Block and Tackle – A mechanism consisting of ropes and one or more pulley-blocks that are used for lifting or pulling heavy objects.

Energy Loss – Losses in a system (mechanical, electrical, fluid, thermal). These losses affect efficiency.

Student Response Sheet 1

- Pulley systems:

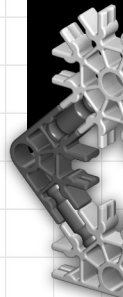
SYSTEM	Number of Support Cords (C)	Mechanical Advantage (MA)	Input Force (F)	Distance Input Force Moves (d)	Distance the Load is Lifted (y)	Work Input (W)
A	1	1	120 N	.05 m	.05 m	6 Nm
B	2	2	60 N	.06 m	.03 m	1.8 Nm
C	3	3	40 N	.06 m	.02 m	0.8 Nm

For the garage door predictions, answers should reflect that there is a mechanical advantage to the garage door due to there being 2 cords pulling the door. This would give a mechanical advantage of 2.

If the motor provides 10 N of force and pulls 50 mm of string onto the spool, at a ratio of 2, the door should rise 25 mm and lift with 20 N of force.

- After testing the garage door, students should be able to confirm the above predictions. The door should rise approximately 25 mm. If they are accurate with their readings, they may see an actual number of 23 mm – 24 mm. Some errors to this number could be caused by loss in the system or inaccurate data collection (the number should never be higher than 25 mm). Loss can occur from:
 - o String tension- string straightens or stretches
 - o Bending of the string around pulleys
 - o Force differences due to friction in pulleys and axles
 - o Error in readings

Pulley diameters would not affect the calculations of the system, but could improve efficiency with the use of larger pulleys. Larger pulleys would provide longer levers to help overcome friction in the axles.



Changes in motion in this system are:

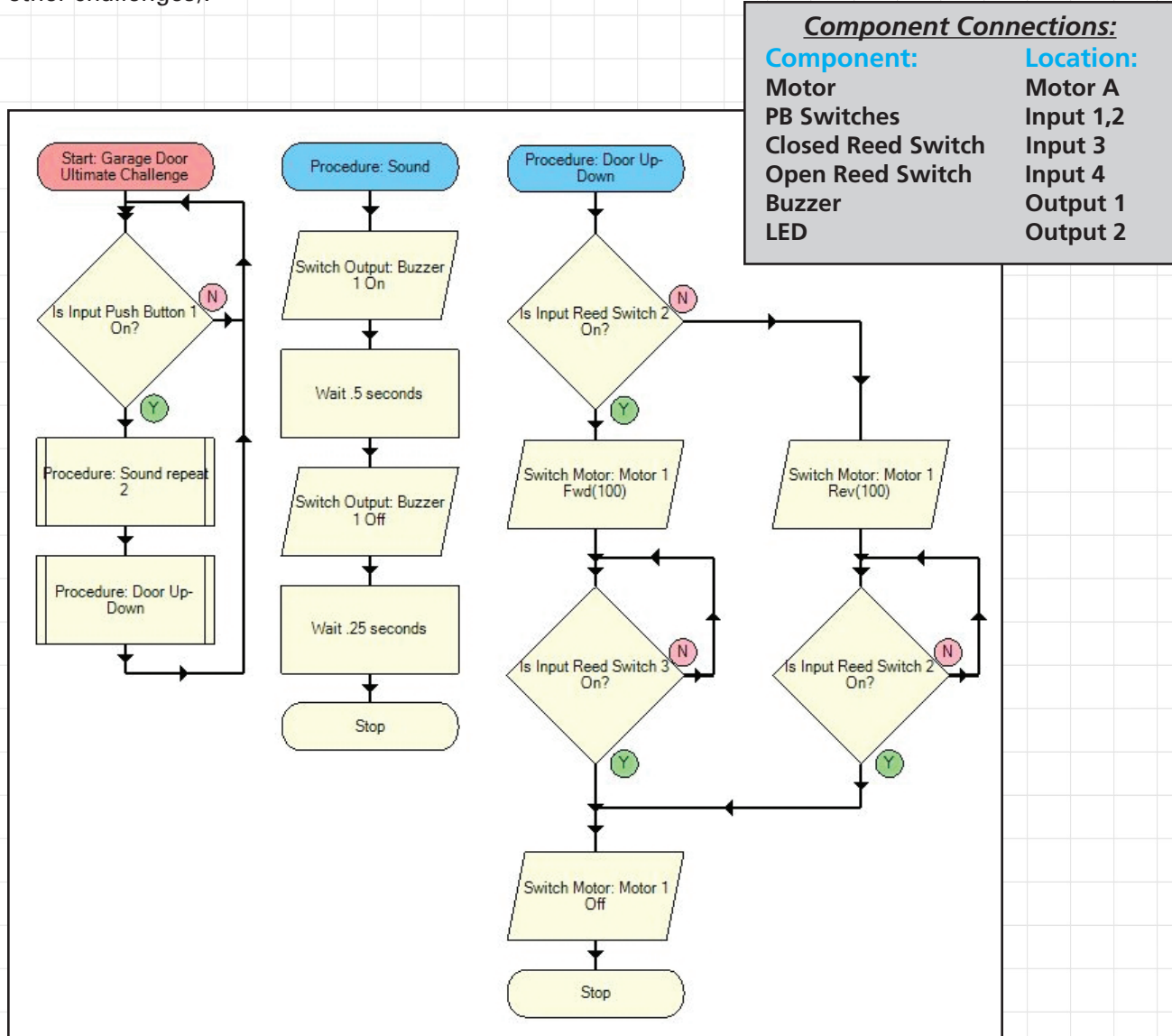
- o Motor- rotary motion
 - o String- linear motion
 - o Door pulley- rotary motion
 - o Door rising- rotary motion (door rides on a pivot point so it doesn't actually go up, just rotates)
- There is an inverse relationship between distance and force in a pulley system. In order to lift more mass, you inversely decrease the distance that it is lifted.
 - Several applications for pulleys:
 - o Flag Pole
 - o Crane
 - o Engine Hoist
 - o Boat Rigging
 - o Tow Truck
 - o Hand Brakes on Bicycle
 - o Throttle on a Car
 - o Elevator
 - o Garage Door
 - o Window Blinds
 - o Fan Belts

Student Response Sheet 2

- While motor speed is a personal choice, a speed of 100% will require approximately 3 seconds to open and close.
- When testing the garage door using timed control, the students will probably experience a faster closing time than the opening time. If they program the door to operate with the same wait time for both opening and closing, the string will become looser with every test, meaning the door will not open as much with each test. This is due to the mass of the door. It requires more force to open the door than to close it so the motor works harder and does not run as fast during the opening cycle.
- When using the reed switches to control operation, motor speed and time should not be factors in the operation of the door. The reed switches will stop the door at the same point every time.
- As mentioned before, the garage door will need more time to rise than to close due to motor strain and mass of the door. Other factors that could affect the operation of the door are:
 - o Friction in the system due to cold and heat. Friction in the system will vary due to climate conditions. Cold weather will cause lubricants to thicken and increase friction while hot weather will cause lubricant to soften. Also, lubricants wear away and need replaced from time to time.
 - o Varying electrical voltage. Electrical output from power lines vary during the day due to demand, causing the garage door opener to run at different speeds. Also, during hot weather, more demands are placed on the power grid because of air conditioning.
 - o Wear in the system such as pulleys, bearing or cord.
- With reed switch systems, the magnet must always trigger the switch so if the magnet or switch becomes damaged or changes position, the operation could fail. If something changes in the system (i.e. pulleys, bearings or cords become worn).
- Safety systems include pressure sensing that causes the door to reverse if something is under the door, optical system reverse the door as well if something crosses the beam, and automatic lighting.
- Examples of variables:\ul style="list-style-type: none;">- o Independent Variables: motor speed, buzzer output, wait times
- o Dependent Variables: time for door to rise, winding of the cord
- o Constants: Distance between reed switches, push car and garage configuration and size, K'NEX interface.

Challenge Design Brief

- Since the design brief challenges are very open ended, there are no specific answers as results will vary. Most of the challenges relate to changing the programming and/or the garage model. Here is a sample program that could be used for the Ultimate Challenge (and parts of it useful for some of the other challenges).



- o Input switches 1 and 2 are the push button switches at 2 locations.
- o Output 2 is the LED that remains on during the cycle, and then turns off 4 seconds after the door is opened or closed.
- o Procedure: Sound beeps twice before the motor turns on.
- o Procedure: Door Up-Down senses door position and runs accordingly.

LESSON #4: THE HIGHWAY RIDE

Research and Design Log Vocabulary:

Simple Machines – Simple machines are tools that make work easier and have few or no moving parts. They also use energy to do work.

Lever – A board or bar that rests on a turning point called a **fulcrum**. The object the lever moves is called the load. The closer the load is to the fulcrum, the easier it is to move.

Inclined Plane – A flat surface that is higher at one end and used to move a load to a higher or lower place. Inclined planes can make work easier by using less force and energy to move objects.

Wheel and Axle – A simple machine where a larger wheel, or cylinder, is mounted on a smaller cylinder called the axle. A wheel and axle can be used in a machine to multiply force or distance.

Screw – An inclined plane that wraps around itself. Used to hold things together or raise and lower objects.

Wedge – Made up of two inclined planes or at least one slanted side, it is used to push two objects apart. The planes meet to form a sharp edge and move to do work.

Pulley – A wheel with a grooved rim around which a cord passes. It acts to change the direction of a force applied to the cord and/or multiply the applied force.

Fulcrum – A turning or pivot point on a lever.

Class 1 Lever – A lever where the fulcrum is between the effort (force) and the load.

Class 2 Lever – A lever where the fulcrum is located at one end of the lever and the effort is at the other end. The load is located between the fulcrum and effort.

Class 3 Lever – A lever where the fulcrum is located at one end and the load is located at the other end. The force is applied between the two.

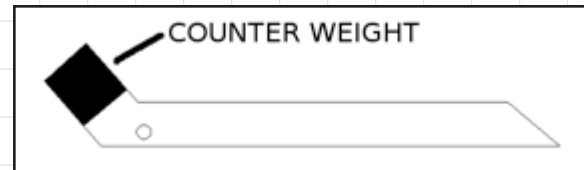
Student Response Sheet 1

- By using the formulas provided on the Student Response Sheet, the chart can be completed as shown:

Lever Class	Input Effort (F_i)	Input Distance (d_i)	Output Distance (d_o)	Mechanical Advantage (MA)	Which has been increased: Force or Distance?	Input Work (W)
Class 1	50 N	0.4 m	0.2 m	2	Force	Nm
	200 N	0.2 m	0.4 m	0.5	Distance	Nm
Class 2	50 N	0.6 m	0.3 m	2	Force	Nm
	33.3 N	0.6 m	0.2 m	3	Force	Nm
Class 3	200 N	0.3 m	0.6 m	0.5	Distance	Nm
	600 N	0.1 m	0.6 m	0.17	Distance	Nm

- Force and distance can never be multiplied in the same lever system. You will always sacrifice one for the other. As with any machine output can never be more than 100%.
- Class 1 levers are able to multiply force or distance by changing the location of the fulcrum. If the input distance is greater than the output distance, **force** is multiplied. If the output distance is greater than the input distance, then **distance is multiplied**. Only class 1 levers are capable of multiplying either.
- Class 2 levers are only able to multiply **input force**. The output distance will always be **less** than the input distance.
- Class 3 levers are only able to multiply **input distance**. The output distance will always be **more** than the input distance.

- Some examples of the various types of levers found around the home and school include:
 - Class 1: See-Saw, Scissors, Elbow w/ Arm Straightening, Hand Truck, Pry Bar, Pliers
 - Class 2: Wheel Barrow, Push-Up, Nutcracker, Bottle Opener
 - Class 3: Baseball Bat, Fishing Pole, Toll Gate, Mouse Trap, Swinging a Hammer
- The K'NEX toll gate is a class 3 lever because the output distance will always be greater than the input distance. In fact, the input force is directly on the fulcrum, much like a fishing pole.
- Motor speeds for the toll gate will be determined by each group. 10%-40% will probably be common. Because the gate is a class 3 lever, it will probably require a higher speed percentage to raise the gate than to lower it to maintain a consistent speed, due to the higher input force.



- As mentioned above, the gate is a class 3 lever with all of the lever mass to one side of the fulcrum. In order to reduce the load on the motor, a counter weight could be added to the gate, like shown. This does not change the type of lever, but reduces stress on the motor by counter balancing the lever. This technique is used in many gate systems.

- Advantages of having a toll booth operator could include:
 - A person is readily available if a problem with the system occurs.
 - Employment opportunities for toll collectors.
 - Personal operation of the gate and tolls collected.

Disadvantages in having a toll booth operator could include:

- Human error in gate operation and toll collection.
 - Cars may not pass as quickly with a human operated system.
 - Human operators need breaks, wages, and benefits.
- Human operated toll gates are being replaced with fully automated systems. The toll is collected electronically and charged to the driver's account while the gate senses the approaching car and operates the gate. In many cases, the driver doesn't even need to stop, just slow down for the sensor to read their pass.

Advantages of an automated system could include:

- Speed that cars can pass.
- There is no need for money since fees are charged to an account.
- Fewer operators needed since the system is automated.

Disadvantages of an automated system could include:

- People could find a way to "fool" the system and not pay fees.
- If a car drives too quickly for the system to sense them, damage or loss of fees could occur.
- Electrical outages would cause backlogs until human operators arrived.

Student Response Sheet 2

- While developing a program to operate the toll gate, students will probably determine motor speeds around 10%-40% will be appropriate for timing and safety concerns. Since it will require more effort to open the gate than to close it, they will probably determine two different speeds for the gate.
- Because the gate is being raised and lowered by wait blocks (time), there is a chance that the cycle will eventually lose its timing causing the gate to either not open or close completely. Travel limit switches, like those used on the garage door lesson, would solve this problem.

- The main problem that the students may encounter with the reed switches will be if the car magnet does not travel close enough to the reed switch to trigger it. Also, if the car “backs up” and triggers the switch a second time, a problem may occur depending on how the students designed the program.
- Some disadvantages that could occur with using only one reed switch on the approach side of the gate could include:
 - o The driver backs up and triggers the switch a second time (dependent on the programming)
 - o The driver pauses too long and doesn’t make it past the gate before it lowers.
 - o Inclined Plane- Lesson 1 Challenge Activity Ramp
 - o Wheel and Axle- Tires on K’NEX car
 - o Screw- Screws used to hold Motor Casing together
 - o Wedge- Ends of K’NEX Rods inserted into K’NEX Connectors
 - o Pulley- Garage Door Pulley System
- Some variables used in the K’NEX toll gate:
 - o Independent Variable- State of the reed and push button switches, Wait block times, LEDs, Buzzer.
 - o Dependent Variable- Distance the gate rotates and time it takes to travel.
 - o Constants- Distance between the reed switches, length and configuration of gate, push car and garage configuration and size, K’NEX interface.

Challenge Design Brief

- Since the design brief challenges are very open ended, there are no specific answers as results will vary. Most of the challenges relate to changing the programming and/or the tool gate model. In order to complete the Ultimate Challenge, students will need to redesign their gate by adding weight to the back side of the lever as a counterbalance. This can be accomplished by adding additional K’NEX components or even pennies. Additional components will also need to be added to attach the reed switch or magnet to the gate.

LESSON #5: OVER THE RIVER

Research and Design Log Vocabulary:

Gear – A toothed wheel that works with one or more other toothed wheels used to control the speed and force in a machine.

Gear Tooth – The projection on the circumference of a wheel (gear) that interacts with the teeth on another gear to create rotation.

Gear Ratio – The ratio of the rates gears turn in a system.

Gear Up – An expression used to indicate that the speed of an output gear is faster than the input gear.

Gear Down – An expression used to indicate that the speed of an output gear is slower than the input gear.

Chain Drive – A device is used to link two or more rotational shafts over a distance

Sprocket – A wheel with teeth used to mesh with a chain in a chain drive system.

Belt Drive – A loop of flexible material used to link two or more rotating shafts mechanically over pulleys.

Tooth or Cogged Belt – A belt drive system where the belt has teeth to act like a chain drive.

Crank – A device for transmitting rotary motion, consisting of a handle or arm attached at right angles to a shaft.

Cam – A projection on a rotating part in machinery, designed to push on another part while rotating. It is used to convert rotary motion to linear or reciprocal motion.

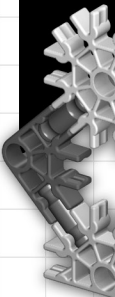
Student Response Sheet 1

- After the students construct the swing bridge, the first question deal with the gear ratio of the bridge:
 - o Number of teeth on the small gear: **14**
 - o Number of teeth on the large gear: **82**
 - o Determine the gear ratio: **5.86:1**
 - o Is this system geared up or geared down? **Geared Down**

The system is considered geared down because the speed is reduced by a factor of 5.86. This means that the small wheel needs to rotate 5.86 times for every 1 revolution of the larger gear. This also means that force is multiplied 5.86 times.

- When answering the questions relating to which motor speed worked best and worst, testing may determine that speed around 50% may work better and higher speeds may provide more inaccuracy. Results may vary between motors.
- Some factors that could contribute to inaccuracies in this system could be:
 - o Motor running faster in one direction than the other.
 - o Inconsistent voltages from the interface
 - o Backlash in the gear system on the bridge
 - o Loose parts on the bridge.
- The following examples use an input force of 100N with gear A as the input (driving) gear:

Example	Gear A # of Teeth (T_a)	Gear B # of Teeth (T_b)	Gear Ratio ($T_{larger} / T_{smaller}$)	Gear Up/Down	Output Force (N)
1	5	30	6 :1	Down	600N
2	20	15	1.33 :1	Up	75.19N
3	10	20	2 :1	Down	200N



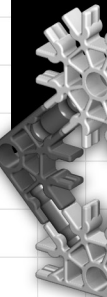
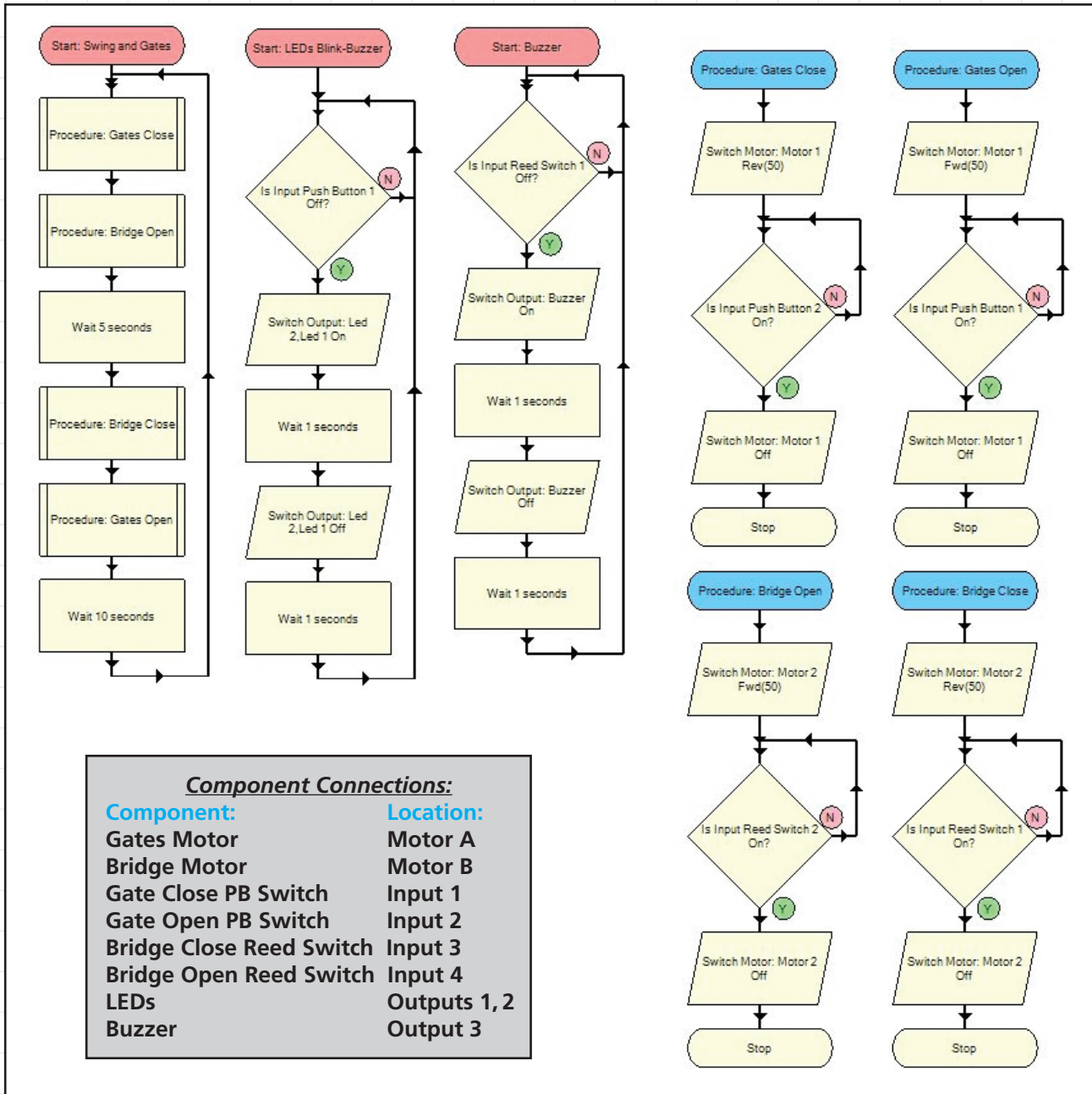
- The example that add a 3rd gear to the system as an idler does not add anything to the gear ratio since it contacts both gears and just acts as a “spacer”. It is still a 2:1 ratio. The benefits to adding this gear can include:
 - o Input and output gears now both spin the same direction
 - o Increased spacing between the input and output gears.

Student Response Sheet 2

- The students may list several different personal challenges for the programming of the gates and bridge swing. The majority will probably mention difficulty with switch contacts and aligning the bridge when closing.
- In real life, a heavy bridge is compensated by using a small drive gear with a large output or driven gear. Input force is increased while speed is decreased. A slower speed actually improves safety. This same principle can be seen on many amusement park rides.
- Students may develop many different ideas to improve the gate system. While the crank idea works well, it can produce a twisting effect on the gate which contributes to alignment issues with the switches. A true cam system would only raise and lower the gates without the twisting effect.
- Some examples of devices that use gears:
 - o Automobile transmissions
 - o Rack and pinion steering
 - o Kitchen mixers
 - o Pencil sharpeners
 - o Door locks
 - o Mechanical toys
 - o Watches and clocks
 - o Hand drill
- Some examples of devices that use belts:
 - o Fan belt on cars
 - o Computer printers (cogged belts)
 - o Timing belts on cars (cogged belts)
 - o Tape decks and VCRs
 - o Assembly line conveyors
 - o Farm equipment
 - o Lawn mowers
 - o Snow blowers
- Some examples of devices that use chain drives:
 - o Bicycle
 - o Motorcycle
 - o Timing chains on cars
 - o Garage door openers
 - o Automatic gates
 - o Engine hoist
 - o Security gates on store fronts
- Some examples of devices that use cranks and cams:
 - o Engines (cam shafts and crank shafts)
 - o Jack in the box handle
 - o Assembly lines
 - o Steam engine (drive wheels)
 - o Cams on certain clamps
 - o Penny smashers at tourist spots

Challenge Design Brief

Since the design brief challenges are very open ended, there are no specific answers as results will vary. Here is a sample program that could be used for the ultimate challenge. Note that only one flow chart was shown for the gate and bridge since they are nearly identical. Input 1 and 2 are the gate switches while inputs 3 and 4 are the reed switches for the bridge.



LESSON #6: TAKING A SPIN AT THE PARK

Research and Design Log Vocabulary:

Sir Isaac Newton – A famous scientist and mathematician that developed laws dealing with motion and gravity.

First Law of Motion – An object at rest will remain at rest unless acted on by an unbalanced force. An object in motion continues in motion with the same speed and in the same direction unless acted upon by an unbalanced force.

Second Law of Motion – Acceleration is produced when a force acts on a mass. The greater the mass (of the object being accelerated) the greater the amount of force needed (to accelerate the object).

Third Law of Motion – For every action there is an equal and opposite re-action.

Gravity – The force that attracts a body toward the center of the earth, or toward any other physical body having mass.

G-force – The unit of force equal to the force exerted by gravity; used to indicate the force to which a body is subjected when it is accelerated.

Frequency – The rate at which something occurs or is repeated over a particular period of time.

Velocity – The speed of something in a given direction.

Acceleration – The increase in the velocity of an object.

Inertia – A tendency of a body in motion to stay in motion and the tendency of a body at rest to remain at rest.

Centripetal Force – A force that acts on a body moving in a circular path and is directed toward the center around which the body is moving.

Student Response Sheet 1

- After the students construct the amusement park ride and develop a program to test motor speed percentages, they will calculate ride speeds for each motor speed for both the swing arm and the seat arm. While different motors and models will produce slightly different results, testing has provided these basic numbers:

Swing Arm Data

(r = 8m)

Circumference = **50.24 m**

Motor Speed	Swing Arm Radius (r ₁)	Revolutions per Second (f)	Velocity (V)	KPH	MPH
20%	8m	.15	7.54 m/s	27.14	16.87
40%	8m	.28	14.07 m/s	50.65	31.48
60%	8m	.35	17.58 m/s	63.29	39.33
80%	8m	.38	19.09 m/s	68.72	42.71
100%	8m	.45	22.61 m/s	81.40	50.59

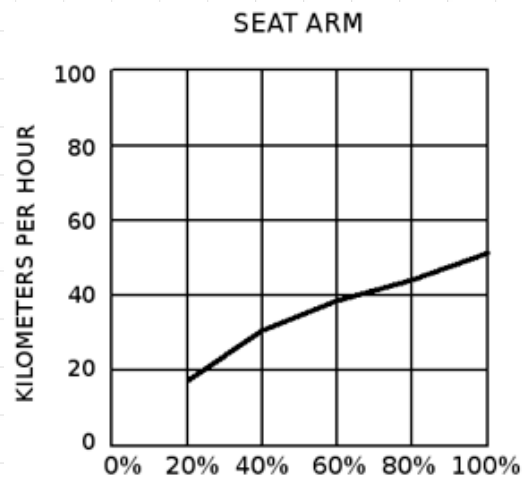
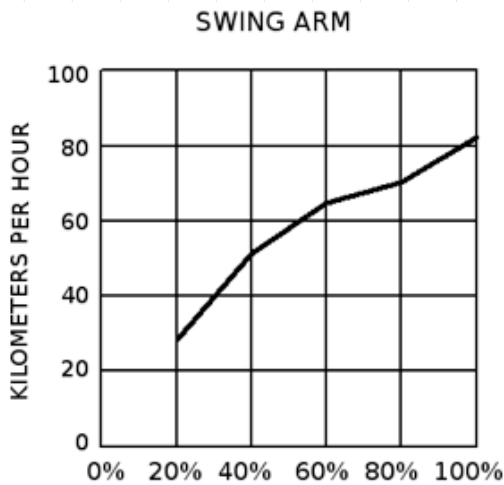
Seat Arm Data

(r = 2m)

Circumference = **12.56 m**

Motor Speed	Swing Arm Radius (r ₁)	Revolutions per Second (f)	Velocity (V)	KPH	MPH
20%	2m	.40	5.02 m/s	18.07	11.23
40%	2m	.70	8.79 m/s	31.64	19.66
60%	2m	.87	10.93 m/s	39.35	24.46
80%	2m	.97	12.18 m/s	43.85	27.25
100%	2m	1.04	13.06 m/s	47.02	29.22

- Graphs for this data would look like this:

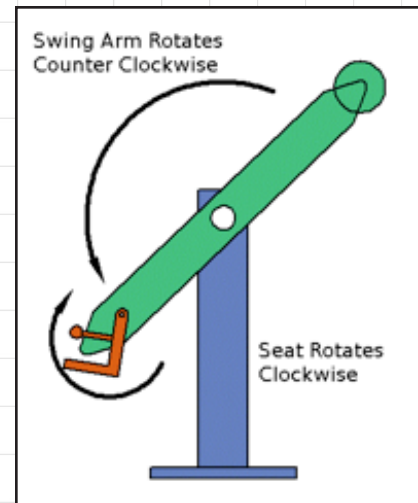


- By using these speeds as a guide:

Carousel (inside horses and outside horses):	6-11 KPH	(4-7 MPH)
Tilt-a-Whirl type ride:	21 KPH	(13 MPH)
Wave Swing type ride:	43 KPH	(27 MPH)
Gravity type (extreme) ride:	56-64 KPH	(35-40 MPH)

For a simple, easy Ferris Wheel type ride, the riders should not experience speeds much more than a carousel ride. Too much force on the rider would not make it as relaxing as commonly expected on this type of ride. From the calculations above, a percentage of 10%-20% would meet these criteria.

- If the forces were consistent throughout the entire ride, you would probably not want to exceed 50-60 KPH, but with 2 swinging arms, the forces will sometimes add together and sometimes subtract from one another. From the calculations above, a swing arm percentage of 20% and a seat arm percentage of 30%-40% should work well.
- For the rotation of the arms, the option of opposite rotations would work best (as discussed in the teacher's notes). This would minimize the "whip" effect when the seat arm reached the outer part of the rotation.



- When applying Newton's Laws of Motion to the amusement park ride, you will see effects as follows:
 - **First Law of Motion:** *An object at rest will remain at rest unless acted on by an unbalanced force.* When the ride is at rest, it will remain at rest until something sets it into motion. Once the ride is up to speed and, if gravity or friction were not there to slow it down, it would remain at that speed and rotation until something slows or stops it.
 - **Second Law of Motion:** *Acceleration is produced when a force acts on a mass. The greater the mass (of the object being accelerated) the greater the amount of force needed (to accelerate the object).*

Since the motor rotating the swing arm needs to move more mass than the motor rotating the seat arm (the swing arm motor needs to move the arm plus the seat), it is logical to assume that the swing arm motor will require more force to move the device. The seat arm requires less force to move it. This can be seen in the gear and chain drives. The gears on the swing arm gear down rotation to increase force. The chain drive is a 1:1 ratio, showing no mechanical advantage.

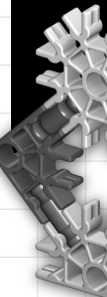
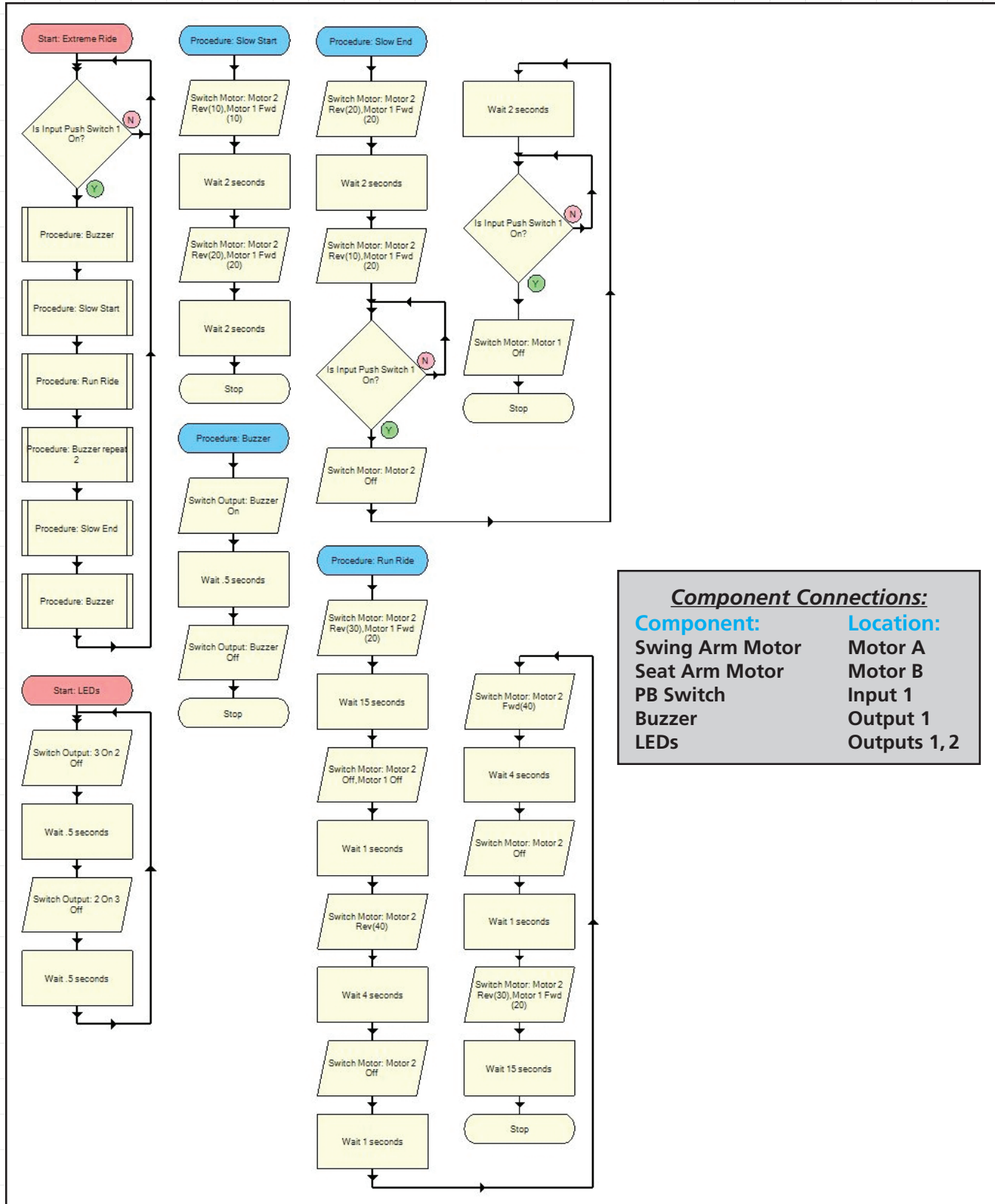
- **Third Law of Motion:** *For every action there is an equal and opposite re-action.* As the ride begins to move, the mass of the object pushes back, requiring more force to move the object. If the first law applied to the ride, it would also require an equal force to stop the movement.

Student Response Sheet 2

- Student responses will vary about the most challenging part of the programming activity. There responses to the problems that may result on a real amusement park ride will also vary.
- When developing a "Riders/Hour" chart, the students will have a variety of answers since they may choose different loading, ride, and unloading times.
- In order to increase the capacity of the ride, the students may suggest:
 - Shorten the ride time
 - Add another seat to the back of the existing seat and add more counterweight
 - Replace the counterweights on the opposite end of the arm with another seat and change the chain drive to match something similar to what was used on the swing bridge.
- Sample simple machines in the Amusement park ride:
 - **Lever-** swing arm, seat arm
 - **Inclined Plane-** not present in the ride
 - **Wheel and Axle-** gears and sprockets
 - **Screw-** Screws used to hold Motor Casing together
 - **Wedge-** Ends of K'NEX Rods inserted into K'NEX Connectors
 - **Pulley-** Not present in the ride.
- Gear ratio on swing arm: 14T: 34T = **2.43:1 ratio**
This system is geared down which results in a decrease in speed and an increase in force.
- The chain drive in the ride has a ratio of 1:1 as both sprockets being the same size. There is no mechanical advantage in the system since input and output are equal. This is also helpful for keeping the seat upright when the seat motor is not used. If the ratio was not 1:1, the seat would always rotate.
- The four tires on the opposite side of the swing arm are meant to simulate counterweights or counter balances. There is more mass on the seat side of the ride that would cause excess strain on the motor if the system was not balanced.

Challenge Design Brief

Since the design brief challenges are very open ended, there are no specific answers as results will vary. Here is a sample program that could be used for the ultimate challenge on the next page. The program displayed uses a manual switch to end the ride with slow start and end procedures.



LESSON #7: PICK IT UP AND PUT IT DOWN

Research and Design Log Vocabulary:

Truss – A structure consisting of a triangle or triangle shapes used to span long distance with great strength due to the fact that a triangle ensures the greatest rigidity.

Base (crane) – Lowest part of a tower crane that is fastened to a large concrete mass that stabilizes the crane.

Mast or Tower (crane) – The vertical riser on a tower crane.

Slewing Unit (crane) – Found at the top of the mast where the crane would rotate. The slewing unit consists of the gears and motor for rotation.

Jib or Working Arm (crane) – The arm on a crane that supports the load.

Counter Weights (crane) – The Counter Weights balance the load and keep the crane from falling over.

Hoist (crane) – The chain or cable and hook that lift the load on a crane.

CNC – CNC stands for *Computer Numerical Control*. This identifies a system that uses a computer to control a machine using accurate motors and sensors to do work.

Coordinate Systems – Systems that use geometric coordinates to establish position.

Cartesian Coordinates – A coordinate system for which the coordinates of a point are its distances from a set of perpendicular lines that intersect at the origin of the system.

Polar Coordinates – They identify locations on a coordinate system by their distance and angle from the x axis.

Student Response Sheet 1

- The first questions in this section require the students to complete some calculations:

- o **Example 1:**

$$M_o = 7,000 \text{ Kg}$$

$$d_o = 35 \text{ m}$$

$$d_i = 10 \text{ m}$$

$$MA = 35 \text{ m} / 10 \text{ m} = 3.5$$

$$M_i = 7,000 \text{ kg} \times 3.5 = 24,500 \text{ kg (counter weight mass)}$$

- o **Example 2:**

$$M_o = 7,000 \text{ Kg}$$

$$d_o = 15 \text{ m}$$

$$d_i = 10 \text{ m}$$

$$MA = 15 \text{ m} / 10 \text{ m} = 1.5$$

$$M_i = 7,000 \text{ kg} \times 1.5 = 10,500 \text{ kg (counter weight mass)}$$

- When searching for typical data for real tower cranes, a good website for information could be:

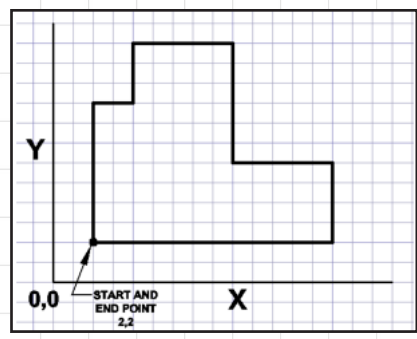
<http://www.knex.com/edusoftware/31.php>

Maximum Unsupported Height:	80 meters
Maximum Reach:	70 meters
Maximum Lifting Power:	18 metric tons
Counter Weight Mass:	16.3 metric tons

- The crane uses two **limit switches** to make sure that the operator does not overload the crane.
- A **maximum load** switch monitors the pull on the cable and makes sure that the load does not exceed 18 tons and the **load moment** switch makes sure that the operator does not exceed the ton-meter rating of the crane as the load moves out on the jib.
- Larger loads can be lifted when the load is in closer to the mast (shorter working arm distance). As the working arm distance increases, the amount of load needs to decrease to compensate for the larger distance to the fulcrum. This is where limit switches would keep the crane from exceeding the limits.
- As cranes exceed their maximum unsupported height (80 meters), the need to be fastened to and supported by the building they are erecting.
- The following information can be obtained from the gears used in the crane:
 - o Number of teeth on the small gear: **14**
 - o Number of teeth on the large gear: **82**
 - o Gear ratio: **5.86:1**
 - o Is this system geared up or geared down? **Geared Down** This is because the driven gear turns at a fraction of the drive gear.
 - o For every 1 revolution of the crane, the motor has rotated **5.86** times due to the gear ratio.
- After building, programming, and testing the crane at various percentages, the students will most likely determine that percentages between 20%-50% will work the best for both drives in the model. Percentages higher than these cause excessive swaying in the chain hoist, causing more chance of error with the reed switch that stops the hoist.
- If students had problems with the hoist, they may present a variety of responses about their solutions. Some may have solved the problem by slowing the movement of the hoist while others may come up with alternate solutions. The answers to the rest of the questions in this bullet will vary. Students who had trouble hooking the box may suggest lowering the hook and then rotating the crane to 'catch' the box.
- The questions related to the group competition will be open-ended without a true accurate response. Look for thoughtful answers that show questioning and understanding.

Student Response Sheet 2

- The shape displayed is drawn using all three coordinate systems:



Absolute Coordinates		Relative Coordinates		Polar Coordinates	
From Point:	2,2	From Point:	2,2	From Point:	2,2
To Point:	14,2	To Point:	@12,0	To Point:	@12<0
To Point	14,6	To Point	@0,4	To Point:	@4<90
To Point	9,6	To Point	@-5,0	To Point:	@5<180
To Point	9,12	To Point	@0,6	To Point:	@6<90
To Point	4,12	To Point	@-5,0	To Point:	@5<180
To Point	4,9	To Point	@0,-3	To Point:	@3<270
To Point	2,9	To Point	@-2,0	To Point:	@2<180
To Point	2,2	To Point	@0,-7	To Point:	@7<270

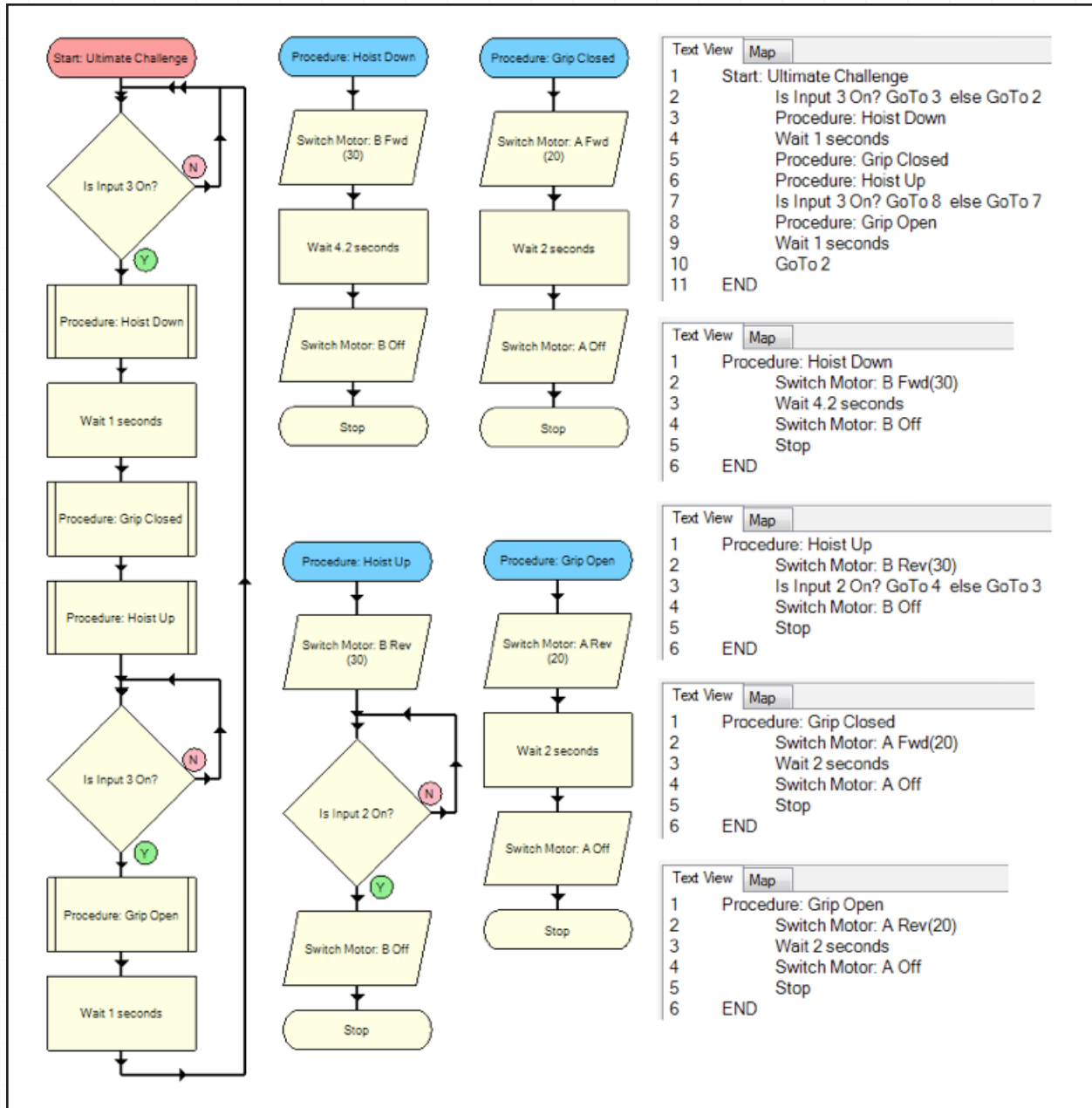
- Results will vary with the paper clip competition. Problems that the students may notice with the model and program may deal with performance as the model moves at each 30 degree increment. This could result from binding in the gears and chain drive, causing the motors to operate differently each time. Variations in electrical and motor performance could cause these effects as well.

Challenge Design Brief

Since the design brief challenges are very open ended, there are no specific answers as results will vary. Here is a sample program that could be used for the ultimate challenge. The program is relatively simple using wait times to open and close the claw. The push button switch is used to activate the operations.

Component Connections:

Component:	Location:
Grip Motor	Motor A
Hoist Motor	Motor B
Hoist Reed Switch	Input 2
PB Switch	Input 3



LESSON #8: A SAFE COMBINATION

Research and Design Log Vocabulary:

Analog Electronics – Analog electrical systems are systems with a continuously variable signal, in contrast to digital electronics where signals usually take only two different levels.

Digital Electronics – Digital electronics only uses two values, rather than a varying level like analog electronics.

Binary Number System – A base-2 number system. In the case of digital electronics, those numbers are 0 (off) and 1 (on).

Bit – A computer bit is a binary digit. It is the smallest unit- a “0” or “1”.

Byte – Bits are usually assembled into groups of 8 called a byte. A byte contains enough information to represent a character, like a letter.

Kilobyte (KB) – A kilobyte is 1,024 bytes. Due to binary counting, it doesn't work out to be quite 1,000 bytes as you would expect.

Megabyte (MB) – A megabyte is 1,024 kilobytes (about 1 million bytes).

Boolean Logic – Boolean logic is a form of algebra where values are reduced to being either *true* or *false*.

NOT Gate – In Boolean logic, a NOT gate simply takes the input (1 or 0) and inverts, or flips it.

AND Gate – In Boolean logic an AND gate will only provide a true output (1) if both inputs are true. Otherwise, the output is always false (0).

OR Gate – In Boolean logic an OR gate will provide a true output (1) if at least one of the two inputs is true (1).

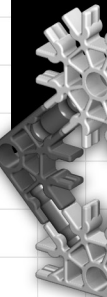
Student Response Sheet 1

After the students construct the safe ride and develop a program to test motor speed percentages and simple operation of the device, they will need to answer a few questions about the machine.

- The students will determine the motor speed they feel works best. In testing, 40% seems to work well and maintain an even operating speed.
- The device used to open and close the door is a crank. A cam rides on an uneven surface while a crank acts like a handle.
- The motor can spin the entire 360 degrees on the safe due to the configuration of the crank. The device cannot over-extend itself and jamb the machine.
- Examples of digital devices:
 - o Personal computer
 - o iPod
 - o Digital TV and signal
 - o Digital radio
 - o Automotive computer system
 - o Cell phone
- Examples of analog devices:
 - o Standard radio
 - o Record players
 - o Dimmer lights
 - o Multi-speed food mixer
 - o Multi-speed fans
 - o Multi-speed cordless drill

Binary	Decimal
11011	27
101010	42
00011	3
11001101	205

Binary	Decimal
10000110	134
10111011	187
1011	11
1110101	117



- Binary addition:

1.

Binary	Decimal
111	7
+111	+ 7
1110	14

2.

Binary	Decimal
10011	19
+11010	+ 26
101101	45

3.

Binary	Decimal
101010	42
+101111	+ 47
1011001	89

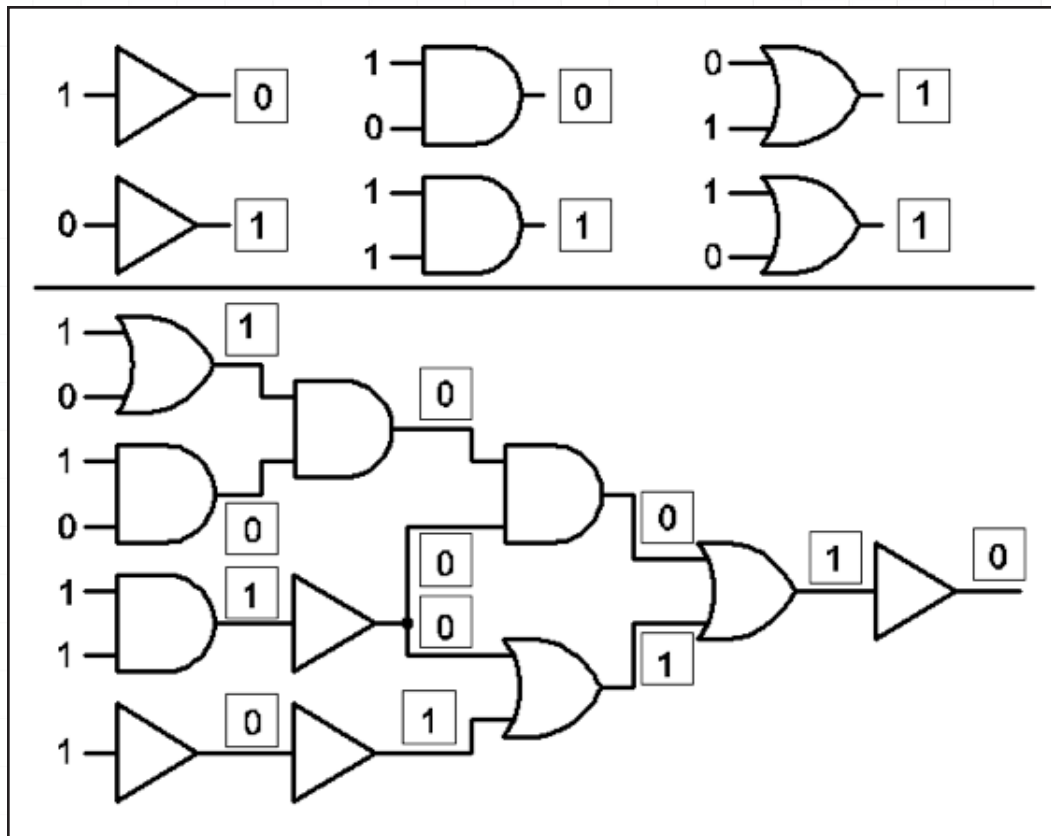
4.

Binary	Decimal
11111111	255
+11100011	+ 227
11110010	482

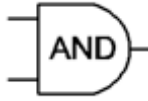
- The file size of the sample open-close file was 2.73 KB. This is about 2,800 bytes of data.
- A 2GB flash drive can hold approximately 2 billion bytes of data. This size drive could hold about 714,285 programs of this size.

Student Response Sheet 2


- After developing a combination lock program, the students may find that creating the actual combination procedure to be difficult. It is easy to lose track of all the branches and where they should connect. Timer issues with button presses could be an issue for some if they did not program for press delays.
- Compare student programs to the one supplied in the lesson. Paths should be as organized as possible and can be controlled to some degree by the placement of the command blocks.
- Logic gate examples:



- Logic Statements:

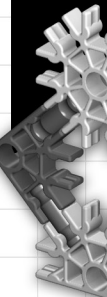
Statement	Inputs	Gate Type	Output
When developing a computer game, a character needs to be able to fall when he walks off an edge, but he should only be able to fall when gravity is present in the game.	Walk off edge		Fall
	Gravity		

Statement	Inputs	Gate Type	Output
Develop a game for both right-handed and left-handed people. The running command can be the "up arrow" or the "W" key.	Up arrow		Run
	W key		

Statement	Inputs	Gate Type	Output
If it is raining, the baseball game cannot be played today.	Rainy day		Play a baseball game

Challenge Design Brief

- Since the design brief challenges are very open ended, there are no specific answers as results will vary. Most of the challenges relate to changing the combination lock program. By modifying the program provided in the lesson note, the challenges can be easily handled.



LESSON #9: A HOCKEY GAME AT THE HOCKEY GAME

Research and Design Log Vocabulary:

Translational Motion – Refers to linear motion or motion along a straight line, such as an axis.

Oscillation – To move or swing side-to-side rhythmically.

Reciprocal Motion – A repetitive up-and-down or back-and-forth motion.

Connecting Rod – A rod that transmits motion or power from one moving part to another.

Game Design Document – A written description of a software product that a software designer writes in order to give the software development team guidance as to the architecture of the software project.

Genre – A category of artistic composition, as in music or literature, characterized by similarities in form, style, or subject matter. In game design, it is the category of the game type.

Game Design Brief – The part of a game design document where the name for your game and a short description is given to catch the player's attention.

Game Objects – The part of a game design document where all objects and actors used in the game are listed along with their descriptions.

Game Controls – The part of a game design document where all controls used in the game are listed along with their functions.

Game Flow – The part of a game design document where a description of the game play is given.

Game Levels – The part of a game design document where the levels and difficulty of each level are listed.

Student Response Sheet 1

After the students construct the hockey goalie, they will need to answer a few questions about the mechanical features of the goalie. *Answers may vary slightly due to student measurements.*

- Gear ratio of the system: **14T: 34T = 2.43:1 ratio**
- This system **steps down or gears down** the gearing which provide a decrease in speed and an increase in force.
- The Output Force of the gear system would be **10 N x 2.43 = 24.3 N**
- If the motor rotates 60 times per minute and the gearing ratio is 2.43:1, stepped down or geared down, the speed of the goalie will be less. **60/2.43 = 24.69 revolutions per minute**. However, this answer does not take the crank part of the system into consideration. This is detailed later in the lesson.
- The Output Force of the crank system would be:

$$F_o = (24.3 \text{ N} \times .003 \text{ m}) / .05 \text{ m}$$

$$F_o = 0.073 \text{ Nm} / .05 \text{ m}$$

$$F_o = 1.46 \text{ N}$$

- The Mechanical Advantage of the entire system can be calculated:

MA using input/output forces:

$$\text{Total MA} = 1.46 \text{ N} / 10 \text{ N}$$

$$\text{Total MA} = \underline{0.146}$$

Total MA using individual MAs (calculate crank MA first):

$$\text{Crank MA} = 1.47 \text{ N} / 24.3 \text{ N}$$

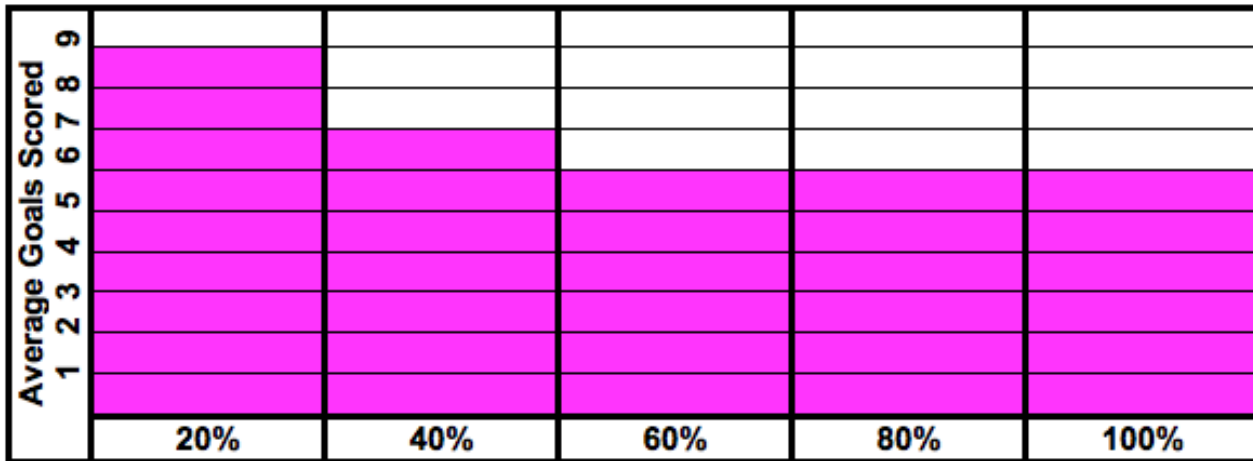
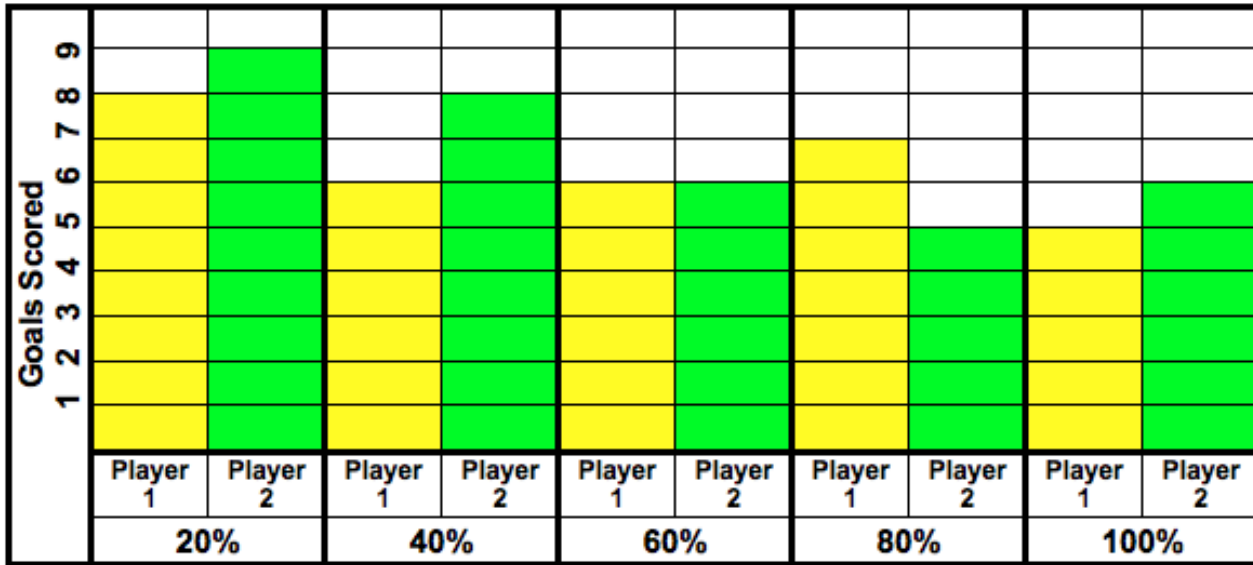
$$\text{Crank MA} = 0.06$$

$$\text{Total MA} = 2.43 \times 0.06$$

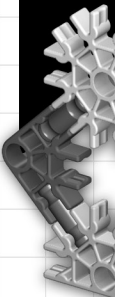
$$\text{Total MA} = \underline{0.146}$$

- While the gears reduce speed, the very small diameter crank axle to the larger crank arm flips the entire advantage. Since *Work = Force x Distance* and *Work In = Work Out*, distance would need to see an increase in order to balance this equation.

- While bar graphed results will depend greatly on student shooting skill, data could look something like these results:



- The goalie will oscillate twice the length of the output, or crank, arm. Since the crank arm is 5 cm, the goalie will oscillate 10 cm. This can be measured with a metric scale to confirm results.
- By looking at the mechanical advantage of the system, we have an MA of 0.146, which provides a fraction of the input force, increasing distance.
- While examining the shooting data, it appears easier to score at slow speeds. This can be affected by player ability levels and distance from the goal. It would make the game more challenging if the speed started slow (i.e. 20%) and increased for each level. If designing a 3-level game, speeds of 20%, 60% and 100% could be logical. Increasing the shot distance from 50 cm would make the game more challenging as well.



Student Response Sheet 2

- The students may be creative with the design document for their game. Here is a possible document:

Game Name: Hockey Shoot Out!

Game Genre: Arcade

Design Brief:

This is a high action game where it is you against the goalie. While the goalie attempts to protect the goal, you will be trying to get the puck past him. The game will continue until you score 3 goals.

Game Objects:

The only game objects are the goalie and goal with the goalie moving at a constant speed; the player's hockey stick and the hockey pucks.

Game Sounds:

The only sounds used in the game are made by the buzzer. There is a sound when a score is made and a sound at the end of the game.

Game Controls:

The game is started with a push button switch that is also pressed after each goal is scored. There is also a hockey stick that the player uses to shoot the puck.

Game Flow:

The game begins when the push button switch is pressed. The goalie begins to move across the goal. The game continues until a goal is scored. At that time, the goalie stops and the buzzer and LED flash to signal a score. The game continues after the push button switch is pressed again to begin the process again. After 3 goals, the game stops and the LED and buzzer signal the end of the game.

Game Levels:

There is just one level to this game.

- After programming the game and testing it, the students are asked if the system can be improved. They may provide responses related to changing the shot distance, modifying the goalie to improve shooting and scoring, or programming changes like speed changes, more sounds and higher scores.
- Programming flow can always be improved and commands can be simplified. The students should be able to demonstrate program improvements.
- Systems within the hockey game can include:
 - Electrical system
 - Computer control system
 - Sound system
 - LED lighting system
 - Goalie control system
 - Scoring (reed switches and magnets) system
- Variable within the system:
 - Dependent Variables:**
Goal scored at reed switch, variable addition in program when a goal is scored, LEDs and buzzer at score
 - Independent Variables:**
Motor speed, player shooting puck (speed, angle), distance to goal, time duration of LEDs and buzzer
 - Constants:**
Interface, power cord and test surface, opening size on goalie where shot can enter
- If the students worked with variables within the program, the variable $x=3$ can be changed to $x=6$ to change the limit score.

Challenge Design Brief

- Since the design brief challenges are very open ended, there are no specific answers as results will vary. A possible solution to the Ultimate Design Challenge can be seen here.

This program is designed to end after 4 goals are scored. There is an introductory LED/buzzer procedure that is also used to signal the end of the game set to repeat 3 times. Like the program designed for the Response Sheet 2, scoring is a separate procedure that uses the LEDs and buzzer. The push button begins the game and restarts it after each score. All 4 goalie levels operate the same except for increasing motor speed. The goalie starts at 40% and increases 20% for each goal scored. The sample program is shown here.

