

GLOSSARY

Analog control: A control device that uses a continuously variable quantity to select the desired outcome; for example, a volume control on a radio, or a dimmer control for a light.

Atom: The smallest unit of matter that preserves the chemical characteristics of a material. Atoms are electrically neutral, because the positively-charged protons in the nucleus are surrounded by the same number of negatively-charged electrons.

Automatic control system: A control system that supplies its own control input by sampling its own output; for example, a thermostat-controlled home heating system.

Charge: A discrete quantity of electricity.

Circuit: The complete path of an electric current including the source of electric energy.

Closed loop system: Another term for “automatic control system.” The closed loop is the path from the output back to the input, and is also known as the “feedback loop.”

Closed system: A system that conserves its own material and does not depend on inputs from the outside. For example, a steam heating system recirculates the same water over and over again.

Compound lever: A device in which one lever acts on another.

Compression spring: A spring whose ends try to push apart when they are compressed.

Conductor: A material that permits an electric current to flow easily.

Control: A device that uses a negligible amount of energy to affect a much larger energy flow.

Control system: A system that uses a control input to manage an energy flow.

Current: A flow of electrical charge.

Digital control: A control device that uses a preset number of possible states to select the desired outcome; for example, an ON/OFF switch, or the buttons for selecting the stations on a car radio.

Effort: The point on a lever where force is applied in order to exert a force at another point; also, the amount of force applied to the effort point.

Effort arm: The distance on a lever from the effort to the fulcrum.

Electron: A sub-atomic particle that carries most of the current in electrical circuits.

Feedback loop: A connection from the output to the input of an automatic control system, which provides control information based on the current status of the system.

First-class lever: A lever arranged with the fulcrum between the effort and the load.

Fixed pivot: A pivot that attaches a link to the base of a mechanism.

Floating pivot: A pivot that attaches two links to each other, but does not fix them to the base of the mechanism.

Flow: Movement of a fluid or electric charge from one point to another

Fulcrum: The support or pivot around which a lever turns.

Gear: A toothed wheel designed to turn another gear with similar teeth.

Inclined plane: A ramp used to lessen the amount of force needed by increasing the distance over which a load must travel.

Input: A point where energy, material, or information is introduced into a system.

Insulator: Material that is a poor conductor of electricity or heat.

Ion: An atom that has lost or gained one or more electrons, giving it a net positive or negative charge.

Joint: A connection between two links or between a link and the base. Major joint types are the pivot, slider, and roll-slide joint.

Law of the Lever: In a lever, the force ratio of load to effort is equal to the ratio of load arm to effort arm. This ratio is called the “mechanical advantage.”

Lever: A rigid bar, turning on a fulcrum, used to exert a force at one point along its length, called the “load,” by the application of force at a second point, known as the “effort.”

Linear motion: Motion along a straight line.

Link: A rod or bar that transmits force and motion to or from other links through joints.

Linkage: A system of links connected by joints.

Load: The output force that results from applying a force at the effort point on a lever; also, the point on the lever where the load force acts.

Load arm: The distance on a lever from the load to the fulcrum.

Manual control system: A control system in which a human user operates the control input; also known as an “open loop system.”

Mechanical advantage: The ratio of load to effort force of a lever; also the ratio of effort arm to load arm.

The fact that these two are equal is the Law of the Lever.

Mechanism: A device with moving parts that converts force and motion at one point to a different combination of force and motion at another point. A linkage is an example of a mechanism.

Neutral: Having an equal number of positive and negative charges.

Open loop system: A manual control system; so called because there is no feedback loop connecting the output to the input.

Open system: A system that does not conserve material, and therefore requires new inputs from the outside.

Oscillating motion: Back-and-forth motion along a circular path; for example, the motion of an agitator in a washing machine.

Output: The motion that results when energy is put into a system.

Parallel connection: A side-by-side arrangement of switches or other devices in an electric circuit so that the current can travel along either or both of two or more paths.

Pivot: A shaft or pin on which something turns; often used interchangeably with “fulcrum.”

Pulley: A device that transmits force and motion by means of a rope, string, or cable wrapped around a grooved wheel.

Reciprocating motion: Back-and-forth motion in a straight line.

Return spring: A spring whose purpose is to return a mechanism to its original position when the input is released.

Roll-slide joint: A joint that combines a slider and a pivot, allowing both translation and rotation.

Rotary motion: Motion that follows a circular path.

Rotation: Clockwise or counterclockwise rotary motion.

Schematic diagram: A map showing the components and connections of an electric circuit.

Screw: A simple machine that consists of an inclined plane wrapped around a cylinder or cone.

Second-class lever: A lever arranged so that the load is between the fulcrum and the effort.

Sensor: A monitoring device that provides information about the output to the control input of an automatic control system.

Series connection: A sequential arrangement of switches or other devices in an electric circuit so that all current flowing through one must also flow through the others.

Simple machine: One of several elementary machines once considered to be the elements of which all machines are composed: the lever, the wheel-and-axle, the pulley, the inclined plane, the wedge, and the screw.

Slider: A joint that allows one link to move in a straight line with respect to another link or the base.

Subsystem: A system that is part of a larger system.

Switch: A device for making or breaking a connection in an electrical circuit.

System: A collection of interconnected parts functioning together in a way that makes the whole greater than the sum of its parts.

Technology: The artifacts, systems, and environments designed by people to improve their lives.

Tension spring: A spring whose ends try to pull back together when they are extended.

Terminal: The part of an electrical device that is used to make connections in an electrical circuit.

Third-class lever: A lever arranged so that the effort is between the fulcrum and the load.

Tool: A device that aids in accomplishing a task.

Translation: Linear motion in one direction.

Two-dimensional linkage: A linkage in which all links have to move within the same plane surface.

Wedge: A triangular device with an inclined plane on either side.

Wheel-and-axle: A large diameter cylinder turned by or turning a long circular rod.

RÉFÉRENCES

Chapter 2

Ardley, Neil. (1992) *The Science Book of Machines*. New York: Harcourt Brace Jovanovich.

This book teaches elementary-age children to make a variety of mechanisms from everyday materials. Included are a gear-driven fan and a toy that changes a rotary-crank-driven input into a “jumping jack” reciprocating output.

Bailey, Omry, et al. (1981) *Modular Courses in Technology: Mechanisms*. Edinburgh, UK: Oliver & Boyd.

Written at Junior High School level, this book teaches basic concepts of mechanisms with diagrams and photographs, mainly of Fischertechnik components. Most of the focus is on gear, pulley and cam mechanisms. Linkages are handled only briefly at the end.

Bolt, Brian. (1991) *Mathematics Meets Technology*. New York: Cambridge University Press.

Aimed at high school teachers of math and technology, this book is designed to show how mechanisms can provide a basis for exploring elementary algebra and geometry. It is also the only reference we have found which discusses the adjustable triangle and four-bar linkages at an elementary level, and contains a wealth of ideas for exploring and designing these mechanisms.

Bridgman, George B. (1966) *The Human Machine: the Anatomical Structure and Mechanism of the Human Body*. New York: Barnes & Noble.

Intended for artists, this book uses mechanical analogies to explain the joints and links that account for movement in our bodies. The drawings are very detailed and insightful.

Bureau of Naval Personnel. (1971) *Basic Machines and How They Work*. New York: Dover Publications.

Intended as a training manual for sailors, this book provides a fundamental background in mechanisms. As one would expect, many of the examples come from shipboard equipment, such as hoists, winches and watertight hatches. However, there is also an excellent and very well illustrated explanation of the manual typewriter in Chapter 12.

Bureau of Naval Personnel. (1973) *Tools and Their Uses*. New York: Dover Publications.

This is a very readable, brief introduction to all of the common hand and power tools. Many of these tools are themselves mechanisms, such as adjustable wrenches, clamps and vise-grip pliers.

Catlin, Dave. (undated) *The Inventa Book of Mechanisms*. London: Valiant Technology, Ltd.

Aimed at upper elementary and junior high school students, this is mostly a cartoon book that describes the simple machines in a very entertaining fashion. For example, gear ratios are discussed by talking gears who are engaged in an argument over whether large or small gears are better.

De Bono, Edward. (1972) *Children Solve Problems*. London, UK: Penguin Books.

De Bono, Edward. (1970) *The Dog Exercising Machine*. London, UK: Jonathan Cape, Ltd.

De Bono is a well-known writer of books on techniques for improving one's thinking skills. These two books look at thought processes from a somewhat different perspective. They document several fascinating studies in which children were asked to produce concept designs for solving some everyday problems. Some of these lent themselves to mechanical solutions: Figure out a way to stop a dog and cat from fighting. Invent a bicycle for postmen.

Driver, R., Squires, A., Rushworth, P. & Wood-Robinson, V. (1994) *Making Sense of Secondary Science: Research Into Children's Ideas*. London: Routledge.

This book is an authoritative compendium of current research on the conceptions actually held by children about physical and biological phenomena. There are chapters on electricity, forces and motion.

Dunn, Andrew. (1993) *Lifting by Levers*. New York: Thomson Learning.

Suitable for third and fourth grades, this book shows how to find levers in a variety of tools, utensils, toys, sports equipment and other common objects. It is well written and well illustrated.

Dunn, Andrew. (1992) *Wheels at Work*. New York: Thomson Learning.

A children's book, aimed at the middle elementary grades, which reveals how wheels and axles can be found in the most unlikely places, and makes the analogy between wheels and levers.

Dunn, Susan & Larson, Robb. (1990) *Design Technology: Children's Engineering*. Philadelphia: The Falmer Press.

Using many examples from both the UK and the US, this book develops a pedagogical basis for design technology in the elementary grades. The beautiful illustrations include photographs of children at work, as well as pictures and sketches of their designs.

Erdman, Arthur & Sandor, George. (1997) *Mechanism Design, Vol. 1: Analysis and Synthesis* (Third Edition). Upper Saddle River, NJ: Prentice Hall.

Though written in technical language, the first two chapters illustrate the subject of mechanisms with an extraordinary wealth of drawings, photos and diagrams of real mechanisms. A CD is included which contains animated displays and background information describing many of these mechanisms.

Eyewitness Visual Dictionaries. (1991) *The Visual Dictionary of Everyday Things*. New York: Doring Kindersley.

This entire book consists of photographs of disassembled objects, with every piece labeled. No explanations are given of how these pieces fit together, let alone how they work, but children who like to take things apart could use this book as a reference. The umbrella, the lamp and the bicycle are among the most interesting.

Graf, Rudolf F. & Whalen, George J. (1982) *How It Works Illustrated: Everyday Devices and Mechanisms*. London: Souvenir Press.

This Popular Science book provides two pages each to explain nearly one hundred common mechanisms, including some not found in other books. The explanations are generally clear and well illustrated. Some of the best are the rotary telephone dial, the tire pressure gauge, the vise-grip pliers, the electric can opener, the traffic light, the bathroom scale, the staple gun and the Medeco lock.

Guilbaud, G.T. (1960) *What Is Cybernetics?* New York: Grove Press.

One of the few non-technical introductions to the field of cybernetics, which is the study of automatic control systems.

Hassenstein, B. (1971) *Information and Control in the Living Organism*. London: Chapman and Hall.

A brief, largely non-technical book with many examples of feedback in nature, particularly in the human body.

Hiner, Mark. (1985) *Paper Engineering for Pop-up Books and Cards*. Sheffield, UK: Tarquin Publications.

This book has cutout pages and detailed directions for making ten mechanisms out of paper, including pull-tab linkages and pop-up parallelograms. The most valuable aspect of the book is the page of "Technical considerations" accompanying each mechanism. These pages discuss the principles involved in each case, and offer suggestions for fine-tuning the design.

Jackson, Paul. (1996) *The Pop-Up Book*. New York: Henry Holt & Co.

This lavishly illustrated book provides detailed instructions for making more than 100 different kinds of pop-up mechanisms, ranging from the simple to the elaborately complex. It includes many ideas for experimentation, as well as photos of professional finished products.

Johnson, Paul. (1994) *Pop-Up Paper Engineering: Cross-Curricular Activities in Design Technology, English and Art*. Philadelphia: The Falmer Press.

This is a detailed manual, intended for teachers, which incorporates a how-to guide for making pop-ups, brief explanations of the principles involved and suggestions for integration with art and language.

Kelly, John, et al. (1994) *The Robot Zoo: A Mechanical Guide to the Way Animals Work*. Atlanta: Turner Publishing, Inc.

This lavishly illustrated book shows how animals operate by replacing the animals' body parts with machine components. The resulting drawings have a robot-like, sci-fi appearance. For examples, the grasshopper's legs have springs in them. The glossary gives a brief discussion of basic animal physiology.

Kempton, W. (1987) "Two Theories of Home Heat Control." In Holland, D. & Quinn, N. (eds.). *Cultural Models in Language and Thought*. Cambridge: Cambridge University Press, Pp. 222-242

A fascinating account of how adults think a thermostat works.

Lehrer, Richard & Schauble, Leona. (1998) "Reasoning about Structure and Function: Children's Conceptions of Gears," in *Journal of Research in Science Teaching*, 35:1, January 1998, Pp. 3-25.

This is one of the few contemporary studies of children's cognitive development in analysis of mechanisms. The authors studied how second- and fifth-graders explain the operation of an egg beater, a ten-speed bike and various configurations of meshed gears on a gear board. The paper demonstrates clearly how children's conceptions evolve; for example, many children believed that the speed depends on the number of gears!

Macaulay, David. (1998) *The New Way Things Work*. Boston: Houghton Mifflin Co.

This newly revised classic is indispensable for beginning a study of mechanisms, and inspired much of the work described here. It has beautiful drawings showing the operation of hundreds of everyday devices in exquisite detail, including the two-arm corkscrew, the automotive window winding mechanism, the sewing machine, the bicycle brake, the toilet tank, the basic circuit, the battery and many, many, more. The book is written at a non-technical adult level, but the drawings are useful for all levels.

Marzio, Peter. (1973) *Rube Goldberg: His Life and Work*. New York: Harper & Row.

This comprehensive biography of Rube Goldberg includes many insights into the messages inherent in his fantastic creations, and also contains many of his original drawings.

McDermott, Lillian C. & Schaffer, Peter S. (1992) "Research as a Guide for Curriculum Development: An example from introductory electricity," in *American Journal of Physics*, 60:11, Pp. 994-1013.

The first part of this article presents research on how college students understand electricity, after being taught the scientific view in a college physics course. Their conceptions are remarkably unaffected by traditional classroom instruction! In the second part, the authors present instructional methods that could challenge the students' prior conceptions directly.

Myska, David. (1999) *Machines and Mechanisms: Applied Kinematic Analysis*. Upper Saddle River, NJ: Prentice Hall.

This book is written for two-year college students of engineering technology. Like Norton (1999), much of the book is difficult mathematically, but the first chapter provides a clear introduction to the subject, and there are many drawings showing examples of mechanisms, particularly in the problems at the ends of the chapters.

Norton, Robert L. (1999) *Design of Machinery: An Introduction to the Synthesis and Analysis of Mechanisms and Machines* (Second Edition). New York: McGraw-Hill.

This is a college-level textbook in mechanism design for engineering students. Although most of the book is mathematically demanding, the first two chapters provide a clear introduction to basic concepts, with many examples from everyday life.

Odum, Eugene P. (1975) *Ecology: The Link Between the Natural and the Social Sciences*.

New York: Holt, Rinehart and Winston.

A brief, introductory college-level book on ecology, which makes extensive use of feedback concepts.

Penner, David, et al. (1997) "Building Functional Models: Designing an Elbow," in *Journal of Research in Science Teaching*, 34:2, February 1997, Pp. 125-143.

This is a report of a study of first- and second-graders modeling a familiar mechanism, the human elbow. It includes two cycles of redesign, as the children improved their models to make them function more like a real elbow. In addition to the excellent examples of design and re-design, the paper shows how children understand the concept of a model.

Petroski, Henry. (1994) *The Evolution of Useful Things*. New York: Random House.

Petroski's primary argument is that designs evolve based on the shortcomings and outright failures of their predecessors. He makes this point through an exhaustive account of how such devices as the hammer, the can opener and the paper clip attained their present form. This book provides a useful historical background for discussing a variety of everyday technologies.

Piaget, Jean. (1978) *Success and Understanding*. Cambridge, MA: Harvard University Press.

In great detail, Piaget explores the development of children's understanding of some basic artifacts, including levers, seesaws, toy cars and bridges. As in so much of Piaget's work, the step-by-step approach reveals not only how children's ideas take form, but also provides invaluable insights into what the concepts are and how they are connected.

Piaget, Jean. (1972) *The Child's Conception of Physical Causality*. Totowa, NJ: Littlefield, Adams & Co.

This is one of Piaget's classic works, which explores in depth how children at various levels understand the causes of common phenomena. Chapter 9, "The Mechanism of Bicycles," uncovers children's understanding of the motion of the pedals and of the rear wheels, and gives examples of fantastic alternative conceptions. The concluding chapter is a very valuable summary of how children's beliefs about causality evolve.

Reader's Digest. (1983) *Complete Do-It-Yourself Manual*. Pleasantville, NY: Reader's Digest Associates.

This comprehensive manual of home repair contains a wealth of information on mechanisms and circuits, including hand and power tools, drapery hardware, garage door openers, toilets, faucets, locks, lighting fixtures and window hardware. The illustrations are excellent.

Scrine, Rick & Clewes, Eric. (1989) *First Technology*. London: Hodder and Stoughton.

Intended for Junior High School level, this book has a long section called "Control Systems" which deals mostly with mechanisms. It offers a clearly written introduction to machines, and a few design problems, using mostly Lego and Meccano technologies.

Shooter, Ken & Saxton, John. (1997) *Making Things Work: An Introduction to Design Technology*. New York: Cambridge University Press.

Intended for use at Junior High School level, this entertaining book deals with electronics and structures as well as mechanisms. Many open-ended design and inquiry activities are suggested.

Staffordshire Design and Technology Education Programme. (1992) *S.T.E.P. Design and Technology 5-16, Key Stage 2 Datafile*. New York, Cambridge University Press.

This package contains 126 photocopyable cards dealing with the operation and design of a wide range of technologies.

Many of the cards offer useful suggestions about how to make and test mechanisms inexpensively. See, for example, “Card and paper,” “Gears,” “Linkages,” “Movement” and “Pulleys.”

Tasker, Ross & Osborne, Roger. (1985) “Science Teaching and Science Learning,” in *Learning in Science: The Implications of Children’s Science*. Auckland, NZ: Heinemann, Pp. 15-27.

This is a thoughtful account of how children understand electric circuits. It presents the “Single-wire”, “Clash of Currents” and “used-up current” theories in their clearest forms. It also shows how traditional instruction ignores these theories.

Van Cleave, Janice. (1993) *Machines: Mind-Boggling Experiments You Can Turn into Science Fair Projects*. New York: John Wiley & Sons.

This book describes twenty mechanism investigations, all of them made with free or very inexpensive materials. Included are directions for making gears from clay and toothpicks, a windlass from a broom, and a linkage that reduces or enlarges the scale of drawings. It is written at upper elementary grade level.

Walton, Harry. (1968) *The How and Why of Mechanical Movements*. New York: Popular Science Publishing Company.

Written in an entertaining, accessible style, this book offers clear explanations of the lever, wheel, inclined plane, screw, pulley and gear. The examples are well illustrated, and range from simple technologies like the hammer and water wheel to automatic transmissions, jet engines and aircraft guidance systems.

Williams, Pat & Jinks, David. (1991) *Design and Technology 5-12*. Philadelphia: The Falmer Press.

Based on many experiences in the UK, this book makes a convincing argument for teaching design technology in the elementary grades. It also provides an outline of basic principles, both of content and pedagogy, and numerous case studies of curriculum units. “Levers and Ducks” describes a unit in which six-year-olds designed and made toy paper ducks with flapping wings controlled by linkages much like those described in this chapter.

Zubrowski, Bernie. (1993) *Mobiles: Building and Experimenting with Balancing Toys*. New York: Beech Tree Books.

In his usual entertaining style, Zubrowski outlines a wealth of activities designed to help children explore what makes things balance. By the end of the book, the mobiles are unsymmetrical and quite complex.

Zubrowski, Bernie. (1986) *Wheels at Work: Building and Experimenting with Models of Machines*. New York: Beech Tree Books.

In this book, Zubrowski provides detailed instructions for making a block and tackle from clothesline pulleys; gears, waterwheels and windmills using cans, plastic cups and plates, and other cheap materials; and other related contraptions. Each set of activities includes a “What’s happening” section, which discusses physics concepts and “Experiments to try” which proposes areas for investigation. The material is most suitable for upper elementary grades and middle school, and is very well thought out.

Chapter 6

- American Association for the Advancement of Science. (1989) *Science for All Americans: A Project 2061 Report on Literacy Goals in Science, Mathematics and Technology*. Washington, DC: Author.
- American Association for the Advancement of Science. (1993) *Benchmarks for Science Literacy*. New York: Oxford University Press.
- American Association for the Advancement of Science. (1997) *Resources for Science Literacy*. New York: Oxford University Press.
- American Association for the Advancement of Science. (1998) *Blueprints for Reform*. New York: Oxford University Press.
- American Association for the Advancement of Science. (2001) *Designs for Science Literacy*. New York: Oxford University Press.
- International Technology Education Association. (1996) *Technology for All Americans: A Rationale and Structure or the Study of Technology*. Reston, VA: Author.
- International Technology Education Association. (2000) *Standards for Technological Literacy: Content for the Study of Technology*. Reston, VA: Author.
- National Center on Education and the Economy. (1997) *New Standards Performance Standards; Vol 1: Elementary School*. Washington, DC: Author
- National Council for the Social Studies. (1994) *Expectations of Excellence: Curriculum Standards for Social Studies*. Washington, DC: Author.
- National Council for the Social Studies. (1997) *National Standards for Social Studies Teachers*.
<http://www.socialstudies.org/standards/teachers/standards.html>
- National Council of Teachers of English & International Reading Association. (1996) *Standards for the English Language Arts*. Urbana, IL: Author.
- National Council of Teachers of Mathematics. (1989) *Curriculum and Evaluation Standards for School Mathematics*. Reston, VA: Author.
- National Council of Teachers of Mathematics. (2000) *Principles and Standards for School Mathematics*. Reston, VA: Author.
- National Research Council. (1996) *National Science Education Standards*. Washington, DC: National Academy Press.