AC 2011-2536: ADAPTATIONS OF CONCEPT MAPPING FOR TECHNOLOGICAL LITERACY COURSES

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Adaptations of Concept Mapping for Technological Literacy Courses

Abstract

Assessment of student learning is a challenging issue in courses on engineering and technology for non-engineers. Equally challenging is finding effective methods to communicate central features of technological systems to a diverse student audience with limited background knowledge. Methods of assessment are needed that extend beyond questions that can be answered by memorization but do not require extensive prerequisite mathematical knowledge. Communication or explanation of how technical systems work requires a method that can represent a diverse range of technological products but that non-engineers can learn to use in a limited amount of time. The technique of concept mapping has been adapted to this purpose. Concept mapping provides a visual method of demonstrating the relationships that exist between the component parts of a larger body of information. Such a feature is well-suited for explaining technical systems. In one application concept mapping is combined with aspects of the engineering design technique of functional analysis or functional decomposition to create a method that non-engineers can use to describe or explain how a technical system works. Another application is reported that illustrates how concept maps can be used to help non-engineering students transfer understanding of underlying principles from one technical system to another.

Introduction

A challenge in technological literacy courses for non-engineering students arises in assessingwhat the non-science, technology, engineering, and mathematics (STEM) students have learned about the science or engineering topics under consideration. The majority of the assessment and evaluation of student learning in most engineering courses is based on solving quantitative problems. While non-engineers should develop some facility for quantitative thinking, assessment that is heavily biased toward calculations and quantitative problems is not reasonable in technological literacy courses. Exclusively quantitative assessments will not only reinforce inaccurate negative stereotypes about what engineering entails, but also fail to access potentially higher levels of understanding that may be taking place with the non-engineers but which they are unable to communicate mathematically. There is a need for some method of assessment that does not require students to perform detailed calculations but extends beyond simple memorization of facts.

Some technological literacy courses engage non-engineers in the engineering design process and are able to use design products to assess learning gains[1-4]. Design requires synthesis and is characteristic of higher levels of cognitive engagement. It is possible to carry out some types of engineering design activities that do not require extensive technical background knowledge. In addition a variety of hands-on design construction activities can be done with limited resources using simple, low cost materials.

Using design projects as a non-quantitative means of assessment is effective only for a limited number of technological literacy outcomes. These activities using simple materials are effective at developing an understanding by non-engineers of the design process; however the technical sophistication possible in these projects is severely constrained. Conducting any type of design activity introduces other limits due to the time needed to complete this type of activity, the facilities and equipment available, and the manual skills of the students.

Some courses addressing technological topics for non-engineers have been able to utilize sketching and drawing as a means of assessment of student understanding[5]. Visual forms of communication such as drawing or sketching offer the benefits of potentially conveying information that non-engineers may otherwise have trouble articulating due to limited facility with technical vocabulary. However the quality of student-generated drawings can vary considerably from one student to another. Faculty may be challenged to discern the difference between a student who understands the principle in question, and a student who has strong drawing skills. In addition, students may not appreciate the distinction between accurately representing how a technical system looks and an understanding of the principles underlying system operation.

In technological literacy courses there is a need for assessment methods that can extend beyond rote memorization-type questions. While developing quantitative proficiency is important, given the limited time available, the assessment method cannot be as reliant on mathematics as that used in most engineering science courses for engineering majors. The assessment method must access higher level thinking, be fairly quick to administer and grade, involve techniques that students can learn in a short amount of time, and not require extensive prior preparation on the part of the faculty.

A key aspect of both technological literacy courses described here is use of a constructivist approach. A foundational assumption is that there is a core essential knowledge that characterizes technological literacy. To obtain this knowledge students must be exposed to the basic ideas in context of some hands-on activity or experiments. Personal experience with the applications is helpful in encouraging students to see the need to encode or represent information accurately. Mental representations, perceptions, and focus of attention are all highly relevant to the learning process and need to be recognized and assessed frequently. One way to address these challenges is to inform instruction by communicating effectively with students during the stages of cognition because the self-aware student will be more likely to think critically[6-8].

A mental representation is where learning begins and is shaped for any student. This representation is a form of an idea or image. Actively seeking, helping, and encouraging metal representations helps students to deepen their understanding of the basics and to relate understanding to observations. Developing mental representations and organizing them into related patterns comes with exposure or experience with new ideas, images, and experiences. A key goal of technological literacy courses is to create the right experience to help students develop and improve their mental representation of technical systems. Kellogg states that "Mental representations…provide the basis for all cognitive abilities." [9] It is difficult to expect students to understand our technological environment without mental representations upon which to build. This creates a challenging environment for many technological literacy students. When faced with unfamiliar concepts and technically challenging observations where no mental representation exists, students likely take more time to conceptualize and become aware of their knowledge gap. Through self-assessment and awareness of cognitive processes that occur in context students should be empowered to create, alter, and improve their expectations and commitment to a particular technological issue.

Concept mapping

Concept mapping has the potential to be used as an effective tool for both conveying engineering content to non-engineers and for assessment of non-engineers' grasp of technological principles. The original development of concept mapping owes considerable debt to the work of Novak and Gowin[10]. Since this initial introduction, the use of concept mapping as a learning tool and method of communication has spread widely. Concept maps are easy to construct by hand, however computer-based aids are available[11].

The potential of concept maps in engineering education has been explored by several groups. Concept maps have been applied to improve teaching and evaluation in biomedical engineering [12]; to connect existing memories to new concepts[13]; to represent knowledge across disciplinary boundaries in a first year mechatronics course [14]; to improve student's ability to apply knowledge across a range of situations[15]; and as a means of helping engineering students to perceive major ideas and improve knowledge transfer[16]. These examples are suggestive of how concepts maps can be applied to help students learn engineering.

The idea behind concept mapping is to convey the relationships that exist between a set of facts, data, or ideas. An emphasis in concept mapping is on the depiction or illustration of connections and associations. Concept maps are particularly helpful in situations in which relationships between ideas are not in a simple linear progression. Concept maps rely on the use of the natural tendency to associate position in space with organizational hierarchy. Figure 1 is an example of a simple concept map.

Concept maps are well-suited to describing technical systems. Concept maps are useful for creating organization in situations in which a large number of pieces of information initially appear at the same level of significance. These are situations where an underlying order is likely to exist but is not apparent on surface inspection. Concept maps place an emphasis on relationships between elements and how these elements or parts of a whole are interrelated. Concept maps help to aggregate information into related groups and convey underlying order. They are also useful in depicting the branching interactions that can exist between parts of a whole and the bidirectional or multidirectional correlations between constituent parts of a whole. All of these features of concept maps are ideally suited for describing technological systems and devices.

A concept map might be viewed as a visual analog to a written description. Development of a concept map requires selectivity and judgment. It can therefore be classified at the synthesis level of Bloom's taxonomy indicating a high degree of cognitive engagement. It is possible to determine if the learner has identified major themes and organized information appropriately

Concept maps are well-suited for assessment of student learning in the context of technological systems and devices. Concepts maps can be used for assessment of the extent to which key elements have been identified or extracted from a particular body of information. Concept maps can be used to determine if relationships between parts has been accurately grasped.

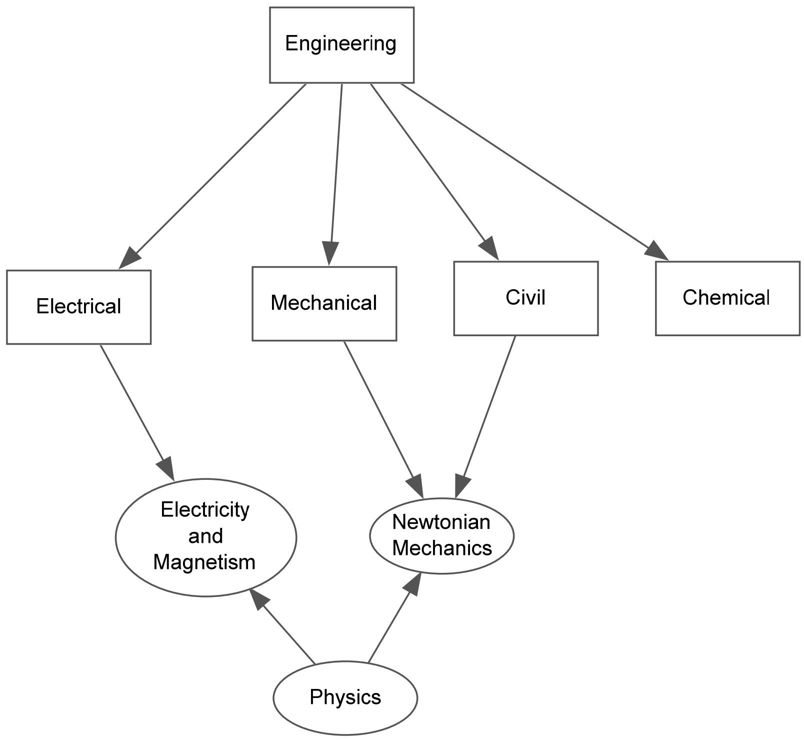

Figure 1: Example of a Simple Concept Map.

Science and Technology of Everyday Life at Hope College.

An effort has been made to introduce this method with non-engineering students at Hope College. The work involves a technological literacy course for non-engineering students entitled: Science and Technology of Everyday Life. The course is a survey of the major technologies familiar from daily life including the automobile, electrical appliances, and consumer electronics. An emphasis is placed on key principles underlying familiar technologies. The course is offered by the Engineering Department at Hope and satisfies part of the general education graduation requirement at the college[17-19].

The use of concept map methods has been introduced in this course in the form of a modification of functional analysis or functional decomposition used in engineering design[20-21]. The method combines aspects of concept mapping, functional analysis and sketching to describe technical systems and to assess the technical content knowledge of non-engineering students.

Brief Overview of Functional Analysis

Functional analysis is a method used in engineering design to develop an abstract or functional description of the way in which a component, system or process accomplishes an intended goal or purpose[22-24]. Any human-made technological artifact is considered as a technical system regardless of its degree of complexity. The technical system then transforms a specific set of inputs into outputs. The system may have different modes of operation which may be characterized by a different set of inputs and outputs. Figure 2 illustrates the basic functional analysis or “black-box” representation of a technical system.

Inputs and outputs are classified in three categories: energy, materials, or information. Energy and materials have the usual meaning from physical science. Information is described as signals, data, or energy with a decision-making purpose.

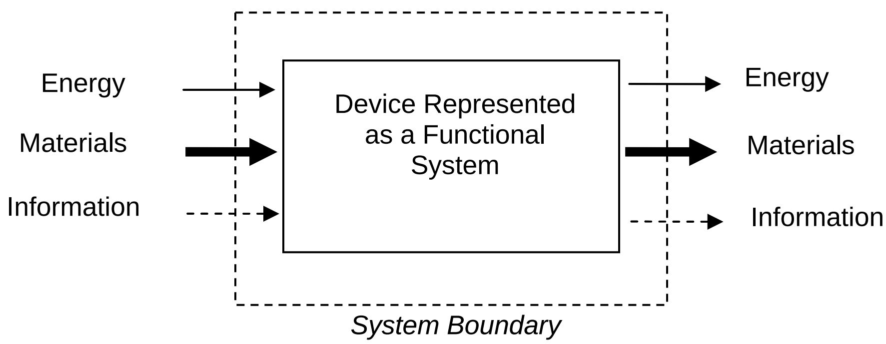

Figure 2: Basic Functional Analysis Representation of a Technical System

The overall function of the device, or technical system, is accomplished via subtasks or subfunctions. Some physical component or collection of components carries out each subfunction. Figure 3 illustrates a hypothetical subfunction structure. Subfunctions are responsible for transforming some subset of the inputs into a subset of the outputs. Intermediate inputs and outputs which are internal to the system may be produced.

The intent of the functional analysis representation is to describe the major or most significant components that contribute to the transformation of inputs to outputs. The analysis can be conducted to progressively finer levels of detail. The purpose is not to represent a detailed physically accurate representation of the components, or to include every electrical or mechanical interconnection within the system. The emphasis is on the major steps in the progression from system inputs to expected outputs.

An advantage of using the functional analysis approach with non-engineers is the ability to illustrate that engineered products utilize combinations of pre-existing components to provide specific portions or subfunctions in the overall operation of the device. The components provide well-defined functions which are also utilized in other devices to carry out similar functions.

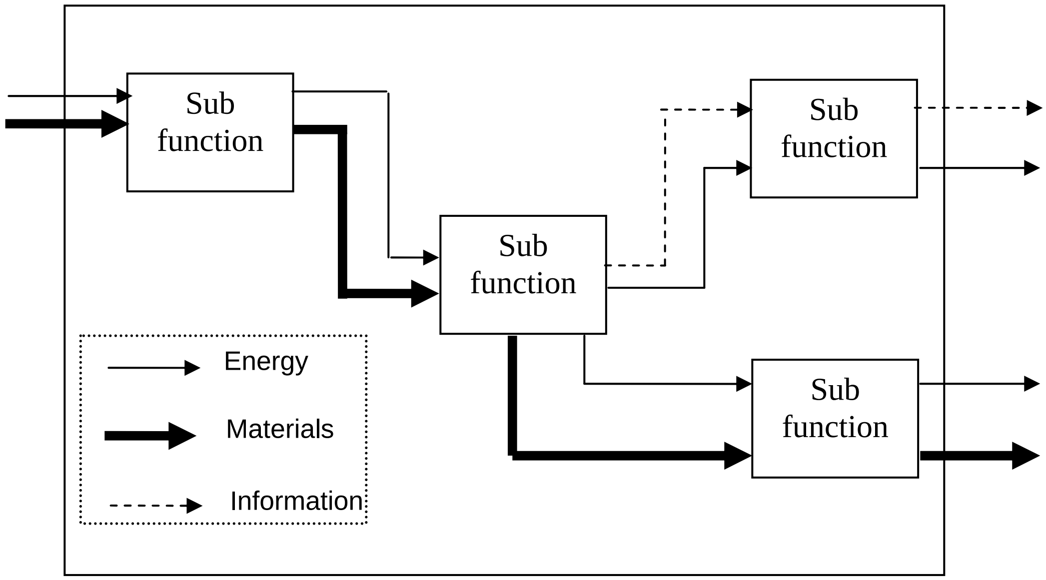

Figure 3: Illustration of a Hypothetical Device Subfunction Structure.

Component Function Mapping

A method for describing how technological systems work has been developed for use with non-engineers. The method, which is termed Component Function Mapping, combines aspects of concept maps, functional analysis and sketching. The overall framework provided by concept mapping is used to characterize the process of using a visual representation to convey relationships between elements of a larger whole. Ideas from functional analysis are used to view a technical device as a system of components that transfer and transform material, energy, and information in the process of accomplishing the overall function or purpose of that technology. Sketching is used to include some visual features that in some way evoke or provide an association with aspects of the idea being conveyed.

The method seeks to achieve balance in two areas. One is between flexibility and uniformity and the other is between describing the physical representation or form of the system and the abstract purpose or function. Concept maps have a high degree of flexibility and opportunity for individuality on the part of the creator of the map. This flexibility however, can make it difficult for other people to benefit from a concept map made by someone else. Inclusion of elements of functional analysis offers a degree of consistency or uniformity that can facilitate interpretation.

In creating visual material to describe a technical system, there is a strong tendency, especially on the part of non-engineers, to create an image or picture that describes the form of the system, in other words, how the system looks. Visual appearance alone however conveys only limited information about the functioning of the technology. An example of this situation is seen in considering Figure 4. This figure shows a drawing of the lubrication system of an internal combustion engine. This image is an accurate depiction of the physical appearance, or the form, of the lubrication system. However this rendering of the system contains a high level of detail that does little to help explain the essential aspects of how the lubrication system works.

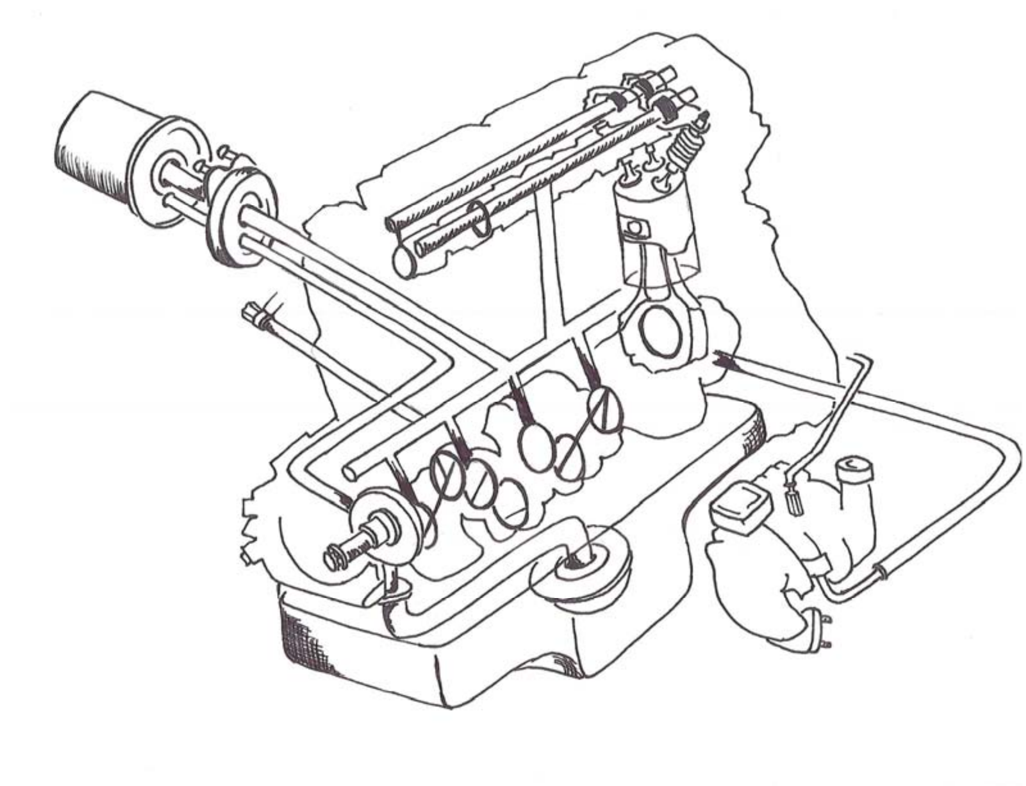

Figure 4: Depiction of the Lubrication System of an Internal Combustion Engine.

While a physically accurate drawing can provide excess confusing detail, at the same time, visual images or cues can provide helpful associations that facilitate interpretation of information. Often, function can be conveyed without an idea or suggestion of form, but knowledge of form provides valuable information for understanding completely the function of a system. Descriptions of technical systems can benefit if familiar forms are represented so as to bring to mind preexisting information or knowledge that the student may have.

The goal of describing technical systems must also contend with the natural tendency of most people to incorporate some type of form images when describing a physical object of any kind. Rather than prohibiting this impulse, it is preferable to embrace it in a constructive manner and channel the information into a representation in a way that is helpful in understanding the system.

A compromise between form and function representations allows students to merge the best aspects of form and function. Illustrations of form can be included but the description should not be entirely a drawing. It is suggested that drawings, if included can be simple. This is helpful not only to not discouraged the artistically challenged but also to leave room for innovative ideas by not prejudicing the form a particular function must take. This inclusion of form elements is not welcomed in strict application of functional analysis in product design. It that circumstance it is crucial to eliminate form so as to not bias the design process. However the application here is primarily to assist in understanding existing technological systems.

Component Function Map Guidelines

A set of guidelines has been created for non-engineering students to use in analyzing a technical system. It is stressed that functional analysis diagrams are more like an essay than a mathematics problem. There is more than one way to convey how the system works. Some details may be different in different people's diagrams just like two people may use different sentences to describe the same event. However the overall meaning should be the same. An essay uses words and phrases to create sentences and paragraphs that convey meaning or tell a story. The component function map uses the conventions of flow of materials, energy, and information to tell the story of how the system works. The function map explains how it works not how it looks.

Guidelines

Identify 5-12 most important components.
Balance sufficient detail against excessive clutter.
Some of the components provide a generic function common to a range of technical systems.
Some components should be unique to that device supplying characteristic functionality.
Determine inputs and outputs of material, energy, and information for each component.
How do they connect to the other components? Combine components into overall system.
Areas to check:

- Is the overall system input and output shown?
- Is energy conserved?
- Where does the energy come from, and where does it go to?
- Is material conserved?
- Where do inputs go once inside the system?
- Does each component have at least one input and output?

In developing guidelines consideration was given to determining what features would be essential to be standardized and what aspects could be left to the discretion of the individual creating the map. It is important that any student should be able to create or replicate this type of diagram. At the same time it should be possible that some standardization to facilitate interpretation should be included. It was determined that differentiation between flows on the basis of energy, materials, and information was important to standardize. It was also thought that the use of simple boxes to represent components prevents error when it comes to knowing specific entrances and exits of flows into and out of a component. With a box it can simply be indicated that a flow enters and exits the component, allowing the student to have some level of understanding of the component but not requiring precise knowledge of connections between components.

Some aspects of the diagram were viewed as able to vary or change. The size representation of the individual components was not seen as critical. These can be depicted to appropriate relative scale or not. The orientation of the components in the overall scheme of the system was also viewed as a feature that can be modified to improve the depiction of the overall system operation. Components can be put in correct respective position, but it is not essential. The diagram can situate components in positions other than right angles if it further facilitates understanding.

The use of form depictions is included as an option in diagram creation. There is no prohibition on conveying aspects of the physical appearance or form but this should not be the only or even the most important feature. Icon-like form representations can be included either inside of, or adjacent to, boxes that represent the system components. This raises the possibility of creating a generic catalog of common components that could be rearranged to redefine a system or think through changes the system might require.

Figures 5 and 6 are examples of different diagrams of the lubrication system seen in a typical internal combustion engine. Figure 5 is an example of how elements of the system form can be retained in a manner that does not compromise the ability to use functional analysis methods to describe how the system works. The diagram includes simplified drawings that evoke the form of the component. These are simple enough to not require well-developed drawing ability but at the same time they resemble the main visual features of each component. This diagram also has the components in approximately correct relative positions and sizes. The oil filter and dipstick are deliberately placed at an angle in the diagram much as they are in the engine that served as a model for this diagram.

Figure 6 is a functional diagram that is devoid of form elements. The components are however in approximately the same relative locations as they are in an engine.

Examples of Hope College Student Work

Figures 7 and 8 are examples of functional analysis work carried out by non-engineers. Figure 7 is an analysis of a coffee grinder. Figure 8 represents an electric shaver. These were done by the students without assistance from the instructor. In each case the devices in question had not been discussed or explained in class. The students are able to indentify the major components responsible for transforming the inputs into the outputs of each device. Both diagrams depict the flow of material, energy, and information in the system. Assessment follows in a straightforward manner and it is apparent that these students have reached the synthesis level by being able to create a depiction of how each device works.

Each figure illustrates different options in the degree to which form elements are included in the functional diagram. Figure 7 is an example of a diagram that does not include representation of the form or physical appearance of the system components. It is often the case that after the students have devoted significant time to analyzing a particular system they become less in need of images and are sufficiently familiar with the device to dispense with visual cues. Figure 8 is an example of how elements of the form of the device are included in the functional diagram. In this case the student created a simplified drawing of the major components adjacent to the box representing that component.

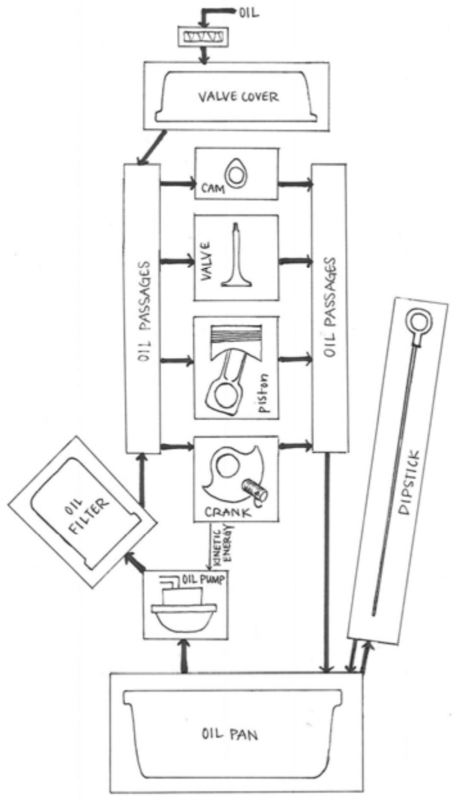

Figure 5: Functional Diagram of Lubrication System Including Form Elements.

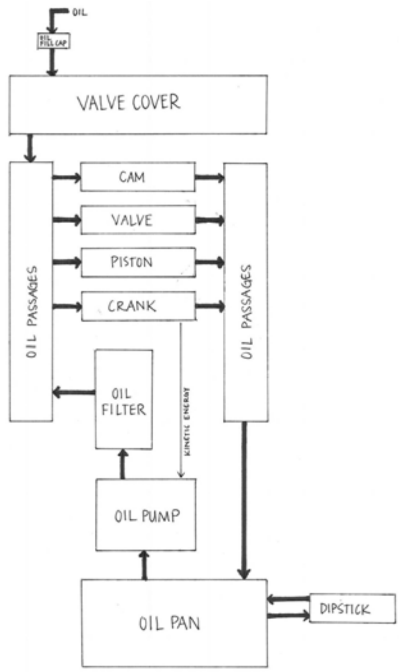

Figure 6: Component Function Diagram of Combustion Engine Lubrication System

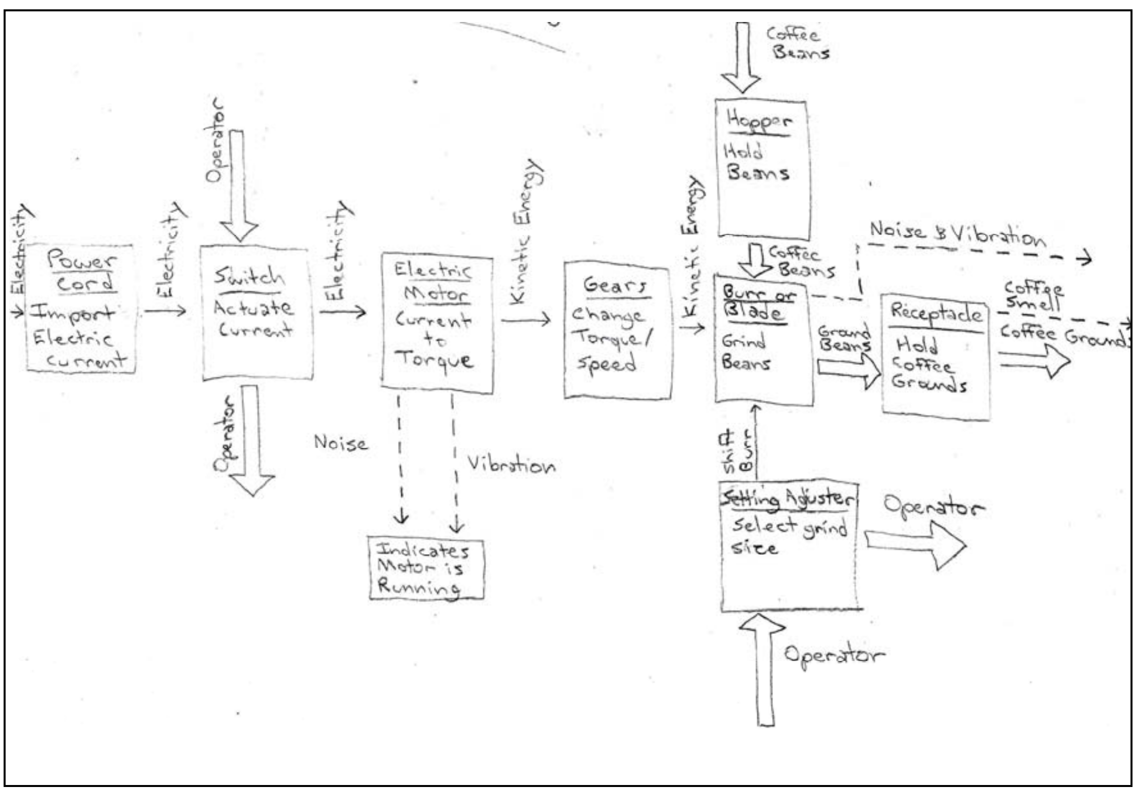

Figure 7: Student-Generated Diagram Explaining How a Coffee Grinder Works.

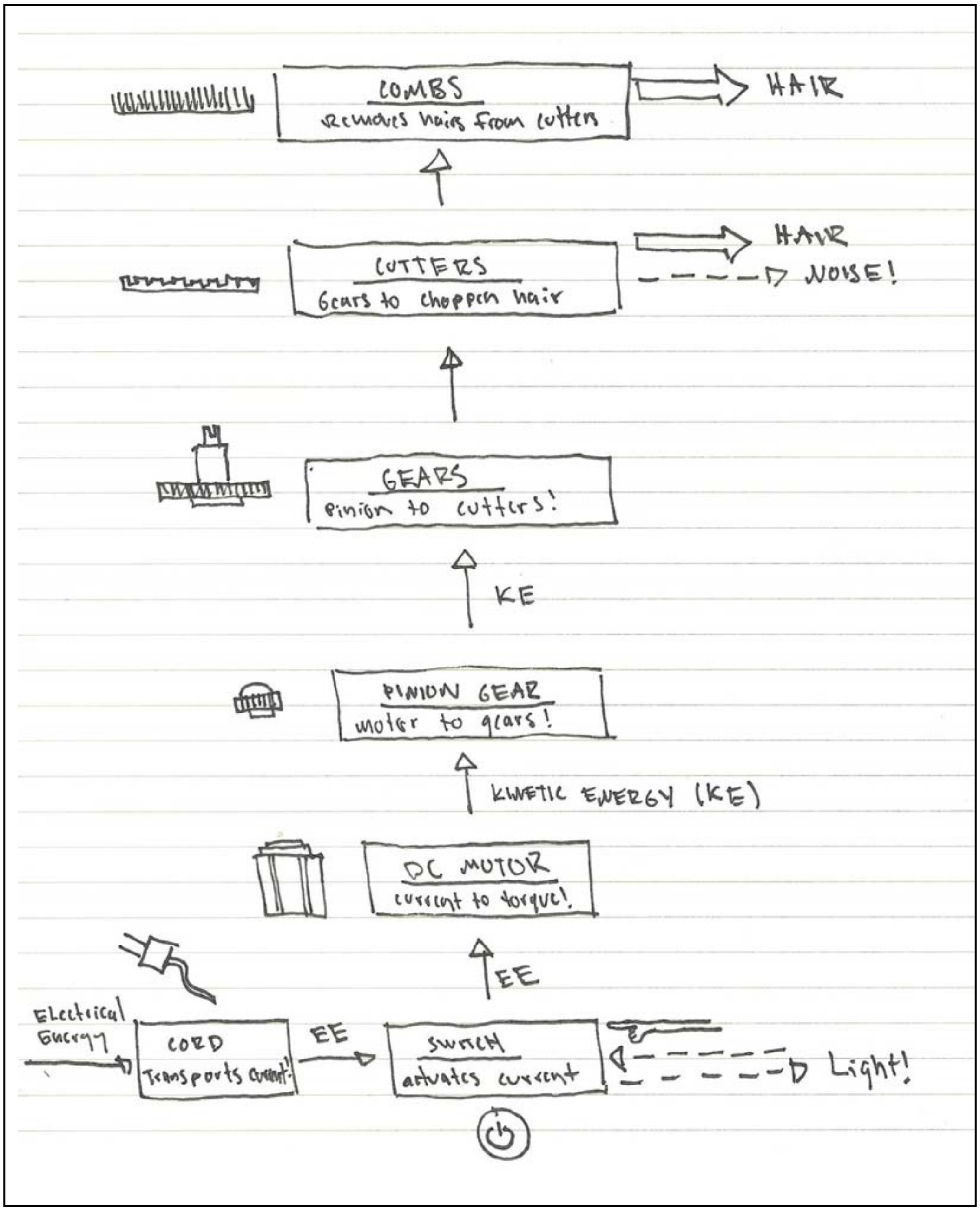

Figure 8: Student Diagram of Electric Shaver Including Physical Representations.

How Things Work Course at Iowa State University

The use of visual aids to help students learn how technical systems work has been implemented in a technological literacy course at Iowa State University. The course is E St 270 Survey of How Things Work. This class is an overview of the similarities and differences of the major engineering disciplines; methods used to manufacture products, build structures, and design systems. The goal of the class is to help students who are not from engineering background to understand how everyday things work. This includes engines, electricity, magnetism, communication, manufacturing, energy systems, and other technological items such as phones, the internet, and other related topics of interest to the students. This class does include hands-on demonstrations and laboratory exercises.

Implementation of Concept Maps

In the Survey of How Things Work, the students carry out an exercise to determine the principle of operation of a technical system and then apply this knowledge to analyze a different but related situation. The exercise involves a ring thrower apparatus based on Lenz’s law. Students operate the device and and reflect on the how it might work. Faraday’s law and examples of some applications are discussed. Students then examine the ring thrower from the point of view of Lenz’s law. Next students are given a copper pipe and a very strong magnet that fits inside the pipe. When the magnet is dropped inside the pipe it falls more slowly than a magnet falling through a non-conducting pipe. This difference is to the magnetic field caused by the current induced in the pipe by the field of the falling magnet. Students are asked to explain the reason for the slower rate of falling. The principle is the same as the ring throwing device but this not revealed to the students initially. Figures 9 and 10 are photographs of these two devices.

Figure 11 shows a sample of student analyses of the ring throwing device and falling magnet made by the non-engineering students. Figure 12 shows a concept map taken from material in the laboratory notebooks of one student group. The students explain how the two devices work.

A key aspect of this situation that is depicted clearly in the concept map is the difference in the location at which currents are induced. In the ring toss the induced current is in the ring. In the falling magnet device the induced current is in the copper pipe. To the non-engineering student, the physical appearance of each device produces misleading information regarding how each device works. In one situation the ring moves, in the other the magnet is moving. Students are prone to assume that this visual similarity implies that the moving and non-moving parts undergo the same aspects of the underlying principle. However, the jumping ring and the falling magnet perform opposite roles. The concept map format helps to make this important aspect of the exercise apparent to the students.

The use of a concept map readily illustrates this fundamental point in a manner more effective than a drawing of the appearance of the device or, for that matter, a mathematical analysis. In carrying out an assessment of student comprehension of this situation, the use of a concept map helps the instructor to quickly determine if the students have transferred their understanding of one situation onto another.

Figure 9: Ring Toss Device.

Figure 10: Magnet Falling in Copper Tube Apparatus.

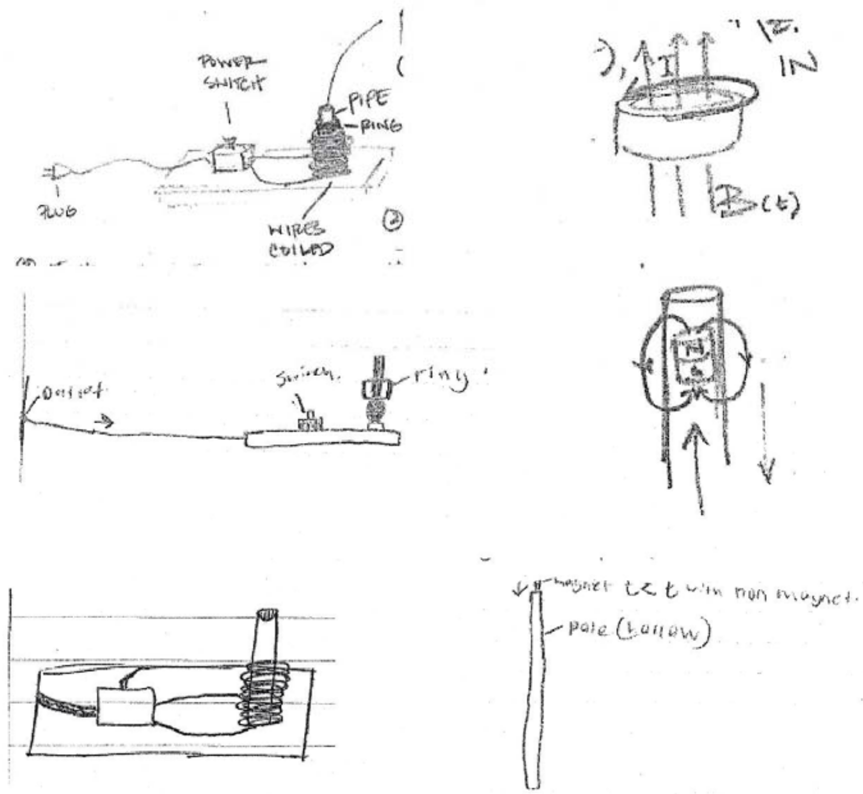

Figure 11: Student Drawings and Analysis of Ring Toss and Falling Magnet Devices.

Current Work

Current efforts are directed toward extending the use of these techniques by students to a wider range of situations. Other work seeks to develop rubrics for helping to evaluate functional analysis diagrams so a larger sample of students can be examined. Attention is also being directed toward developing assessments to characterize the ability of students to use the framework to understand technical systems with which they have no prior familiarity.

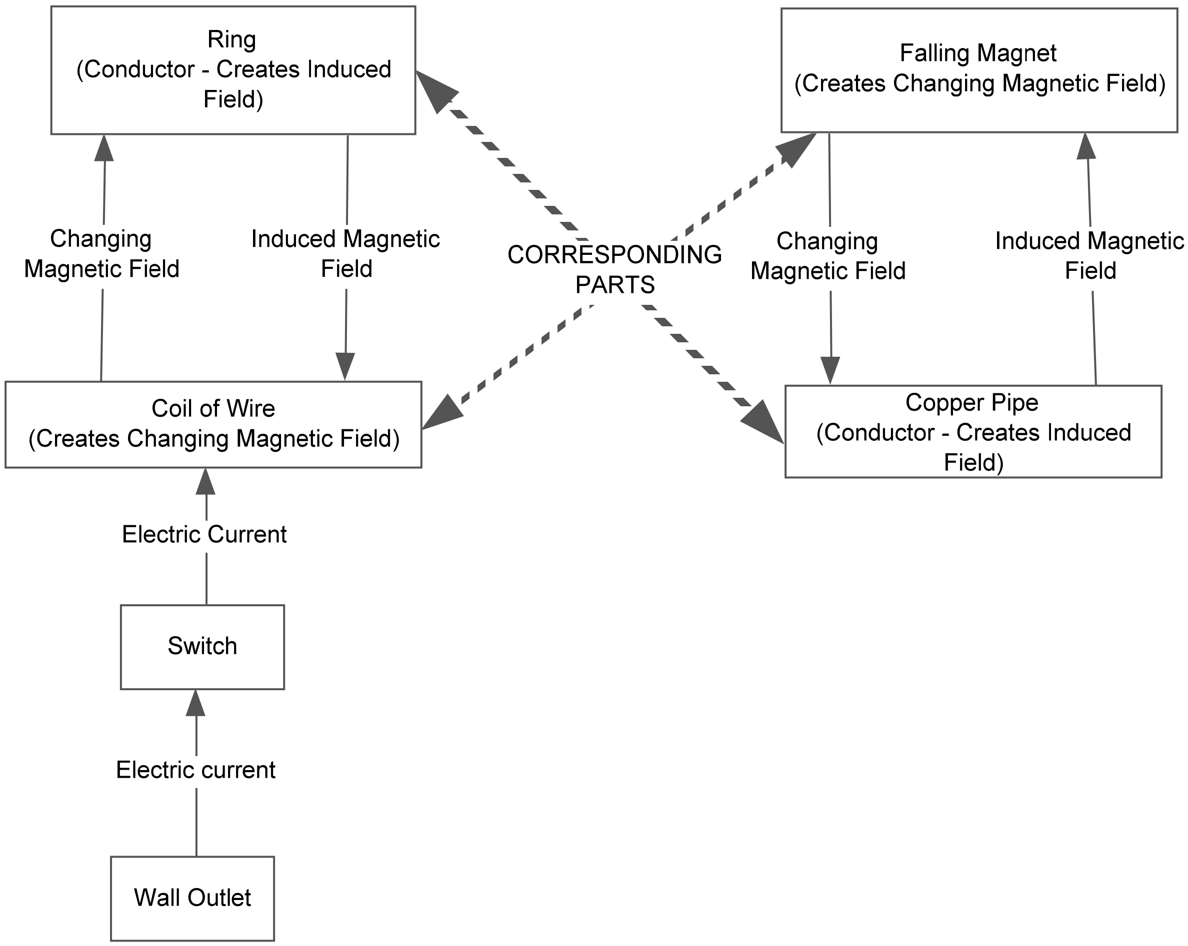

Figure 12: Concept Map of Ring Toss and Falling Magnet Devices.

Conclusions

The technique of concept mapping provides a means for non-engineers to describe technical systems. Because the creation of concept maps requires discernment and synthesis, applications of concept mapping can be used to access aspects of higher level thinking on the part of non-engineers. Such methods are beneficial as alternatives to assessment based on questions that can be answered by rote memorization. A method of using concept mapping that combines aspects of functional analysis or decomposition and sketching has been found to be suitable for use with non-engineers. Non-engineering students are able to learn this method of describing a technical system and can apply it to somewhat novel situations. Non-engineers also benefit from use of concept mapping methods when trying to discern the underlying principles of technological devices and to transfer this understanding to new situations. This initial work shows promising indications that non-engineering students are able to use these techniques to understand how things work.

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