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Gains in Engineering-Related Skills Achieved by Students in Technological and Engineering Literacy Minors

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Abstract

The need for a greater understanding of engineering and technology by non-engineers is widely recognized as important for both a well-rounded education and economic competitiveness. Informed citizens in today's world should possess a broad understanding of technology and be empowered by this understanding to make informed decisions on technologically-related issues. In response to this need, some engineering programs have successfully reached across campus in efforts to improve the technological and engineering literacy of non-engineers. The establishment of the Technological Literacy Division of the American Society for Engineering Education attests to the interest among some engineering faculty in advancing technological and engineering literacy among non-engineers. A key issue in these efforts is the extent to which non-engineers can develop engineering-related skills and abilities. This work reports results obtained regarding increases in engineering-related skills by undergraduate students who are not engineering majors. The non-engineers were successful in using the systematic and quantitative methods of the decision matrix to evaluate options and technological trade-offs. In addition, the non-engineers, when surveyed, expressed a recognition and appreciation of the value of these systematic and quantitative methods compared to their ability to make similar decisions without the use of engineering methods. The non-engineers were not just becoming comfortable with what engineers do, they were acquiring engineering-related skills and appreciating the value of those skills in solving a particular type of problem. The non-engineers also showed increases in their abilities to explain a technological system, including recognition of key underlying principles, identification of major components, and consistent description of system operation.

Background

The use of advanced technology defines our modern way of life. At the same time, the importance of technology-driven industries to the nation's economic well-being is commonly acknowledged. Simultaneously, many issues of the day such as global warming, food safety, and identity theft are linked with our dependence on specific technological systems. In this situation, engineering programs should share some of the responsibility in helping to educate all Americans about technology.[1–5]

In undergraduate education formidable barriers exist to discourage non-engineers from trying to develop an in-depth understanding about technology and engineering. The engineering major is a highly-sequenced and lengthy course of study. Access to the major is hindered by a significant array of prerequisite courses. In these circumstances it is difficult to combine the study of engineering with any other undergraduate major.

Most undergraduate programs require some type of science course as part of the general education graduation requirements. Typically this is one course with an associated laboratory. Such preparation is hardly adequate to enable non-engineers to make informed decisions about topics such as the development of fossil fuel alternatives, appropriate regulation of nanotechnology, or the importance of rare-earth elements to national security.

In this situation a formal minor can provide an effective way for non-engineers to obtain a significant and useful understanding of technology. Minors provide a workable intermediate approach between an almost inconsequential one-course science requirement and an unmanageably lengthy engineering major. Minors offered by engineering departments are not meant to provide the depth of vocational skills obtained in a ABET-accredited BS engineering degree. Minors are, however, a means to acquire the general competencies needed by all citizens in our technologically-dependent world. Minors can provide the type of broad understanding of technology as is advocated by the National Academy of Engineering (NAE) in *Technically Speaking*[6] and *Tech Tally*.[7] In *Tech Tally*, the NAE considered a broad understanding of technology to include the specific areas of technology and society, the design process, and technological products and systems. A minor is also a formal credential that appears on a student's undergraduate transcript. This is a potentially useful credential that students can use when entering the job market. Acquisition of minors is a strong incentive and motivating factor for many students.

The results reported here are part of a broader study to develop a detailed understanding of the value and structure of minors offered by engineering programs for non-engineering students.[8-12] Critical questions include the extent to which potential employers view the minor as a valued set of knowledge or skills and the degree to which non-engineers can acquire engineering-related skills through a minor program.

A potential structure for the minor programs was developed and reported in detail in an earlier work.[13] These prior results are summarized here. The structure for a minor was based on development of a set of objectives and outcomes rather than a prescribed set of courses. The use of a standard set of outcomes rather than a standard series of courses allows flexibility for institutions to develop a minor or minors that are best suited to its local conditions. This is similar to the way engineering departments meet the ABET a-k requirements for engineering degrees.

Data were also obtained from surveys of employers regarding factors influencing potential interest in engineering literacy minors or certificates.[14] In summary, information obtained from potential employers regarding their perception of the value of engineering-literacy minors generally favored such minors as a desirable set of abilities valued by employers. A summary of the results from the employer survey is given in Tables 4 and 5. A total of 21 different educational outcomes were evaluated. Table 1 shows those outcomes that were ranked highest by the employers and managers. The outcome for non-engineers ranked highest by employers and engineering managers was the ability to function effectively on teams with varying technological expertise. Also highly valued were the abilities to communicate effectively on technological issues and an understanding of basic engineering concepts. The outcomes considered by those surveyed as important include the ability to evaluate trade-offs, critical thinking, an ability to work independently, and skill in discriminating the role of problem-solving in troubleshooting, invention, innovation and research.

Table 1: Summary Results from Employer Survey of Desired Educational Outcomes.

Rank	Topic	Outcome Question As Worded on Survey	Score (Max=4)
1	Team Effectiveness	Function effectively on teams with varying technological expertise.	3.56
2	Communication	Communicate effectively, both orally and in writing, regarding technological issues.	3.52
3	Engineering Concept Knowledge	Define basic engineering concepts and terms, such as systems, constraints, and trade-offs.	3.44
4	Role of Problem-Solving	Discriminate the role of problem-solving for troubleshooting, invention, innovation, research and development.	3.32
5	Critical Thinking	Think critically and creatively regarding technological issues including an ability to assess, rank, or to compare proposed designs on the basis of the desired outcomes, consequences, and constraints.	3.28

Non-Engineers' Use of the Decision Matrix

To investigate the potential of non-engineer undergraduates to learn engineering-related skills, the use of the decision matrix was selected as the subject of a pilot study. The decision matrix is a well-known technique often used as part of the engineering design process to evaluate options.[15-17] The method is also known as *Pugh Concept Selection*. Other terms used to describe this method include Selection Matrix and Evaluation Matrix. The decision matrix is a useful technique for selecting an option in situations in which multiple selection criteria exist and these criteria are not necessarily of equal weight or importance. In addition, the decision matrix accommodates the possibility of multiple options each of which vary in the degree to which the set of selection criteria are satisfied. In these circumstances, the decision matrix provides documentation or a record of the decision-making process. The selection criteria used and the relative importance assigned to each criterion are documented. The various options considered are recorded. The relative merits of each option can be seen by review of the matrix results. The decision matrix is most useful in situations in which the various options considered are all equally well-defined and a comparable level of information is known about each potential choice.

Table 2 shows the general format of a decision matrix. There are many variations on the basic format for a decision matrix. Table 2 shows one of the common embodiments of the technique and the format that was used in the work reported here.

Table 2: General Format of a Decision Matrix.

Selection Criteria	Weight	Reference Option 1	Option 2		Option 3	
			Rating	Points	Rating	Points
Criterion 1	W_1	0	$R1_1$	$P1_1=W_1*R1_1$	$R2_1$	$P2_1=W_1*R2_1$
Criterion 2	W_2	0	$R1_2$	$P1_2=W_2*R1_2$	$R2_2$	$P2_2=W_2*R2_2$
Criterion 3	W_3	0	$R1_3$	$P1_3=W_3*R1_3$	$R2_3$	$P2_3=W_3*R2_3$
Criterion 4	W_4	0	$R1_3$	$P1_4=W_4*R1_4$	$R2_3$	$P2_4=W_4*R2_4$
Criterion N	W_N	0	$R1_N$	$P1_N=W_N*R1_N$	$R2_N$	$P2_N=W_N*R2_N$
	100	**0**		**Sum Points 1**		**Sum Points 2**

To summarize briefly how the decision matrix is used, a first step is to determine a set of criteria to be used to evaluate the possible options. Typically five to ten criteria are used. This range insures a sufficient diversity of criteria without becoming an unmanageable or cumbersome amount. The criteria are then each assigned a weighting based on their relative importance. This is often achieved by allocating weighting points to each criterion based on importance. The total number of points available is limited to 100. Next, one of the possible choices or options is arbitrarily or randomly selected and assigned as the reference or datum option. Each of the other options is compared to the reference option in terms of the degree to which the option satisfies the each criterion. The comparison rating is given a numerical value. Table 3 shows a commonly used rating scale. For each option points or scores are determined by multiplying each criteria rating by the weight for that criteria and then summing to determine overall points or score. The option receiving the highest overall score is considered to be an optimum choice based on the criteria and weighting specified. The total points for an option may be negative. If all options have negative total scores then the reference option is considered to be the best choice.

Table 3: Commonly Used 5-level Rating Scale to Compare Options.

Comparison	Rating
Much better than reference	**2**
Better than reference option	**1**
Same as reference option	**0**
Worse than reference option	**-1**
Much worse than reference	**-2**

Use of the decision matrix was introduced in a course called Science and Technology of Everyday Life at Hope College. Non-engineering students learned how to apply this technique to develop the ability to assess, rank, or to compare options on the basis of the desired outcomes and constraints.

An example exercise from this course is an assignment to use a decision matrix to make a hypothetical purchase of a television. One segment of the course addressed consumer audio and video technologies. The television was one of the devices studied. The topics included the encoding video information in both analog and digital form. Also addressed were some of the current technologies for display of visual images such as LCD, LED, and Plasma displays along with storage and retrieval of video information.

The purchase of a television was chosen as a decision matrix exercise because it is a dilemma that many people actually encounter. Also the purchase of a television is by no means a simple process. The diversity of television options has proliferated in recent years. Television sets are now described using an array of specifications and options. Consumers purchasing a television must reconcile the expansive range of options with equally expansive and diverse sources of rankings, ratings, recommendations. The diversity inherent in the purchase of a television today is well-suited to illustrating the utility of the decision matrix method.

The goal of this exercise was to simulate an actual purchase in a context that is not too dissimilar from that which is experienced by a typical consumer. A goal of technological literacy is to help empower citizens to make decisions related to technology as encountered in their daily lives. Typically consumers must purchase a product from a fixed set of options and are often under time constraints that impose some limit on the amount of time available for deliberations. In addition, consumers are usually constrained to purchase from the set of options made available by manufacturers at the moment in time when the purchase must be made. While there are many ways to analyze the impact of the television on society and the global environment, the particular exercise reported here operated under the assumption that the consumer intended to purchase a television and was willing to make that selection from the available options using information readily provided by the supplier. Future work could expand the analysis to include topics such as life-cycle assessment or the labor practices of the manufacturer.

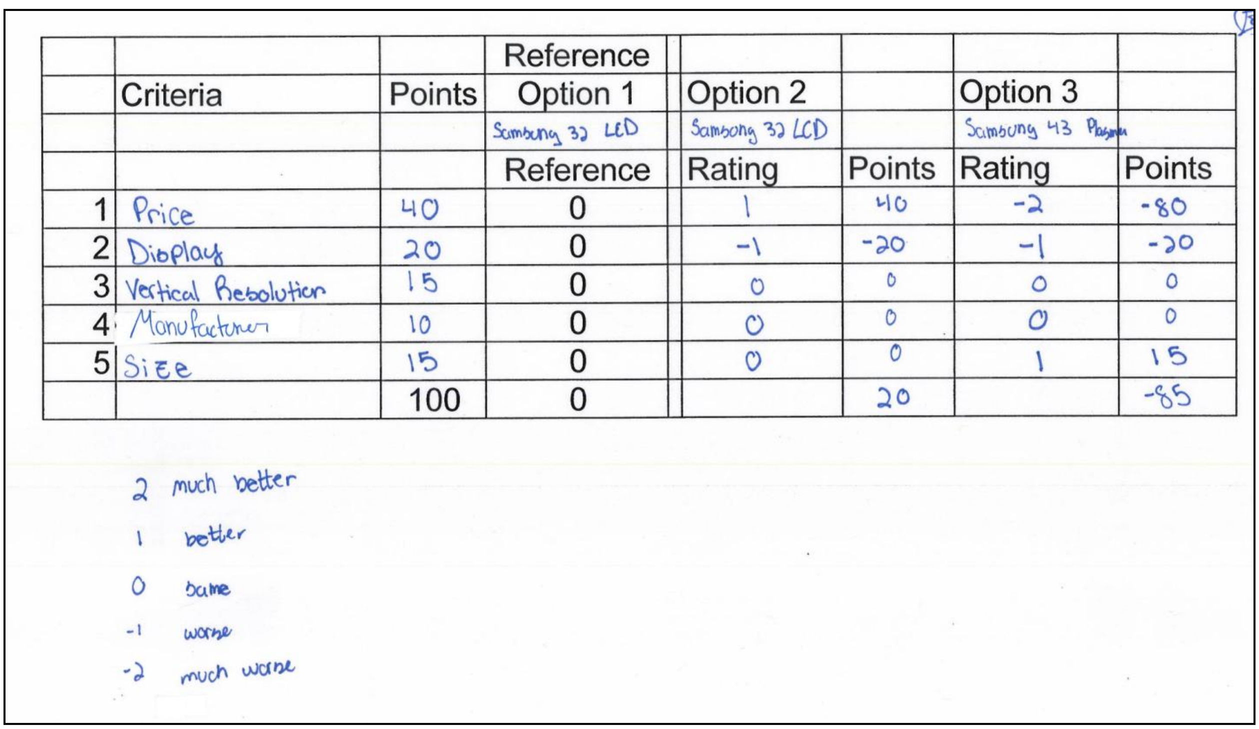
In this exercise, criteria were based on the information made available to the consumer in typical television advertising or on supplier websites. The possible decision criteria included the size of the screen, the vertical resolution, the display type, the screen refresh rate, the manufacturer, and the price. All of these specifications are typical of those generally included in advertising material describing a particular television.

For this exercise, the students were given actual information about eight different televisions and asked to make a hypothetical purchase. All of the information provided was actual unedited advertising. The assignment was stated as follows: “If you had to make a purchase of a television now or in the near future, and these were the choices, what would be the best choice based on your needs and preferences?

The eight television options provided were taken directly from the advertising materials of a major retail store. To help make the use of the decision matrix meaningful it is important to include sufficient diversity and range of options. However it is also important to not include any choices that are obvious outliers. To achieve an appropriate degree of diversity, the eight options included five different manufactures. The choices included four different sizes ranging from 32 to 46 inches. Theses sizes were selected to be generally comparable while also including some smaller and larger options. The eight choices included two different vertical resolutions (720p and 1080p) and three different display types (LED, LCD, Plasma). Screen refresh rates included three choices of 60, 120, and 600 Hz. The televisions ranged in price from 300 to 500 dollars. The price range was intended to avoid the extremes of high and low prices which might simplify the decision-making process. The students were not given a particular budget but, since this was a hypothetical purchase, it was emphasized: “If you were to spend your own money,” what would be the best choice based on your needs and preferences?

To help establish the benefits of using a decision matrix, the students were first given the eight choices and asked to select their best choice for a television. No decision matrix was used, however the students were already familiar with the meaning of the various specifications used to describe a television. Next, each student completed the decision matrix to select his or her own particular best choice. In using the decision matrix it was suggested that five criteria and 3-4 options should be considered. A typical student-generated decision matrix for this exercise is shown in Figure 1.

The work sample shown in Figure 1 is a photograph of an actual decision matrix made by a non-engineer. The photograph shows the student’s own handwriting since this particular exercise was done in during a class session. The students are provided with a blank generic matrix from which to work. This method of proving a blank matrix into which students write by hand was found to be fruitful in facilitating the completion of the exercise in a reasonable amount of time without resorting to complete automation of the process via a spreadsheet. The calculations are not difficult to complete by hand and, in the opinion of the authors, it is beneficial for the non-engineers to demonstrate an ability to complete the basic arithmetic by hand.



	Criteria	Points	Reference Option 1	Option 2		Option 3	
			Samsung 32 LED	Samsung 32 LCD		Samsung 43 Plasma	
			Reference	Rating	Points	Rating	Points
1	Price	40	0	1	40	-2	-80
2	Display	20	0	-1	-20	-1	-20
3	Vertical Resolution	15	0	0	0	0	0
4	Manufacturer	10	0	0	0	0	0
5	Size	15	0	0	0	1	15
		100	0		20		-85

2 much better
1 better
0 same
-1 worse
-2 much worse

Figure 1: Photograph of a Television Purchase Decision Matrix as Made by a Non-Engineer.

In this particular exercise, all 25 students in the class were able to successfully complete the decision matrix. This was not a particularly significant result since the process is straightforward and the procedure is not difficult to follow. More significant is the perceptions of these non-engineers of the value or usefulness of the decision matrix as a technique to be used in evaluating technological options. Table 4 shows the results from a survey of students before and after using the decision matrix to select a television.

These results show that the non-engineers feel that the decision matrix helped them to understand the criteria they used to make a decision and helped them to be aware of where they are compromising. Increases were also found in the degree to which the non-engineers felt assured that they were making an appropriate choice and in their level of confidence that an inappropriate choice was avoided.

Table 5 includes some sample student comments about the use of the decision matrix. The underling has been added for emphasis. These comments highlight the recognition on the part of the non-engineers that the systematic nature of the decision matrix helps the decision-maker to think through the process leading to confidence that the final choice was well-considered.

Table 4: Results from Student Survey Before and After Using Decision Matrix.

Question (1-5 rating)	**Pre**	**Post**	**Change**
I understand the criteria I used to make this decision.	4.00	4.57	0.57
I am aware of my priorities.	4.24	4.52	0.29
I understand in what areas I am compromising.	4.05	4.43	0.38
I feel assured that I made an appropriate choice.	3.86	4.29	0.43
I am confident that I avoided a choice that is not appropriate.	4.05	4.43	0.38

Table 5: Sample Non-Engineering Student Comments about Using a Decision Matrix.

- *When doing the matrix I understood much better where I was compromising and what I wanted specifically.*
- *The decision matrix helped me weigh the options in a systematic way, so that all the specs would not blur together.*
- *I think that the decision matrix helps me to really think through my purchase. I have a tendency to be an impulse buyer, so being able to use a decision matrix was useful.*
- *I also hate how many choices there are, so having something like the decision matrix helps simplify things and makes it easier for a choice.*

Communication: How does a Toaster Work?

The ability to communicate effectively regarding technical issues was identified in the employer survey as one of the most desirable outcomes of an engineering or technological literacy minor. As a way of both developing and measuring this ability in non-engineers, the process of explaining how a particular technological device works was identified. Explaining how a particular technological system functions involves several important aspects of engineering and technology, including a familiarity with the systems nature of technology, the underlying principles utilized in a particular system, and the nature of the components used in a particular application.

A pilot study was conducted with the students enrolled in the Science and Technology of Everyday Life at Hope College. On the first day of class students were asked to answer the question: "How does a toaster work?" This part of the exercise was done immediately at the start of the first class. The intent was to establish a baseline of knowledge as students begin the course prior to the many hands-on activities they will experience throughout the semester. On this first day, each student was asked to work alone and answer the question in writing. Students were given access to a partly disassembled common domestic kitchen toaster. A total of 23 students participated in the exercise.

Student responses were scored using a rubric that included the following items:

- Overall function of the system noted.
- Identification of major components included.
- Explanation of underlying principles utilized.
- Identification and explanation of a control system.
- Major inputs and outputs required to accomplish desired function listed.
- Indication of an order or sequence of operations.
- Recognition of information available to describe the status of the system.

The scores were allocated on the basis of a maximum of 100 points. The average for the group on the pretest was 41. It seems reasonable to consider this average as indication of general technological and engineering illiteracy among this group of non-engineers. While there was some familiarity with the workings of this common device, the knowledge was lacking in depth and inconsistent.

During this course students had the opportunity to disassemble and analyze several technological systems. Each student conducts disassembly and analysis of a four-cylinder automobile engine and numerous appliances including a hair dryer, coffee maker, blender, and hand mixer. At the end of the course, the exercise was repeated. Students were asked the same question: "How does a toaster work?" It is important to note that the toaster itself was *not* specifically studied in the class. The course did include disassembly by the students of home appliances as mentioned above but not the toaster. The intent of the exercise was to gain an idea of the ability of the non-engineers to apply knowledge and abilities learned to a slightly novel system.

The "Science and Technology of Everyday Life" course is intended for students from non-technical majors and includes students from business, history, fine arts, and pre-service education students. An objective of the course is to develop a familiarity with both the engineering aspects of how various technological devices work, and an understanding of the basic scientific principles underlying their operation. The course focuses on the wide variety of technology used in everyday life to help in engaging the student's interest. The course topics were selected to represent the technologies most frequently encountered in everyday life and were based partly on the results of surveys of student interests. The course follows an approach rooted in functional analysis and systems thinking.[18-20] Course emphasis includes an elaboration of the general nature of technological systems.

A comparison of the pre and post test results are shown in Figure 2. All but 3 of the 23 students showed increases in the ability to explain the functioning of a technological device. The average for the group increased to 74. This is a statistically significant increase. It is reasonable to conclude that this group of non-engineers, on the average, achieved a "passing" or "fair" degree of technological literacy.

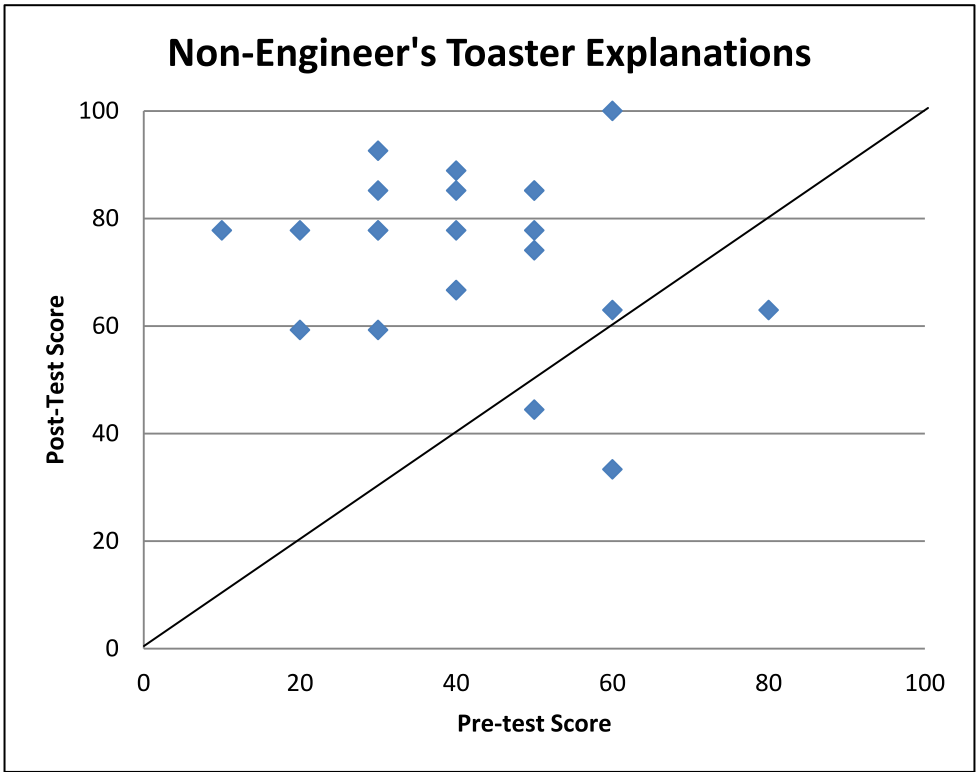


Figure 2: Pre and Post Test Resutls for Non-Engineer's Toaster Explanations**.**

Conclusions

These results are encouraging for improving the engineering and technological literacy of non-engineers. In this instance, non-engineers are able to learn a semi-quantitative decision-making technique that is a characteristic of engineering methodology. Most importantly, the non-engineers recognized the value and utility of this method as empowering them in a situation involving technology of direct relevance to their daily lives. In addition, the skill the non-engineers acquired in ranking or comparing options on the basis of the desired outcomes and constraints is a skill that employers have identified as one of the most important learning outcomes of a technological or engineering literacy minor for non-engineers. A group of non-engineers also showed increases in the ability to communicate in writing regarding a technologically-related issue. The non-engineers were able to utilize an understanding of the nature of technological systems to convey a fair understanding of the workings of a familiar technological device which they had not specifically studied.

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