The Engineering Decision Making Model: Its Importance as Applied through the Context of a World War II Simulation

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Abstract

The NSF sponsored Galileo Project, at the University of Connecticut, aims to bring engineering education and experiences to high school level classrooms and curriculum. In attempting to provide a comprehensive engineering experience, it was vital to define what is meant by engineering experience. While decision-making is not unique to engineering problems, it is a fundamental component of the engineering experience. Judgments based on qualitative and quantitative analysis forms the basis for the "engineering"-type decision making processes. As such, it is important to provide a meaningful context for decision-making involving both qualitative and quantitative skills. The decision-making process is explicitly defined as: (1) formulation of the problem, (2) statement of the objectives, (3) problem solving, (4) action assessment, (5) judgment and action, (6) validation analysis, (7) communication of results. Engineering education, especially at the high school level, should focus on a curriculum that lends to practicing the decision-making heurist in the context of any of these attributes. *Axis & Allies* by Milton Bradley is used as an example to apply the decision-making heurist.

Introduction

The National Science Foundation funded grant titled, de Vinci Ambassadors in the Classroom, the Galileo Project (NSF Project #DGE-0139307), at the University of Connecticut, aims to bring engineering education and experiences to high school level classrooms and curriculum. Central to this goal, several curriculum units, termed *modules*, have been developed and deployed to participating high schools throughout the state of Connecticut. These modules attempt to integrate some examples of engineering-type applications into existing mathematics, science and technology curriculum. While these modules have been successful in providing examples of engineering applications, they simultaneously fail to provide students with engineering experiences. This document and project has been created in an attempt to address this deficiency.

The Engineering Experience

In attempting to provide a comprehensive engineering experience, it is vital to define what is meant by an "engineering experience." In order to distinguish engineering from science, and hence engineering experiences from applied scientific ones, the similarities and differences in the respective fields was explored. It is commonly accepted that both engineers and scientists have a specialized knowledge-base in their own field of practice as well as a broad background in the natural, physical, and mathematical sciences [1]. It is easy to continue the list of similarities between the two, as there is often extensive curricular overlap. It is much more difficult to define the differences between the two disciplines. Our group, the Galileo Fellows, comprised of Master's and Ph.D. students in engineering, proposes:

"..that it is the role of decision making in engineering, along with educational paradigms and cultures that cultivate decision-making skills, that marks the most significant distinction between these two disciplines [1]."

Thus, decision-making is identified as the quintessential component of the engineering experience. Several educational research groups have corroborated this assertion in the literature [1-5].

What is Decision Making?

Decision-making is not unique to engineering problems but in fact it is done routinely often with little or no attention paid to the process. Simplistically, "when making decisions we have to make choices and in order to prefer one action or view over another we have to assign values of a moral or technical kind or, both [4]."

Most daily decisions are made pseudo-arbitrarily, e.g. without the consequence of constraints, and therefore naive to the necessity of careful consideration. Many judgments do not qualify as an engineering experience, yet, "many [other] judgments will involve the use of both qualitative and quantitative skills of analysis" in order to reach an appropriate conclusion [4]. Judgments that form the basis as "engineering"-type decision making processes are much more complex. Autran elaborates on this idea [2],

"The complexities inherent to most decision processes that are to rely on some engineering knowledge arise from the identification of conflicting, quantitative as well as qualitative criteria, imprecise and incomplete data, multiple actors and pressure groups, etc.."

This is corroborated by Kazerounian & Vieth [1] who point out that:

[Engineering] "Decision making calls for prudent exercise of a series of choices, with controlled risk, against the cost and the consequences of the probable and potential outcomes."

Consider these two statements in the context of a simple set of examples. Imagine that a friend approaches you with the request, as well as limitless financial resources, to procure for him the *best* available sports car. Many would argue that the decision of *which* sports car to procure, based on the ambiguity of the word *which*, would be an example of a rigorous decision making process. While it is true that there are several criteria that must be met for a sports car to be the *best* one, it is fairly straight forward to find an existing consensus of which is the best sports car by reading a few automobile magazines. The simplicity of this decision is immediately evident when compared to Autran's statement. In this example, there are no "conflicting, quantitative as well as qualitative criteria", only the *best* needs to be considered. There may be no "quantitative criteria" as *best* is purely qualitative. For such a problem, it is reasonable that the reviewers in the automobile magazines were precise and complete in their evaluations. There are no additional actors and no outside pressured. Thus the decision-making described by Kazerounian cannot be measured in this example. Only one decision needs to be made based on the available literature, since cost is not an issue, and the outcome is already known. In contrast to the previous example, the following specifications were handed down to a senior engineer at General Motors.

"We need to build the *best* sports car in the world. It must have performance numbers similar to the fastest and best handling sports cars in the market place today; It must be comfortable to drive and include all the standard amenities; It must be capable of transporting three passengers; It must meet the current strictest environmental standards in the United States as well as those projected to be in place in Europe for the next two decades; It must be as invisible as possible to police radar and laser systems; It must be easy for the entire family to drive; And it must be affordable to the typical American household."

Upon reading the scenario, it is apparent that the specifications given to the senior engineer at General Motors are full of "conflicting criteria:" according to Autran[4] A sports car with all of the amenities listed using stealth technology in the design is likely to be quite expensive; A car capable of hauling multiple passengers is generally not as fast or agile as a smaller 2-seater. Extremely powerful cars are generally not as easy to drive as tamer ones; etc. In addition, there are other specifications to be considered such as its environmental requirements. While the strictest environmental standards exist in the United States, there is no definitive way to predict absolutely the environmental standards that will be adopted in Europe over the next 20 years nor does it address what environmental standards are being referred to in the design. Is it only emissions requirements, fuel efficiency, or others? These are examples of imprecise and incomplete data. Finally, this car needs to be *easily* driven by the whole family. What does *easily* mean? Who exactly is the *entire* family? Questions that arise as the senior engineer ponders the "conflicting criteria."

On first glance, it appears to be easy to develop erroneous conclusion that this car is impossible to design because of its requirements. However, the design of this vehicle necessitates exactly the type of engineering decision-making referred to by Kazerounian [1]. Each item on the specifications list must be carefully examined both in its individual achievability as well as its impact on the other aspects of the vehicle. The design is then a series of value judgments used to optimize the total efficacy of the final product as pertains to the original specifications.

In truth, the creation of this sports car with its many specifications will be proffered by the appropriate application of relevant mathematics, science, and technology. It should be noted that there are many more facets to successful decision-making, even in an engineering scenario, than the mere application of science, mathematics and technology. Other disciplines such as economics, ergonomics, sociology, behavioral science, marketing, research, and political lobbying are necessary for the optimal design of this automobile to be created. The importance of this observation is summarized by:

"The key idea behind teaching engineering decision making … should be that engineers are not simply cost minimizers but they must rely on the whole spectrum of technical analyses …in order to effectively add value to their decision making processes [2]."

The Decision Making Model

The Scientific Method is considered the absolute heurist for all scientific exploration. If the decision making process is to engineering as hypothesis testing is to science, then there needs to be an equivalent step by step methodology for the decision making. While several models have been proposed in the literature [1, 2, 4], none of these have obtained unanimous *defacto* approval, perhaps due to their lack of comprehensiveness. The following proposed seven-step model for decision-making is a compilation of the heurist models found in the literature.

Seven Steps Toward Successful Decision Making:

1. Formulation of the Problem
2. Statement of the Objectives
3. Problem Solving
4. Action Assessment
5. Judgment and Action
6. Validation Analysis
7. Communication of Results

Formulation of the Problem

This first step in the decision making process is a rigorous formulation of the problem to be addressed. The situation, as well as all necessary constraints for success, needs to be clearly identified. While this step need not be overly complex, once completed there can be no ambiguity to what constitutes a successful solution. If the problem becomes overly complex, it is often an indication that there are several sub-problems of which each needs to be addressed in a hierarchy with this same heurist. Gary Mintchel, a senior editor of *Control Engineering* [6], has elaborated on the top 5 reasons why engineers make poor decisions. The number one reason is simply that engineers are working on the wrong problem, i.e. they are working on a problem that was poorly formulated. It follows that successful decision-making is critically dependant on the accurate and thorough formulation of the problem.

Statement of the Objectives

Step 2 is to clearly identify objectives that will demonstrate a successful solution to the defined problem. It is important that objectives not be confused with the constraints placed on the original problem. In the example given about the design of a sports car, one of the constraints is that the car must exhibit performance standards on par with existing vehicles. The objectives are considered to be identified items which, when met, are expected to fall within the constraints to realize the solutions. For example consider the following objectives:, an engine with so much horsepower and torque, a high power to weight ratio, and a balanced center of gravity. These objectives should be met in order to satisfy the constraint of "excellent automotive performance." It should be noted that making poor decisions is a failure to properly explain all objectives [6].

Problem Solving

Step 3 is to generate an exhaustive list of possible ways to meet each of the stated objectives. The third leading cause poor decision making is found in this step, namely, "People too frequently accept the set of alternatives offered rather than create new alternatives [6]." Problem solving often requires a high degree of creativity in which engineers must "think out of the box" in order to come up with novel means for satisfying the objectives. Typically, the decision making process is mistakenly compared to glorified problem solving of a technical nature. It is important to realize that problem solving, while critically important, is still but one step in the engineering decision making process.

Action Assessment

In Step 4, the values of the all of the methods developed in the problem solving section are compared relative to each other. Typically, this is where an engineer refers to his/her technical expertise to choose an appropriate set of analytical methods and to develop the necessary tools to apply these methods toward generating and assigning the corresponding values [2]. In our example of the sports car, if an engineer needs to assign relative values to the power output of various engine designs, the engineer develops and creates a useful test system to measure the output power. One critical component of this step often overlooked, yet mentioned in Kazerounian and Vieth model, is the inclusion of "risk assessment and analysis. [1]" The fourth shortcoming in decision making is often in "not recognizing invisible factors, or circumstances generated elsewhere [6]". Recall that many of the constraints may be qualitative in nature or may need to be solved with imprecise and incomplete data. Since it may not be possible to test solution methods analytically, it is important for the engineer to assign value judgments based on confidence levels discussed in the assumptions and the models used to represent these imperfect items.

Judgment and Action

In Step 5, all of the various options and trade-offs are evaluated and a course of action is determined and implemented. The last cause of faulty decision making is often a result of people not thinking their decisions through thoroughly enough [6], i.e. jumping directly to this phase without enough time, thought and energy dedicated to the preceding steps. In projects involving the construction of a physical product, this is the phase where the prototype design is built. In projects involving more abstract products, this is the phase where the semi-final decision and / or recommendations are submitted.

Validation Analysis

In the final step before the results are realized they are carefully examined to ensure that: (1) the objectives are met; (2) the constraints satisfied; (3) and the solution is complete. This is also the portion of the process to reflect on whether the made decisions were good ones. Is the current solution the most elegant, the most powerful, and the most appropriate? Is there a better way yet to do it? Depending on the results of this phase, the product will enter what is known as the "redesign" or "refinement cycle" where the *best* possible solution is further perused.

Communication of Results

The final step and most important one, the communication of results, completes the decision making process. Although this step may be time consuming, and the motivation to complete it stymied at the end of a long project, it is an extremely important step that must not be overlooked. Communicating the results allows others to develop alternative projects based on the results of your decisions. It is critical that all of the precious steps in the decision making process be explicitly documented. Many times, a developed product may stand as a valuable contribution based on its own merits. Most often, the product is the result of complex decision-making. The future of the product's further development is determined by its usefulness to others who wish to expand on it. It follows that the usefulness of your decision making process to others is a direct reflection, not only of the quality of the process itself, but also of the effectiveness of the communication of results.

Additional Components of the Decision Making Process

Traditionally, it is assumed that engineering only encompasses mathematics and science as a needed background for the discipline. However, because of the broad diversity of topics encountered in the engineering decision making process, many other areas of study is necessary for the requisite background and attributes in a successful engineer. With respect to engineering education in the high school, it is equally as important to understand how other disciplines play an integral part in the decision making process [1]. In his research, Nguyen identified key attributes in various areas that are important for decision making background as listed below [5]

- Mathematics and Science Skills
    - Problem solving
    - Research and development
    - Analysis and synthesis
- Computer and Technology Skills
    - Computer
    - Programming
    - Technical
    - Design
- Social Science Skills
    - Communication
    - Social
    - Presentation
    - Interpersonal

- Business and Management Skills
    - Leadership
    - Business management
    - Teamwork
    - Accounting

Thus engineering education, especially at the high school level, should focus on curriculum that lends to practicing the decision-making heurist in the context of any of these attributes.

Decision Making Through a World War II Simulation

The engineering decision making process is a multifaceted experience which draws upon a broad range of multidisciplinary skills. When introducing engineering education at the high school level, it is important to provide students with complete decision making experiences rather than examples of high-tech design trade-offs or one-dimensional cost minimization problems. This project provides an example of how to implement the decision making process into an experience for high school students while introducing an integrated approach to academic disciplines.

Using the Milton Bradley board game, *Axis & Allies*, students begin with the context of learning about the history at the beginning of World War II. This game was chosen because of its strategy implications where armies must be procured, allocated, and deployed. There are five players, or countries, in the game called 'Allies' (Russia, Great Britain, and the United States) and two opposing powers called 'Axis' (Germany and Japan). Similar to WWII, the object of the game is for one set of countries to defeat the other.

Teamwork is essential in this game as students will be divided into 5 groups, one for each country. Their task is to approach this game using the decision making process on how to win the war. Each group, or country, must function as an autonomous unit and make the final decisions for their respective country, however, teamwork between countries is encouraged. Due to time constraints and the scope of the game, the description provided below will be limited to the first round of the game, i.e. the opening moves in the war. Students are encouraged, however, to continue the game until the end on their own. At the end of the experience, students will make recommendations, based on their own decisions as well as the decisions of others. Their final task is to predict which side would most likely have won the War based on all data available. Applying the decision making model previously discussed in this paper, the authors have hypothetically created a scenario for purposes of explanation of the process. This is by no means the "correct answer" to solve the game, Axis & Allies; it is only an example of how to apply the decision-making model to the game strategy.

Step 1: Formulation of the Problem

It is the spring of 1942. The world is at war. Five powers are struggling for supremacy. You and your opponents control the military and economic destiny of one or more of these countries. The "Axis" powers are Germany and Japan. Challenging their expansionism are the

"Allied" powers of the United Kingdom, the U.S.S.R. and the United States. You must work as a team with the country or countries in your alliance [7].

Comparing this problem to the description given by Autran [2], i.e. *conflicting, quantitative as well as qualitative criteria, imprecise and incomplete data, multiple actors and pressure groups, etc.., we will apply the first step in the decision making process, e.g. formuation of the problem.* While the war must be won, there is an obvious quantitative conflict between the numbers and types of military units that are available and the economic infrastructure that is needed to support them. With the exception of the U.K., each major power is in the position of fighting a two-front war, e.g. where the XXXXXX (Elias explain what you mean by this) This presents a qualitative conflict in criteria as the wars on both fronts must be won with a limited amount of resources. The lack of knowledge for what units the opponents will develop is an example of *imprecise* data while the lack of knowledge of an opponent's strategy represents the challenge of decision making in light of *multiple actors*. Each country must make the best decisions in light of the *pressures* from their allies, which may or may not be also making decisions in line with their own. Thus, the *complexities inherent* in this problem necessitate choices to be made, e.g. *(1) controlled risk,; (2)against the cost; (3) and the consequences of the probable and potential outcomes*. These choices were identified by Kazerounian and Vieth [1] as the essence of decision-making.

In this scenario, the problem, as well as the primary medium for exploring the problem, i.e. the board game as a World War II simulator, have been provided to the students. Even though formulation of the problem is a critical step in the decision making process, it is appropriate, for educational purposes that the instructor discuss and help the students to formulate the initial problem [3]. Even in industry, a problem and expected toolset to solve the problem is often delegated to an experienced engineer. In this case, the first step of the decision making process becomes an exercise in validating the appropriateness of the toolset for this given scenario.

According to the *Axis and Allies Game Play Manual* [3], the Axis powers begin the war with many more military units than do the Allies. Conversely, the combined economic power of the Allied forces far surpasses that of the Axis. Other specification provide to the students per the Manual include: (1)) the actual number of units and their types, (2) the initial location of the units; and (3) the initial buying power of the individual countries. In order to validate this scenario, students need a background of the history of WWII and a confidence value must be assigned to the model. (Elias, explain what that means.)

The topic of "*who should have won the war"* has been discussed in research at great lengths and the models used have been developed in meticulous detail. The scope of this board game is extremely involved, yet to cover all of the possible angles and nuances of WWII is nearly impossible. It is not the intent of this project for students to embellish or improve upon the model provided by the board game. For students to validate the initial set-up of the game and approximate the military and economic climates at the beginning of WWII is a step toward using the decision making model. The assumption is that the problem as well as the model of the game is a meaningful exercise for decision making

Step 2: Statement of the Objectives

Identifying the objectives of the game will demonstrate a successful solution to the defined problem. In the case of the Allied powers, there is only one acceptable objective: the complete military destruction of the Axis forces. In terms of the game play, this is equivalent to capturing, and holding, both of the capitols of Germany and Japan. There are two possible objectives present, however, for the Axis powers. One objective is a military victory over the Allied forces, which occurs when 2 out of the 3 Allied capitols are captured. The other is an economic victory over the Allied powers, which occurs when the combined *Gross National Products* of the Axis Powers exceeds that of the Allied powers by a certain number of economic units [7].

Since the problem is to win the war, then an equivalent problem is not to loose the war. Thus another objective of the Allies is to maintain their economic superiority over the Axis while perusing their strategic campaigns. Thus the Allies have two objectives that must now be satisfied simultaneously; (1) defeating the Axis forces while (2) concurrently protecting their economic infrastructure. Appropriate decisions will need to be made to accommodate both objectives. The Axis powers need to accomplish only one of the objectives for victory. Thus careful analysis of the methods for achieving each of these objectives must be considered and compared before a plan of action is chosen.

Step 3. Problem Solving

In this step, the possible means of meeting the objectives is exhaustively explored. Often this means that meeting the objectives will be realized and will present complete problems that need to be additionally considered. These problems then need to be evaluated using the iterative decision making process as listed in Step 2. In this important element of the decision making process, additional questions are asked, possible solutions are explored and the necessary tools, for each are created and deployed. It is vital that in this portion of the decision making model that the decision maker either possesses problem-specific knowledge already, or has a sufficient background to search for, obtain, and understand enough knowledge to address the problem [3]. This is a primary reason that problems involving more general knowledge be emphasized, as opposed to mathematically and scientifically rigorous ones, at the high school level. When identifying possible solutions, there is generally not one uniquely right or wrong answer nor is there a precise methodology on how to proceed. In fact, creativity is highly encouraged here as a means to develop novel methods to solve the problem. Thus the following suggestions and questions are merely an example of one, albeit limited, approach to exploring the example objectives.

When trying to identify possible solutions, it is often useful to review the decisions of others to similar problems. Research is one of the most important, yet underrated, components of decision-making. Information lies at the heart of all good decisions, and good research skills and habits are critical to obtaining this information. Recall that the last step in the decision making process, is communicating results. It is in this step that others may review your decisions and you their results. Questions that may arise include, but are not limited to:

(1) What were the plans of the various countries in 1942?
(2) What were the notable victories won as well as the notable defeats suffered?
(3) What were the causes of these victories and/ or defeats? Were they due to luck or good planning?
(4) Is there another seemingly better plan of action that was considered yet not taken, or even not considered at all?

Considerations as listed above can put the decision makers into a better position to create new objective solutions.

Prioritizing the decision is equally important and consideration as to which of the two fronts should be allocated resources and when is paramount. From this viewpoint, other questions arise such as:

(1) How many units do the enemies have on each front?
(2) How far away are they from my territories?
(3) What types of units are they, i.e. offensive or defensive? (This type of exploration can be done iteratively again.)
(4) Will any help be coming from ones allies for either front or territory?
(5) Do I need to allocate along a front to aid an ally?
(6) How strategic is each territory to defend?
(7) How strategic are the enemy territories on each front?

Now that the important territories have been identified, both offensively and defensively, a qualitative battle plan can be developed. As an example, the United States player may decide qualitatively that an all out naval assault should be carried out against the Japanese with limited support from the U.S.S.R. Certain territories are identified as necessary targets and preliminary plans for unit procurement, allocation and deployment are developed.

Step 4: Action Assessment

Up to this point, only qualitative ideas have been generated as possible solutions to meet the objectives. Now quantitative values must be weighed and assigned to each attribute in the proposed solution. When evaluating attributes, it is important to have developed a rubric to assist in the assignment of weighted values. By summing up the weights of all identified attributes, an analytical decision can be made as to which solutions may be most advantageous. Each solution can be checked against the constraints to make sure that it is a feasible solution. For example, do we have the economic resources to buy all of the airplanes needed for the critical aerial assault on a naval carrier group?

The technical background of training for engineers gives them an advantage in the decision making process. For example, since each type of unit has different offensive and defensive properties, it may not be obvious, by looking at the collection of units, who should win a given battle. When developing a battle plan, it is critical to have an idea which battles can be expected to be won. For example, if three tanks are defending a territory, it would be a poor battle strategy to depend on capturing that territory with only 1 attacking infantry unit. An example of this strategy is given in Table One. In this Table, both the attacking units and the defending units are represented.. Qualitatively, one could argue and defend either position as expected to win the battle. If this were a critically important battle, such as the defense of a capitol city, a qualitative argument may not lend enough confidence to the results. Instead, it would be advantageous to develop a battle probability calculator to aid the analysis for who can be expected to win.

Type of Units	**# in Attacking Unit**	**# in Defending Unit**
Tanks	6	4
Infantry	10	8
Fighter Planes	3	3
Bombers	1	3
Battleships	1	1
TOTAL in Unit	**21**	**19**

Table 1: Example of Offensive and Defensive Units

The development of a battle probability calculator is another decision-making process. While this is smaller in scope than the original project, each of the steps in the decision-making paradigm must be followed in order to develop the *best* battle calculator. The exact purpose for the battle probability calculator must be defined and all of the constraints and assumptions identified. For example, the battles in the game take place on a turn basis, e.g. which units will an opponent remove when they are destroyed? Is it situationally dependant? Are there *better* units to remove than others for different circumstances? Research must be conducted on the appropriate statistical methods and the means of implementation must be considered. A confidence rating must be given to the final product. If the calculator is only expected to be marginally accurate, appropriate weight should be given to this when summing up valued attributes. On the other hand, if the battle calculator is expected to be extremely reliable, then the expectation to win or loose a given battle can be considered an extremely *heavy* attribute.

Step 5: Judgment and Action

The judgment phase is the first in the two-step process in Step 5. After all of the various options and trade-offs are evaluated, a course of action is selected from the list of possibilities. In this case, the entire strategy for the game should be laid out. This strategy should include a sequence targets to attack detailed with types of attacking units and expected allied support. Because this project is subject to *multiagent* effects, it is unreasonable that everyone's initial plans will be successful. The action plan should thus also include alternative plans of action based on expected unknowns. For example, it is reasonable that Russia will attack one or more German territories on the opening move. The German plan of action should reflect this in its sub-plans. If the Russians capture a certain territory, then the German plan of action might be to take it back with these units. If the territory is not taken, then these units will move to reinforce it defensively and another planned offensive move may commence. Realistically, as the amount of unknown and imprecise information becomes increasingly larger, it becomes more difficult to plan out contingency plans for the later stages of the game. The best decisions will also be those that provide the greatest longevity of the units. Keep in mind that even the best plans often fail because either there are too many unknown variables or the opposing plans are better strategies.

Students should completely document their decision making process, as well as their battle plan, before the action phase is begins. "Shooting from the hip" is not a good strategy to implement as planning is a key factor in the decision making process.

The action phase of the process begins with the opening round of play in the game. Each power takes turns implementing the items off of their battle plan until one group of powers reaches the objective and wins the war.

Step 6: Validation Analysis

The last step in the decision making process before the final results are realized reflect on whether the made decisions were good ones, thus validating the decisions made or rejecting them. The data used in the validation analysis phase needs to be collected as the action phase of the process proceeds. For example, in order to validate a battle calculator, the participants and results of significant battles should be recorded during the game. When all of the battles have been fought, the actual results can be compared to the expected results to check and see if the calculations were reasonable. It is best to create a data table to collect such information for later analysis. Data should also be collected and compiled in the form of notes during the action process phase. If an unknown variable that was not considered earlier in the process suddenly materializes, it should be recorded as valued data. If a plan of action failed, the circumstances relating to that failure should also be recorded. Questions to be considered include, but are not limited to: (1) Were not enough units allocated? (2) Were they the wrong type? (3) Did the forces promised by my allies not materialize? (4) Were the probabilities of winning battles consistently overestimated or were a probable victory lost merely to chance? Answers to these questions are critical and vital for *redesigning* future plans. Once all considerations have been analyzed, the relative success or failure of the decisions made can be assessed.

Step 7: Communication of Results

Communicating the results brings the decision making process to a close. The process, from beginning to end, must be documented so that others can understand and improve on the decisions that were made. For example, classes performing this exercise in future years may refer to your documentation as a source of information, in addition to the history books, when researching existing thoughts and ideas for initial strategies.

It is a common misconception that only products that solve the problem unequivocally are examples of successful decision making. The real success of a decision making process are all of the lessons learned from the experience and how they are presented. If the decisions are judged to be successful ones, then the report should broadcast the elements that made it so successful. Similarly, if the decisions were judged not to be successful, the reasons for failure should be highlighted and explained so that others may learn from the mistakes more easily. In the engineering community, one group's failures, when communicated properly, ultimately lead to another group's success. Indeed, the future growth of technology is as much dependant on the lessons learned from failed projects as it is on the products produced by successful ones. As a culture, particularly in engineering, we need to embrace failure[1] and not shy away from projects where failure is a possibility. Either way, the lasting value of any decision making process is how effectively the results are communicated.

Conclusions

This project is an example of the engineering decision making process as is appropriate for students at the high school level. Complex problems are solved, analysis performed, and decisions made without losing the essence of the decision making paradigm to unnecessary technical details. This project is multidisciplinary in nature and fosters teamwork. It includes technical analysis, and requires practice with many interdisciplinary attributes including, but not limited to, research, problem solving, and communication. The decision making process as outlined in this discourse can be used successfully in all avenues of engineering as well as applied to engineering education in the high school classroom.

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Biographical Information

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CATHERINE KOEHLER is a Ph.D. candidate in the Neag School of Education at the University of Connecticut. Her field of study is in curriculum and instruction concentrating in science education under the direction of David M. Moss. Her dissertation work explores a pedagogical model of teaching the nature of science to secondary science teachers. She has taught Earth Science, Physics and Forensic Chemistry in public high school for 7 years prior to her graduate school training. Currently, she is a full time science education faculty member at Central Connecticut State University in the Department of Physics/Earth Science.