Utilizing the Decision Matrix to Introduce the Engineering Design Process

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The art and science of managing combat power on the battlefield is essentially a scientific/engineering endeavor, requiring a commander to solve a complicated physical problem. Yet this is also an exercise in the humanities/social sciences because we are using people, not just weapons and machinery.

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ABSTRACT

Instructor observations of cadets enrolled in the mechanical engineering sequence at West Point noted that cadets seemed unnecessarily challenged by the concepts of the formal engineering design process. This material is presented and utilized during the final course of a three semester engineering sequence aimed at providing an overview of the varied facets and applications of mechanical engineering. The two courses leading up to the capstone design course cover a broad range of engineering concepts and topics to include: statics, materials, thermodynamics, fluid dynamics, and heat transfer. To facilitate the transition into the design portion of the course, the decision matrix (DECMAT) was introduced into the ME350 course. The DECMAT is a logical decision making process, with all the characteristics of the formal design process, but in an abbreviated form. It is a tool that not only enables cadets to learn how to formalize their thoughts to develop recommendations and justifications based on relevant facts – the essential elements of the engineering design process.

INTRODUCTION
Historically, the Army’s officer corps was a technically skilled group of individuals. The simple fact that the West Point was the nation’s first engineering school highlights this fundamental aspect of officership. Over time, national, international, and public demands on the US Army have added many layers of complexity to what is expected of officers in today’s Army. Graduates of West Point now fill roles as ambassadors, mediators, and engineers, as often as they do platoon leaders. A broad range of majors exists at West Point now to enable cadets to explore their interests in diverse fields and hone their skills to effectively engage future challenges.

Though cadets no longer must major in engineering, the requirement still exists that all cadets receive formalized engineering training. If they choose an engineering major, then this facet is encompassed within the scope of their major. If they choose to pursue a non-engineering major, then cadets must take a three course engineering sequence to fulfill this requirement. Though this seeming vestige of another era has remained, current operations have brought renewed focus to the essential value of engineering/technical expertise in its officer corps. In light of this essential component to the education of future Army officers, and the inherently human activity of design, I sought to evaluate and better integrate the various facets of the engineering curricula that comprise the mechanical engineering sequence taken by non-engineering majors at West Point.

**BACKGROUND**

Everyone designs who devises courses of action aimed at changing existing situations into preferred ones.

Herbert Simon

The phenomena described by Herbert Simon is indicative of human kind and can be seen time and time again though the historical evolution of man from the pre-historic era to the present day. Some of the first physical evidence of this is the formation of stone tools. Though they did not change man’s world, they did make his existence in it easier. Individuals naturally and intuitively design to improve their lives; however, within the scope of an engineering education, it is frequently separated from science concepts and viewed as a separate entity that must be understood, mastered, and then over-layed onto the knowledge base established from the content of core engineering courses. In doing so, design and its processes tend to be an enigma for students and interestingly, become counter-intuitive.
Before proceeding to far, I want to explicitly define some key terminology, in particular: technology, science, design and engineering. They are used repetitively and I want to maintain a consistent definition.

- **Science**: a systematic knowledge of the physical or material world gained through observation and experimentation.
- **Engineering**: the art or science of making practical application of the knowledge of pure sciences, as physics or chemistry, as in the construction of engines, bridges, building, mines, ships, and chemical plants. Skillful or artful contrivance; maneuvering.
- **Technology**: the branch of knowledge that deals with the creation and use of technical means and their interrelation with life, society, and the environment, drawing upon such subjects as industrial arts, engineering, applied science, and pure science. In short, it represents the sum of ways in which social groups provide themselves with the material objects of their civilization.
- **Design**:
  - To prepare the preliminary sketch or the plans for (a work to be executes, especially to plan the form and structure of an object (v)
  - An outline, sketch, or plan, as of the form and structure of a work of art, an edifice, or a machine to be executed or constructed (n).

Through the natural course of secondary education curriculum and the course requirements at West Point, cadets begin the engineering sequence with a broad exposure and awareness of science and its governing laws. Life itself has enabled them to appreciate and exploit current technologies and develop a willingness to embrace emerging technology. However, unbeknownst to most cadets, these daily used but poorly understood phenomena occur due to engineering and the design process undertaken in order to practically apply science and its laws. This linkage to enable understanding and sorting out a seemingly complicated physical problem is the objective of the engineering sequence for cadets.

**METHODS**

To reduce the seemingly complex and ambiguous aspects of the design process that persists at the outset of ME450, the capstone course for the mechanical engineering sequence, I sought to determine the extent that the engineering design process is currently integrated into the sequence and then develop an alternative approach to facilitate its integration and understanding.
Existing Course Sequence. The current courses and content of the mechanical engineering sequence are as follows along with the course objective/s that apply to design:

- CE300 – Fundamentals of Engineering (Mechanics and Design)
  - Understand and use the Engineering Design Process; solve engineering problems utilizing a methodical problem solving approach.
- ME350 – Introduction to Thermal Systems with Army Applications
  - Apply a systematic thought process to solving engineering problems
- ME450 – Design of Army Systems
  - Design solutions to open-ended problems through an organized design process
  - Apply basic engineering science to the design of mechanical devices

Within the scope of CE300, cadets are exposed to the engineering design process, which is depicted in Figure 1. It is presented during the first lesson, and focus is then placed primarily on the design and analysis portion of the process, which is consistent with the material and construction of the course. During ME350, the cadets once again see this engineering design process diagram depicted in Figure 1 when the course design project is presented during the last quarter of the course. Finally, during ME450, the cadets see this model once again. During this course; however, it is augmented with sub-tasks which reflect the content of the textbook

![The Engineering Design Process](image-url)
used for the course. The overlay of the 10 step explicit design process presented in ME450 with the one previously presented to the cadets is shown in Figure 2. The structure of ME450 is to present the extended engineering design process with the cadets working through it on a concurrent individual project. The cadets then, in groups, conduct the complete design process two more times with different and increasingly complex problems.

Figure 2

**Implemented Modifications.** Feedback from previous instructors of the sequence courses indicated that the cadets had consistent difficulty transitioning to the capstone design course and understanding the components of the detailed design process. Additionally, they were challenged to effectively apply the knowledge and concepts they had been learning in the sequence. Seeing that to date, cadets had only experienced intermittent exposure to the design process, I incorporated an introduction to design activity into ME350. This occurred approximately halfway through the course. The focus of this activity was to present a systematic decision making process that incorporated facets of the engineering design process, but in an abbreviated form to that provided in ME450. In particular, this activity presented the decision matrix (DECMAT), which has been a standard decision making tool used in Army organizations. Though used primarily for mission planning, it actually represents a compressed
design process. I believed that this would not only effectively present the general methodology of the engineering design process, but also provide the cadets with a useful tool after graduation to help provide justification and rationale for a recommendation they were asked to make.

RESULTS

Evaluation of the impact of the activity came from several sources. The primary ones used included:

- Personal observations
- Instructor journal entries
- Cadet survey results
- Grades comparison

Interesting and distinctive results were obtained from these various sources – some expected and some not.

Personal observations. One key aspect that I focused the introduction design activity on was on determining viable engineering requirements. Multiple facets are necessary to fully define one; however, a key element of any engineering requirement is that it must be quantitative, not qualitative. Understanding and making this distinction has consistently been a significant challenge during ME450. The DEC MAT activity was sufficiently structured to focus cadets on making that particular distinction. In general, this was successful, and has proven to reap continued rewards as the cadets quickly become attuned to ensuring that they maintain a quantitative component in their engineering requirements.

To date, I have seen no issues with the cadets choosing qualitative engineering requirements during ME450. In fact, cadets appeared to more readily and efficiently pick up the content of the course, which allowed them to have time to actually build existing products and collect the data for competitive benchmarking as a part of the first design project.

Cadet surveys. Survey data was collected from cadets at multiple points during their time in the mechanical engineering sequence. The first population surveyed represented cadets who had just completed the introduction to the design process in ME450 and had received no further instruction on the design process beyond that present in the existing course sequence. A consistent theme from their input was that they would have liked to have an introduction to the design process during ME350 given the format of ME450. Additionally, they were relatively
unclear about how to develop engineering requirements, some to the extent that uncertainty existed about ever being presented with the material.

A second survey point was at the end of ME350 which targeted their perceived understanding of engineering requirements and an assessment of whether the introduction to design activity was useful to their understanding and completion of the design project at the end of ME350. This included the same questions as the first group received, with additional ones added to specifically target the introduction to design activity. To this end, the general consensus was that the introduction to design activity was useful preparation for their design project. The process facilitated the understanding of engineering requirements, and though not confident to determine them independently, the understanding certainly existed on their essential quantifiable nature.

A third survey point occurred after completing the first EDP and engineering design process instruction during ME450. The group of cadets surveyed represented effectively the same population as that at the second survey point. Interestingly, there was some change in opinion, ultimately leading to more of a split decision on its effectiveness. Generally, there was consensus on the following topics:

- Sustain an introduction to design in ME350
  - Successful presentation of general underlying design concepts
  - Presented an intuitive process
- Discontinue design aspects in ME350
  - Two course completely different and should remain separate
  - Didn’t prepare for ME450 requirements

**Instructor journal entries.** Reviewing the content from a journal maintained during the implementation of the introduction to design activity which culminated with the introduction of the formal design process in ME450 reinforced the benefit generated from the activity. Cadets early on distinguished between quantitative and qualitative engineering requirements. In particular, instances occurred where cadets actively questioned how to quantify a design aspect they wanted to evaluate when they could only think of a qualifying one. Additionally, a few cadets in ME450 did not take ME350 last semester, thus, did not experience the introduction of the decision matrix and design process in ME350. During AI, it was apparent that they were challenged to determine quantitative engineering requirements. These cadets now, however, have full understanding of the concepts and can effectively determine quantitative engineering requirements and fully implement the design process.

**Grades Comparison.** To gain perspective on the impact the earlier integration of the design process had on cadet grades, the figure below compares the average performance of cadets
enrolled in ME450 during various terms leading up to term 09-2. Term 09-2 is the one where the cadets saw the decision matrix prior to learning the complete design process at the outset of ME450.

<table>
<thead>
<tr>
<th>Term</th>
<th>IPR 1 Design</th>
<th>EDP 1 Brief/Design</th>
<th>EDP 1 Report/Design</th>
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</thead>
<tbody>
<tr>
<td>07-1</td>
<td>87.75</td>
<td>85.76</td>
<td>78.56</td>
</tr>
<tr>
<td>08-1</td>
<td>88.25</td>
<td>96.00</td>
<td>73.46</td>
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<tr>
<td>08-2</td>
<td>92.25</td>
<td>86.33</td>
<td>55.92</td>
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<td>09-1</td>
<td>87.88</td>
<td>84.83</td>
<td>74.69</td>
</tr>
<tr>
<td>09-2</td>
<td>87.11*</td>
<td>88.89</td>
<td>88.75</td>
</tr>
</tbody>
</table>

*This value is adjusted to reflect the average score from the assignments turned in on-time.

**DISCUSSION**

Ultimately, more data would be useful to better evaluate the effectiveness of integrating the decision matrix into the curriculum of ME350. Instructor observations are essential. Having instructor continuity in continued assessment of the effectiveness of the decision matrix into the curriculum would be necessary for the veracity of observed trends. Survey results are also useful sources of information; however, they present their own interpretation and perspective challenges which could be normalized over time. There are a variety of other factors that also could not be accounted for in this assessment to include, but not limited to:

- Instructor continuity between ME350 and ME450. Previously, different instructors taught each course. This continuity potentially has an impact on the performance of the cadets.
- Varying grading styles. The grade information presented is from five different individuals. Though evaluation rubric remain constant, actual grading styles impact the overall averages. Given that some assignments have only small differences in scoring between terms, nuances of individual grading styles could noticeably impact the data.
- Inclusion of physical model building during EDP1. Prior to term 09-2, the initial project was only conducted on paper. The inclusion of this type of activity may have impacted the overall understanding and performance of the cadets.

What is evident; however, is that the inclusion of the decision matrix into the curriculum did not hinder cadets’ overall performance on the initial requirements in ME450. A positive trend exists towards a better overall performance as cadets progressed through the requirements that comprised the introduction of the design process.
CONCLUSIONS

Overall, the data supports that the inclusion of the decision matrix into ME350 created a value added experience for the cadets. Given the apparent positive impact that the decision matrix had on the initial cadet performance in ME450, coupled with the undeniable utility it has for the cadets as officers in the US Army, I believe that it should remain a part of the curriculum and serve as a segue to the explicit engineering design process.