AC 2008-1642: TEACHING ENGINEERING TO THE DISINTERESTED: A CASE STUDY IN TEACHING ENGINEERING PRINCIPLES TO NON-ENGINEERING MAJORS

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Teaching Engineering to the Disinterested: A Case Study in Teaching Engineering Principles to Non-Engineering Majors

Abstract

As our infrastructure ages, Civil Engineers, balanced by a firm core of social, economic and political theory, are a strategic asset for the future. Yet, the number of students that elect to undertake engineering majors for their undergraduate degree appears stagnated and even trending downwards in recent years. The Executive Director of the National Society of Professional Engineers, Patrick Natale, believes this trend is caused by selling the wrong message; that is, engineering is only the application of math and science. Rather, the message that should be communicated is that engineering is about innovative problem solving and creating what was not there before; about defining a problem and finding a new path to forge ahead; and building the future now. A medium for communicating this message is a broad-based introduction-to-engineering course early in the undergraduate curriculum. Many universities currently offer or are developing such courses. A consideration when developing these courses is the challenge of teaching engineering to those who are not fully committed to an engineering major. As a critical piece of the liberal education at the United States Military Academy, a sequence of engineering courses is required for all majors, including non-engineering majors. Many of the means and methods used in these courses are applicable to the introduction-to-engineering courses at other universities. This paper focuses on a semester-long Engineering Design Project (EDP) - used in the third sequence course - for the design and construction planning of a base-camp to house, support and sustain a given population. The EDP is developed within a broad math, science, social, economic, and political context. Base-camp objectives are developed based on population requirements, constraints governing the solution and necessary base-camp functions. Specific techniques used include trade-off decision analysis, using Google © SketchUp to communicate the design, and a "K'nex-ercise" to illustrate the construction process. This paper assesses the effectiveness of the EDP to deliver the contemporary engineering message - innovative problem solving for building the future - and outlines the applicability of the EDP in other universities.

Introduction

As our infrastructure ages, Civil Engineers, balanced by a firm core of social, economic and political theory, are a strategic asset for the future. Yet, the number of students that elect to undertake engineering majors for their undergraduate degree appears stagnated and even trending downwards in recent years[1]. The Executive Director of the National Society of Professional Engineers, Patrick Natale, believes this trend is caused by selling the wrong message; that is, engineering is only the application of math and science. Rather, the message that should be communicated is that engineering is about innovative problem solving and creating what was not there before; about defining a problem and finding a new path to forge ahead; and building the future now[2].

A medium for communicating this message is a broad-based introduction-to-engineering course early in the undergraduate curriculum. Many universities currently offer or are developing such courses. A consideration when developing these courses is the challenge of teaching engineering to those who are not fully committed to an engineering major or those in non-technical degrees who may not recognize the value of an engineering background for the techno-culture. At the United States Military Academy (USMA), a critical piece of the liberal education is a sequence of engineering courses, which is required for all majors, including non-engineering majors.

USMA offers three-course engineering sequences in a variety of engineering subdisciplines (civil, mechanical, electrical, etc). The three courses in the Civil Engineering sequence are: CE300, Fundamentals of Engineering Mechanics and Design; CE350, Design of Structures in the Theater of Operations; and, CE450, Infrastructure Development and Construction Management.

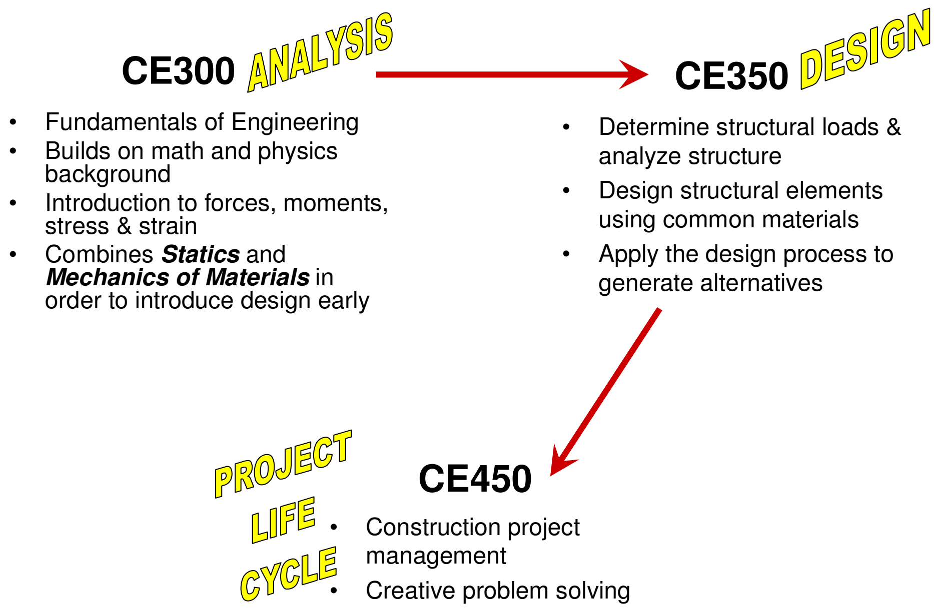


Figure 1 The Civil Engineering Three-Course Sequence for Non-Engineering Majors

As shown in Figure 1, CE300 students are introduced to statics and mechanics of materials. By the end of the course, they are able to analyze and design axial members (such as trusses and cables), beams, and torsional members[3]. CE350 provides instruction on designing structural members from common construction materials (wood, masonry, and concrete). This course takes the fundamentals developed in CE300 and applies them in the context of design codes. Understanding analysis procedures and current design codes, CE450 serves as an opportunity for the students to put their knowledge to use in a broader context.

CE450 focuses on the engineering design process (see Figure 2). While this process is introduced in CE300 and reinforced in CE350, it is not until the third course that students are able to apply their knowledge to a large engineering problem. This paper focuses on the semester-long Engineering Design Project (EDP) in CE450. In this project, students are required to design and develop a construction plan for a base-camp to house, support and sustain a given population.

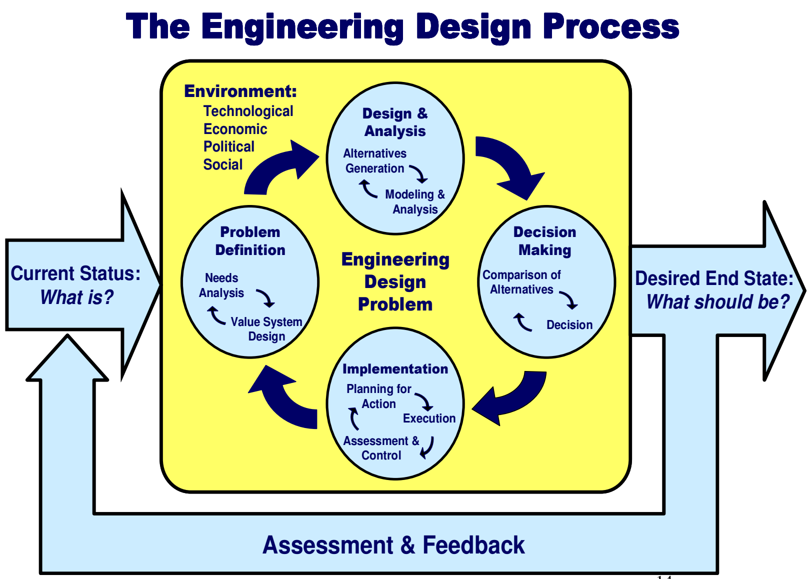


Figure 2 USMA Engineering Design Process Model[14]

The EDP is developed within a broad math, science, social, economic, and political context. Base-camp objectives are developed based on population requirements, constraints governing the solution and necessary base-camp functions. Specific techniques used include trade-off decision analysis, using Google © SketchUp to communicate the design, and a "K'nex-ercise" to illustrate the construction process. This paper assesses the effectiveness of the EDP to deliver the contemporary engineering message - innovative problem solving for building the future - and outlines the applicability of the EDP in other universities.

There are a number of benefits to be gained through this sequence of engineering courses for non-engineering majors – benefits for the student, the engineering programs, the engineering profession, and more broadly - society. Such a course provides a more liberal education for the students. In many universities, an engineering student is required to take a variety of liberal arts courses in order to provide that student with the well-rounded education necessary for success in today's world. However, those choosing non-technical degrees can often graduate by taking only a single math course and perhaps a science course. By requiring these students to also take an engineering course they will leave with a better understanding of the physical world and the engineering processes that improve it.

By offering an introduction to engineering course early in the undergraduate process, students are exposed to what engineering really is and the engineering faculty has an opportunity to overcome preconceived notions students may have. By doing so, students can make a more informed decision about their choice of major. This has two benefits: students studying what they are truly interested in and attracting students who may not have otherwise chosen to major in engineering. And that's the benefit to the profession: more engineers - who can serve the technical needs of society.

The paper is organized by presenting the appropriate taxonomies for assessing the effectiveness of the EDP, the background of the non-engineering students who enroll in the course with the EDP, the details of the EDP, and an assessment of the effectiveness of the EDP. A broad set of conclusions is drawn such that the EDP could be considered in other programs to achieve similar goals as presented in this paper.

Appropriate Taxonomies for Assessment

To assess the effectiveness of an engineering course for non-engineers with the EDP requires adopting a broader context of taxonomies than traditionally may be employed. A common approach is to utilize the work done by Benjamin Bloom's 1950's education committee. The committee established a set of taxonomies in three learning domains: cognitive, affective and psychomotor. The domains have been identified as, "arguably one of the most influential education monographs of the past half century [4]." The taxonomies are a language that is proposed to describe the progressive development of an individual in each domain and are defined as follows [5]:

- Cognitive: of, relating to, being, or involving conscious intellectual activity.
- Affective: relating to, arising from, or influencing feelings or emotions.
- Psychomotor: of or relating to motor action directly proceeding from mental activity.

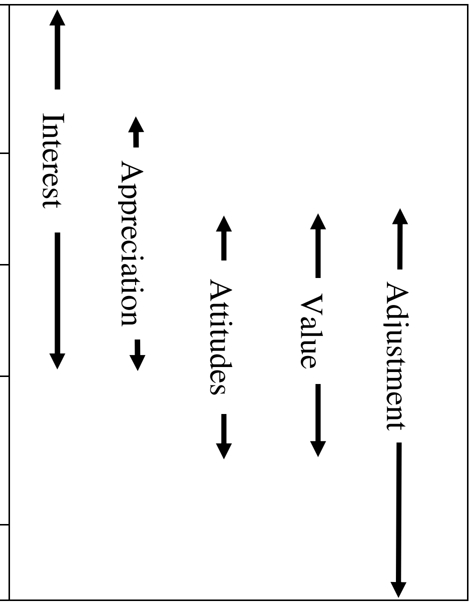
Of these domains, the cognitive is used to assess the development of knowledge[6]. However, recent works to be published by the American Society of Civil Engineers [7], Lynch et. al. [8], and Hanus et. al. [9] propose the necessity and advantage of using multiple domains, specifically in the areas or outcomes that require the development of knowledge (cognitive) and value (affective). The authors propose that these domains are appropriate to assess the effectiveness of the EDP in this paper and the domain categories are shown in Table 1 and 2, respectively.

Table 1 Cognitive Domain Categories and Sub-Categories[5]

1.0 Knowledge	1.1 Knowledge of Specifics 1.2 Knowledge of Ways and Means of Dealing with Specifics 1.3 Knowledge of the Universals and Abstractions in a Field
2.0 Comprehension	2.1 Translation 2.2 Interpretation 2.3 Extrapolation
3.0 Application	
4.0 Analysis	4.1 Analysis of Elements 4.2 Analysis of Relationships 4.3 Analysis of Organizational Principles
5.0 Synthesis	5.1 Production of a Unique Communication 5.2 Production of a Plan, or Proposed Set of Operations 5.3 Derivation of a Set of Abstract Relations
6.0 Evaluation	6.1 Judgment in Terms of Internal Evidence 6.2 Judgment in Terms of External Criteria

Table 2 Affective Domain Categories and Sub-Categories[10]

1.0 Receiving	1.1 Awareness 1.2 Willingness to Receive 1.3 Controlled or Selected Attention
2.0 Responding	2.1 Acquiescence in Responding 2.2 Willingness to Respond 2.3 Satisfaction in Response
3.0 Valuing	3.1 Acceptance of a Value 3.2 Preference for a Value 3.3 Commitment
4.0 Organization	4.1 Conceptualization of a Value 4.2 Organization of a Value System
5.0 Characterization by a Value Complex	5.1 Generalized Set 5.2 Characterization



In the following section it is shown that the students are challenged to achieve a high level in the cognitive domain – up to the evaluation category – in the EDP. The EDP develops in successive order high categories in the domain until completion and the base camp results are evaluated in a group presentation format. However, the authors consider the achievement of a high category in the affective domain as an equal goal for the EDP; that is, using the EDP to develop in the students an interest, an appreciation, and a value for engineering.

Background – The Disinterested

"I'm not an engineer and will never design a bridge, so why should I care?" Teachers at all levels wrestle constantly with student indifference and how to convince them of the importance of the curriculum to their professional lives. At the university level, one could hope that students *would* be more interested in classroom content since they are possibly more mature, potentially can extrapolate independently how it may impact their lives or, at least if for no other reason, most are paying (sooner or later) to be there. Students do begin to exert their freedom to choose curriculum during their sophomore or junior years by specializing in an academic major, but that does not necessarily ensure student interest in each course. Montmarquarette et. al., (1997) theorize that undergraduate students choose their major based upon probability of successful completion of the academic program and level of expected post-university earnings, rather than interest in the subject matter alone.[11] Perceived 'probability of academic success' seems to support Mr. Natale's belief that the focus on math and science as a major part of engineering may be the wrong message to sell.

The three-course engineering sequence requirement at USMA places non-engineering students in challenging engineering classes, two of which are virtually identical to those taken by Civil Engineering (CE) majors. However, in a recent semester, 46% of the 108 students enrolled in the CE core sequence did not choose it and many perceive that they lack the aptitude in math and science to be successful in these courses. Lack of interest and motivation to learn the material causes many of the students to view these three classes as merely another barrier to graduation with little relevance to their success later in life.

Student surveys conducted in CE450 at the beginning of a recent semester showed that only 8 of the 95 expressed an interest in civil engineering and only 6 considered branching into the Army Corps of Engineers following graduation. Clearly, the majority demonstrates very little interest in pursuing a future related to engineering and perceives the engineering courses to have little relevance to their life or career. The following list breaks down the majors in the population surveyed:

- Economics (17) – 17.9%
- Foreign Language Studies (16) – 16.8%
- History (15) – 15.8%
- Political Science (12) – 12.6%
- Management (10) – 10.5%
- Philosophy (5) – 5.3 %
- Law (4) – 4.2%
- Leadership/Military Art (4) – 6.3%
- Math/Physics (4) – 4.2%
- Geography/Geospatial Information Systems (3) – 3.1 %
- Life Science (2) – 2.1%
- Physics (2) – 2.1%
- Psychology (1) – 1.0%

The Base Camp Engineering Design Problem

This paper refers to civil engineering in the broad sense as a "discipline that deals with the design, construction and maintenance of the physical and natural built environment…" [12] or simply, civil infrastructure. The third course of the CE core sequence at USMA, CE450, approaches fundamental civil engineering principles at the macro level as a means to teach construction project management skills of planning, organizing, estimating, scheduling and controlling. To accomplish this, CE450 students complete a semester-long EDP with a simple, open-ended, problem statement: "Design a base camp in a select foreign country to support military operations for a given population of military units, their personnel and organizational equipment."

In its current state, this EDP introduces several civil infrastructure topics. The students use an air deployable package of equipment nicknamed "BEAR," or **B**asic **E**xpeditionary **A**irfield **R**esources, as the building block for their base camp designs. Students determine base camp requirements during the problem definition phase based on basic human needs planning factors. Students determine the tent (housing), electrical power, fuel storage, and potable and non-potable water requirements along with solid waste and waste water generated per day by the base camp population. Next, students develop power generation, water purification and water storage systems and a fuel storage plan. They also develop a plan to properly dispose of waste from BEAR package components. Students then determine physical security requirements for a perimeter fence and shipping container bunkers and generate base camp layouts using bubble diagrams, affinity matrices and Google © SketchUp to communicate their design logic. Additionally, students must anticipate and plan for growth of the population. The students estimate activity durations and develop a comprehensive construction schedule. Finally, the students are exposed to soils and transportation engineering through ground access road design for a given wheeled traffic density and airfield flexible pavement evaluation based on certain aircraft types.

Though the EDP scenario for CE450 is a military base camp, the scenario can easily be restructured for a humanitarian relief scenario. In fact, the second homework assignment in the course requires students to develop a plan for an emergency refugee camp after Hurricane Katrina. This assignment provides students with an opportunity to practice defining the problem and determining base camp design requirements. In the humanitarian base camp scenario, students could develop their base camp designs using a selection of off-the-shelf generators, potable and non-potable water supply systems, on-site water purification systems, commercial tents, portable toilets or any other available temporary systems. Figure 3 shows an example base camp layout for the humanitarian problem set using Google © SketchUp.

Figure 3 Example Humanitarian Base Camp Layout using Google © SketchUp

The base camp EDP introduces students to infrastructure management, construction planning, soils and transportation engineering, environmental engineering and a few other faces of civil engineering at the macro level. The scenario can be easily modified or restructured to introduce other facets of civil engineering such as hydrology (rain water runoff and flooding), levees or cofferdams using sandbags and even simple structural design using wood or concrete.

Emergency and disaster management scenarios open the door wide for practically any approach to civil engineering issues. One is limited only by their imagination.

Teaching Fundamental Engineering Principles through a Global Learning Lens

Though the EDP does not result in a structural design, students must apply the Engineering Design Process (see Figure 2) to define the problem; generate, analyze and evaluate alternatives; decide; and communicate a plan to implement the design. In conjunction with reviewing the Engineering Design Process, the CE450 instructors illustrate similarities to the Army Problem Solving Process (Figure 4) in order generate student interest and demonstrate relevance to their future in the Army. This is a consistent theme throughout the course: engineering is not simply math and science, but a logical methodology for finding innovative solutions to challenging and often ambiguous problems.

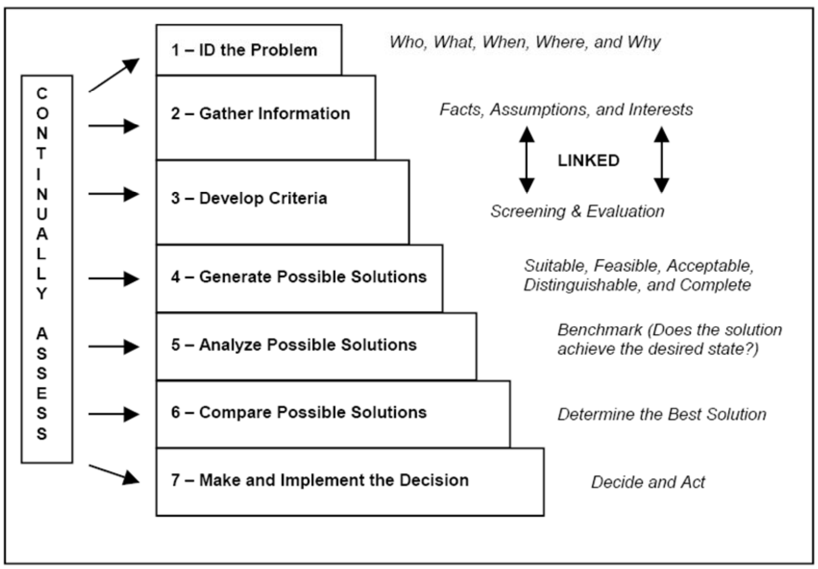


Figure 2-1. Seven Step Problem-Solving Model

**From FM 5-0, Army Planning and Orders Production

Figure 4 U.S. Army Problem Solving Process[13]

Early in the course, CE450 instructors walk the students through the problem definition phase of the base camp design using the method depicted in Figure 5. This deliberate explanation serves a number of purposes. It demonstrates the correct implementation of the problem definition process, provides an introduction to the base camp EDP and sets the stage for a follow-on discussion of how constraints and requirements develop into design requirements during the conceptual design phase. This process is reinforced in another lesson where the students develop a design of their own house in order to develop a Square Footage estimate.

Problem Definition Phase

- Problem Statement (5 W's)
- Clarify Objectives
- Define User Requirements
- Establish Constraints
- Determine Required Functions

Figure 5 Problem Definition Phase

Perhaps most important, however, a deliberate presentation of the problem definition process demonstrates to the students a logical method to determine what one knows about a problem and what portions may require research or reasonable assumptions. Admittedly, the students have very little to no experience with a base camp, let alone how to design one. It is a complex and multi-faceted problem. The base camp EDP presents the students with an ambiguous problem that can have multiple feasible solutions: a situation that is rarely encountered in undergraduate academics.

An ambiguous Engineering Design Problem, like that posed by the base camp design, can both excite and frustrate students. As already stated, this could be a unique situation for a young student. Many students, particularly those that are not greatly interested in the subject matter, desire a clearly defined solution path, a process they must learn and simply re-apply to a similar problem, which ultimately results in one correct solution and clearly defined success criteria. In fact, the math and science oriented students may exhibit the most frustration. They are often uncomfortable with not knowing if they have a "correct" solution. However, when presented properly and perhaps with guided coaching to make the right connections, the logical application of the macro Engineering Design Process to an ambiguous problem can excite students.

Introduce Basic Engineering Concepts through Elements of the Base Camp Design

The EDP exposes students to fundamental engineering concepts such as forces, moments, compression, tension and stress through design of elements of the base camp. In its current state, CE450 does this through the design of base camp access roads, machine power in heavy/highway construction and the end-of-course K'NEXercise.

In road design, students are introduced to soil-structure interaction, soil properties and the action of compaction to achieve desired results. With flexible pavements, the force exerted on the road surface is distributed in an inverted cone downward into the soil over gradually increasing area thereby reducing the stress on weaker subsurface soils. Students must understand basic properties of soils gathered through sampling results such as gradation, plastic and liquid limits in order to determine the design strength (California Bearing Ratio – CBR) of a given soil layer in the road cross-section. An example of the road design students produce is shown in Figure 6. Students in CE450 use an established process outlined in the U.S. Army road design field manual (FM 5-430-00-1) to complete the design (many state departments of transportation have similar documented processes). The desired end state for this exercise is an understanding of the concepts rather than all of the supporting calculations.

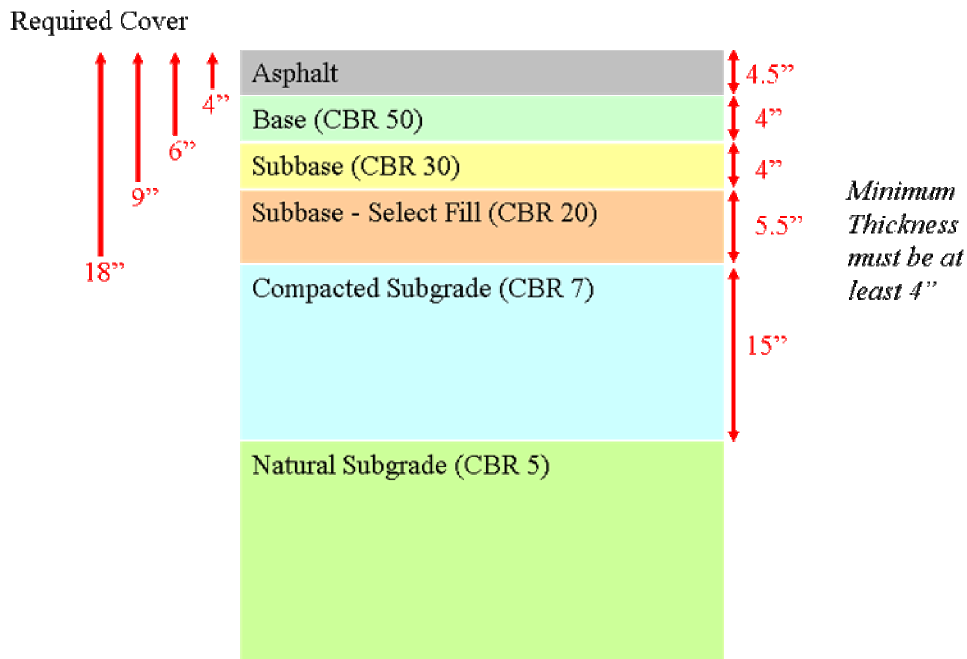


Figure 6 Example Road Design Cross-Section

CE450 reinforces physical science, mechanical engineering and systems engineering concepts through a block of classes on highway construction and excavation. Again, students are exposed to properties of soils as a representative soil sample changes volume through induction of air voids when excavated from its in situ (bank) state to its loose state during transportation and finally expulsion of air voids during compaction. In a class on machine power, students learn how site conditions (including surface soil conditions, site set up and slope of haul routes) affect performance and productivity of construction machinery. Students select construction equipment to efficiently excavate a section of linear roadway and excavate the location for the fuel farm in their base camp. This instruction is supported by technical performance and specification information produced by Caterpillar for their line of construction equipment (other manufacturers produce similar, readily available, information). As in the road design, the focus of this exercise is not on complex calculations but understanding the concepts.

The concepts of forces (compression and tension), moments and performance of fundamental structural elements is accomplished through the design and construction of a simple structure in a fun exercise. The K'NEXercise, in its current form, requires students to design and construct a bridge within the context of the EDP scenario using the popular children's construction toy as building blocks. During construction, students see how a bridge, designed as a simply supported beam, acts like a cantilever beam during construction (Figure 7). The pier in the river in Figure 8 was a "fix" to the design when the students realized their error (at a considerable monetary cost). Figure 8 illustrates a finished bridge being "load tested." Figure 9 illustrates a student design for temporary construction to carry construction loads. Following the load test, the bridge is progressively loaded with heavier loads (Figure 10) until the structure begins to fail. As seen in

Figure 11, the connections along the tension chord of the bridge are oriented to successfully carry the load. However, if those connections are rotated 90 degrees to the left or right, as often happens during construction, the connections pull apart and fail. The students see how a structure acts under load.

Figure 7 Students Discover Construction Stresses

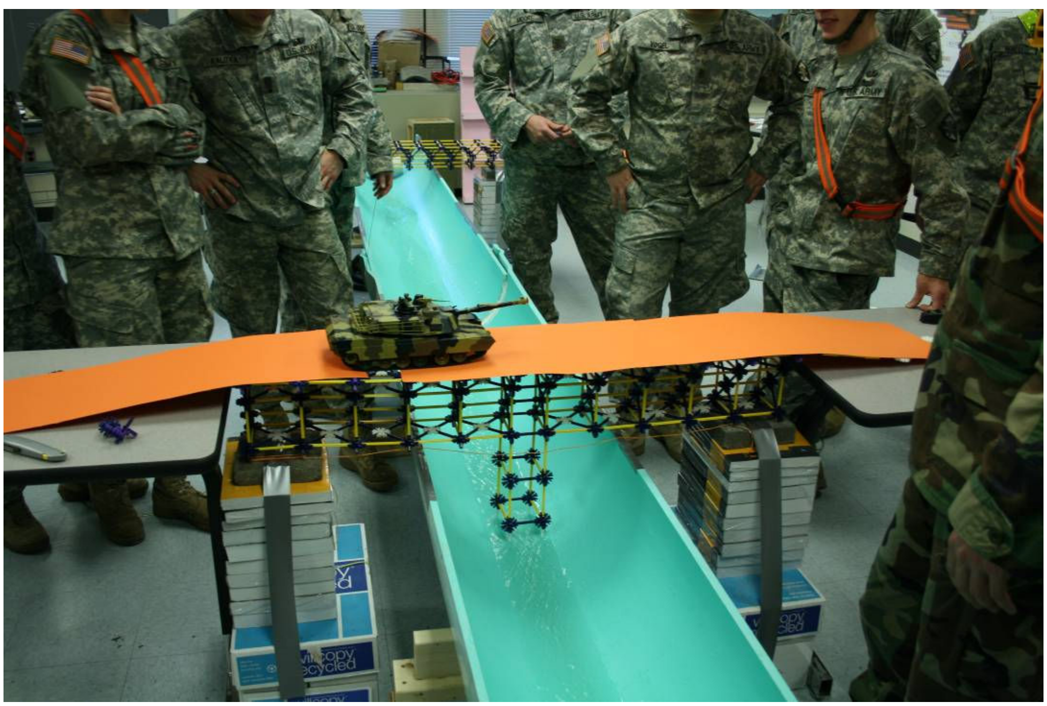


Figure 8 Load Testing of a Student Bridge

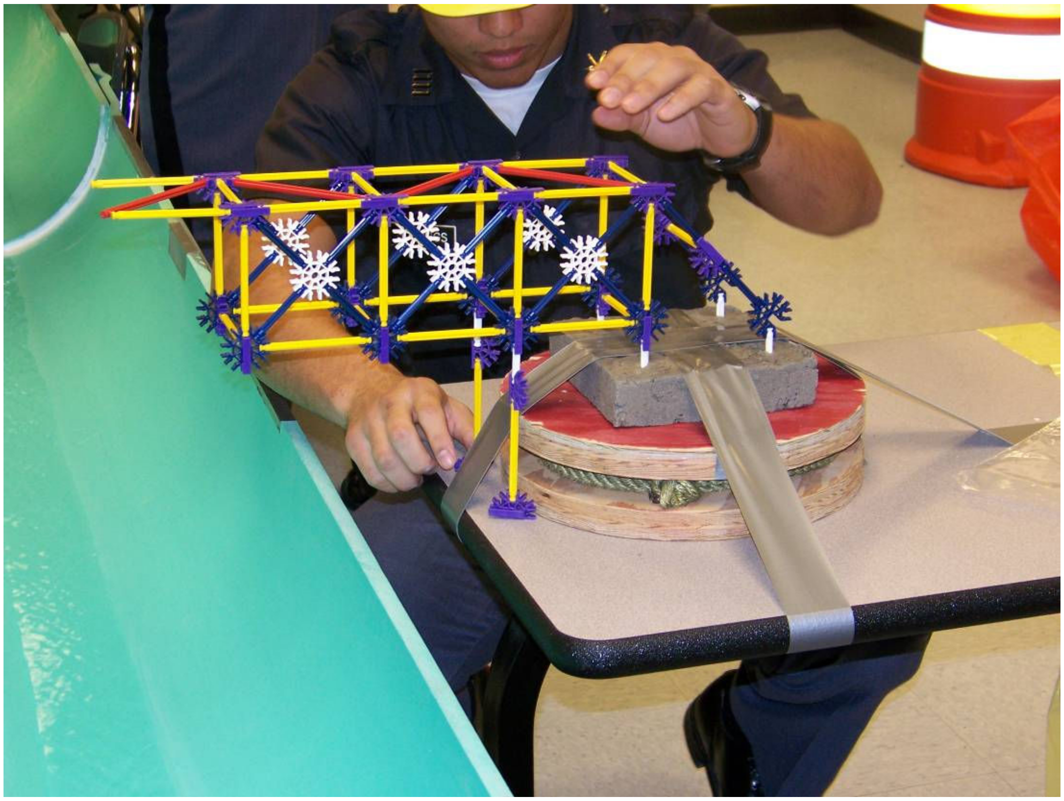


Figure 9 Student Design Accounts for Construction Forces

Figure 10 Progressive Loading of Student Structures

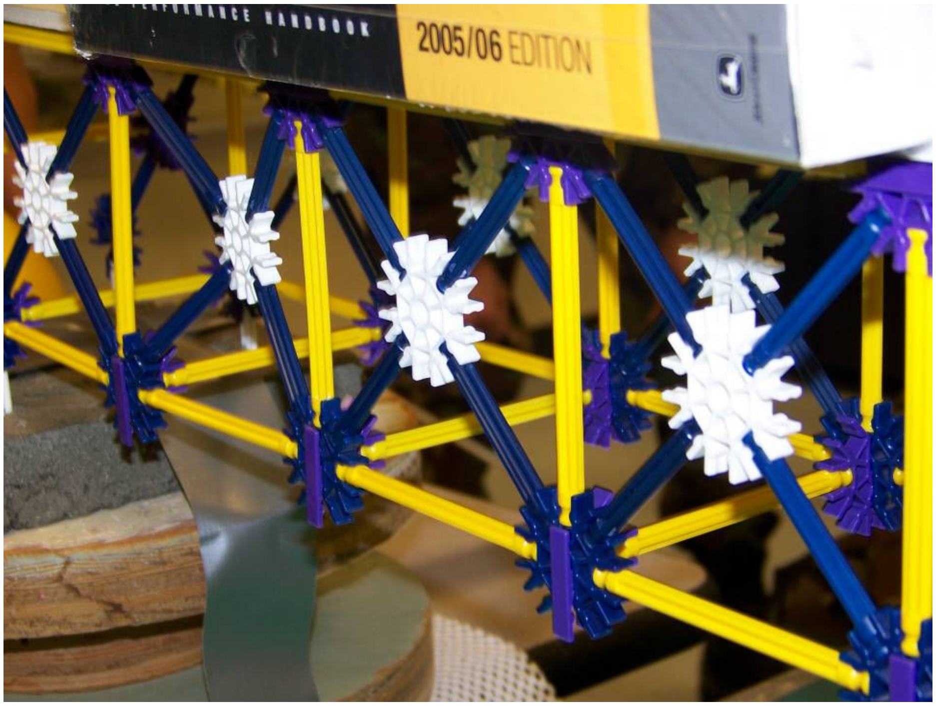


Figure 11 Tension Chord Connections

Assessing the Effectiveness of the EDP

Qualitative and quantitative data was considered in assessing whether the EDP achieved the desired categories in the cognitive and affective domains, as previously discussed. Data from the last completed term, Fall 2007, was included in this assessment. The first data set considered was the student's performance in the EDP relative to their incoming grade point average (GPA). The students entered the course with an average GPA of 3.01 on a 4.00 point scale. The students achieved an average score of 586/650 points (90.1% or 3.67) on the EDP. This net increase indicates that the students did learn the engineering skills necessary for success in the EDP and likely developed an appreciation for those skills in achieving their grades.

The second set of data considered came from the end-of-course survey administered across the institution for all courses. Of particular interest were four areas related to learning and techniques used in the course. The four areas are shown in Figure 12 with data from the institution and the course. The survey scale measured from disagree to agree on a five point scale, with a [5] representing "Strongly Agree". As can be seen in the data, the course results exceeded the institution results in all four areas. The authors recognize that the data is representative of the course as a whole, but the EDP was a significant event in the course and the results to some degree transcend to this assessment.

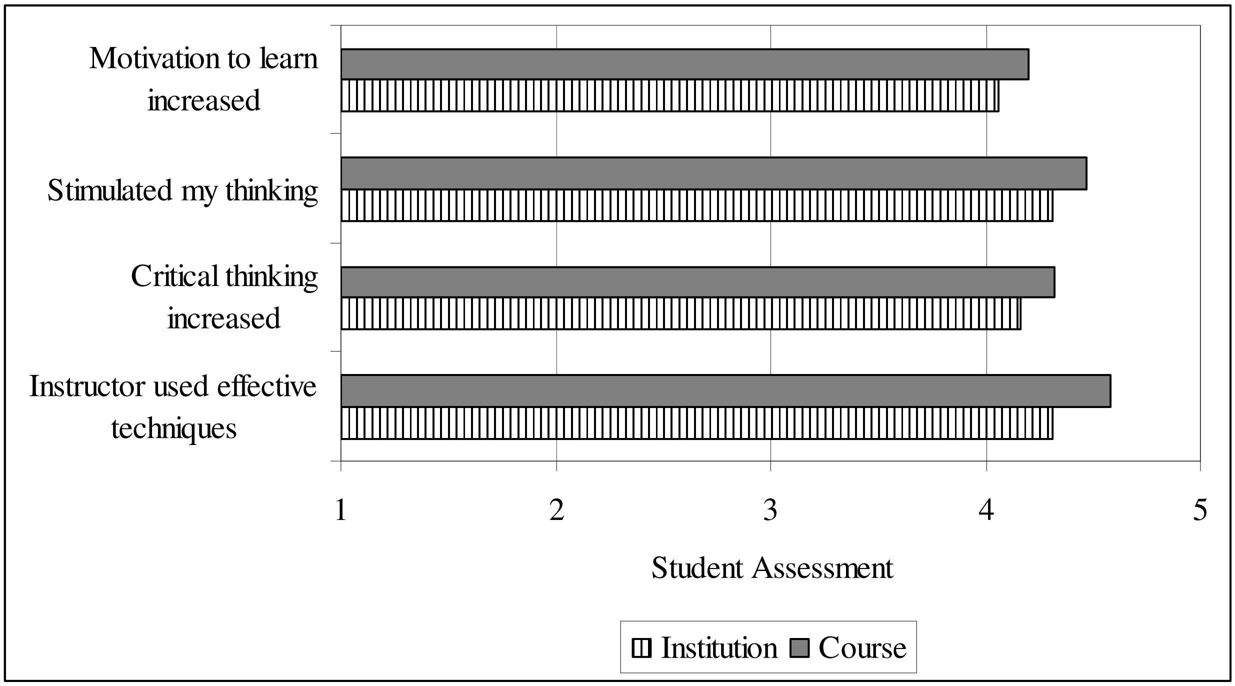


Figure 12 End-of-Course Survey Results

In addition to the data discussed above, anecdotal evidence is compelling that the students achieved the high categories in the cognitive and affective domains through the EDP. In open text questions associated with the end-of-course survey, student responses frequently praised the EDP in a manner such as:

What did you learn in this course that will be of help to you in the future?

- *Anything that had to do with the EDP.*
- *The engineering design process which I feel is just a generally good way to approach a problem*
- *The EDP and KNEXercise were a lot of fun and probably the most invaluable of experiences I have had during this track - they taught from a big picture in how different things must work together (social, political, economic, technology).*

As evidence of how students changed their interest level and how they "valued" engineering after their CE450 experience, examples of student feedback to open response questions are:

- *Were it not for the fact that I hated math, I definitely would have majored in your department.*
- *Increase- I've never been that interested in construction type projects, but now I am enough to learn more about it for my own projects one day.*
- *It is about what I expected... and I have a strong interest to continue to learn about CE*

Additional observations beyond the survey were interesting for students that are gifted in both the physical and liberal arts, but not interested in being an "engineer" because of perceptions about the field. The authors believe these students begin to appreciate an alternative problem solving process, which may not be present in their non-engineering major. Some students become excited about their ability to use creativity to develop a feasible solution to an "engineering problem." The gem is when one of the especially strong students (that somehow did not major in engineering) approach the instructor after class and state that they "never knew engineering was like this." Usually that is followed by an "I wish…" statement. They suddenly understand that engineering is not simply numbers and scientific processes; it is an understanding of how the world works around them and developing innovative solutions to the challenging problems in it. The authors propose that this could not be achieved by knowledge alone, but student feedback like this demonstrates the achievement of a higher category in the affective domain. Overall, the authors believe that the students achieved up to the evaluation category in the cognitive domain and at least to the value category in the affective domain.

Conclusions

In order to overcome the dire strategic problem for the United States of dwindling enrollments in math, science and engineering majors, universities must find ways to expose students to engineering early in their undergraduate studies using higher levels in the Cognitive and Affective Domains. The EDP presented in this paper achieves this by teaching fundamental engineering knowledge and inspiring in the students increased value of that knowledge. Students must not only value engineering and the potential reward to a career in engineering after graduation, but also perceive a reasonable probability of attaining that success. This paper by no means advocates a lowering of the standard for engineering majors; incapable students should not become engineers. But there is a large, untapped population of extremely bright and capable students that simply do not know what civil engineering is, let alone what engineers do. A well-thought out introduction-to-engineering freshman class or high school outreach program can generate excitement and interest in engineering early enough to affect major and career decisions.

This paper advocates the use of a temporary base camp Engineering Design Problem as an excellent vehicle to introduce students to the many faces of Civil Engineering. The base camp EDP conforms easily to the development, design, construction and management of infrastructure systems. Individual blocks of instruction and elements of the EDP can be structured at the global level to teach fundamental engineering principles and develop engineering judgment. After all, the message we may want to convey is that we need innovative problem solvers schooled in engineering judgment, not engineers that can be problem solvers.

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