Engineering Connections: Teaching Engineering Mechanics to K-12 Teachers

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Abstract

This paper describes an innovative course designed for K-12 educators to integrate engineering principles in mathematics and science curricula. "Engineering Connections" was first offered as an experimental summer workshop for practicing teachers and will continue as a semester course for preservice teachers in spring, 2000. The course is constructed as a study of three modules: force, levers, and gears; principles of bridge design; and electricity. Students experience hands-on, inquiry-based instruction through simple investigations and apply engineering concepts in a four-week internship. This paper presents the course objectives and content, the teaching and learning model, and the student-conducted experiments.

Introduction

Competency in science and mathematics is regarded as a basic skill for high school graduates. Similarly, making connections among mathematics and other disciplines[1] and among science and other disciplines[2] are key components of professional standards for K-12 teachers. Connections between mathematics and science provide natural opportunities for students to engage in active study of both disciplines[3]. An exceptionally appropriate field of study in which to integrate these two practices is engineering. "The component of technology most closely allied to scientific inquiry and to mathematical modeling is engineering"[4].

A surprisingly high percentage of middle school students express a desire for a career in science or engineering. That preference, unfortunately, declines as students move to upper level classes[5] and find science, mathematics, and engineering courses as "dull and unwelcoming"[6]. For many students, "The way science and math are taught critically affects their interest and later participation in science and engineering"[7]. If this is the case, then the responsibility falls primarily on the teaching profession. A report to the National Science Foundation recommends that colleges and universities employ science, mathematics, and engineering departments to work collaboratively with departments of education, the K-12 sector, and the business world to improve the preparation of K-12 teachers.[8]

Course Development

"Engineering Connections" is a semester course designed to provide elementary and secondary education majors with a foundation of engineering concepts and a means of applying mathematics and science curricula. The content of the class focuses on three units of study:

force, as demonstrated through levers and gears; engineering principles that affect bridge design such as stress, strain, and buckling; and components of electricity. The unit on electricity is not addressed in this paper. Course goals involve making a connection between science and engineering, between mathematics and engineering, introducing engineering concepts in the elementary classroom, and experiencing engineering design. Two developments in education directly relate to these goals: the supported theory that students learn by "constructing" knowledge and the integration of the National Science Standards in K-12 science curriculum.

Educators are becoming aware that coursework must move from a traditional approach where learning is viewed as absorbing or passively receiving knowledge to the theory that knowledge is constructed by the learner and made meaningful through experiences. Constructivism, a learning theory that has received support from cognitive research, suggests that learners actively construct knowledge by integrating new information into what they already understand. Through active inquiry and contextual learning, old knowledge is revised and reinterpreted as one makes sense with the new[9]. Experiencing hands-on, inquiry-based instruction allows the student to internalize information.

The National Science Education Standards[10] call for students to be able to develop and learn subject matter disciplines in the context of scientific inquiry and integrate all aspects of science content. Similarly, the National Mathematics Standards[11] call for students to actively engage in resolving worthwhile mathematical tasks and to make connections within mathematics as well as between mathematics and other disciplines. Both sets of standards articulate a clear vision for changing the current views about mathematics and science teaching and learning. As the nation moves towards integrating national science and mathematics standards within course curricula, it is important to model this within coursework designed for future educators as well.

In the following section, the course is broken into specific course topics. Each topic is then related to one or more national standard for both mathematics and science. The reader will notice some repetition in the mathematics and science standards highlighting each topic. This serves to verify the idea that engineering is a powerful context in which a teacher can synthesize several elements of a school curriculum.

Student-conducted Experiments

With these views in mind, the course instructor developed simple student-conducted experiments to demonstrate engineering concepts.

Levers

Students discover the concept of a moment and static equilibrium of moments by conducting experiments using various classes of levers.

National Mathematics Curriculum Standards Grades 5-8

Standard 12: Geometry

- explore transformation of geometric figures
- identify, describe, compare and classify geometric figures

- visualize and represent geometric figures with special attention to developing spatial sense

Standard 7: Computation and Estimation
- compute with integers and rational numbers
- develop, analyze, and explain methods for solving proportions

Standard 9: Algebra
- understand the concepts of variable, expression, and equation
- analyze tables and graphs to identify properties and relationships
- apply algebraic methods to solve a variety of real-world and mathematical problems

National Mathematics Curriculum Standards Grades 9-12

Standard 8: Geometry from an Algebraic Perspective
- deduce properties of figures using transformations and using coordinates;
- analyze properties of Euclidean transformations and relate translations to vectors;
- deduce properties of figures using vectors;
- apply transformations, coordinates, and vectors in problem solving.

Standard 5: Algebra
- represent situations that involve variable quantities with expressions, equations, and inequalities
- solve equations and inequalities

Gears

Students apply moment equilibrium learned in the levers session to determine force and torque in simple gear systems. Hobby store plastic gears are used to illustrate rotational angle ratio, gear ratio, and torque transfer. Power is defined and how power is transferred through a gear train is investigated.

National Mathematics Curriculum Standards Grades 5-8

Standard 12: Geometry
- explore transformation of geometric figures

Standard 7: Computation and Estimation
- compute with integers, and rational numbers
- develop, analyze, and explain methods for solving proportions

Standard 13: Measurement
- extend students' understanding of the process of measurement

- select appropriate units and tools to measure to the degree of accuracy required in a particular situation
- extend students' understanding of the concepts of area, volume, angle measure, and weight & mass

National Mathematics Curriculum Standards Grades 9-12

Standard 8: Geometry from an Algebraic Perspective
- deduce properties of figures using transformations and using coordinates;
- analyze properties of Euclidean transformations and relate translations to vectors;
- deduce properties of figures using vectors;
- apply transformations, coordinates, and vectors in problem solving.

Standard 5: Algebra
- represent situations that involve variable quantities with expressions, equations, and inequalities
- solve equations and inequalities

Standard 9: Trigonometry
- apply trigonometry to problem situations involving triangles

Bridges

A series of lessons and experiments are used to give practical knowledge about how material characteristics must be taken into account in a bridge design. A stability unit is used to introduce tresses used in the truss unit, and shear stresses and panels used in buildings, furniture, torsion, and wings.

National Mathematics Curriculum Standards Grades 5-8

Standard 12: Geometry
- explore transformation of geometric figures

Standard 7: Computation and Estimation
- compute with decimals, integers and rational numbers
- develop, analyze, and explain methods for solving proportions

Standard 9: Algebra
- understand the concepts of variable, expression, and equation
- analyze tables and graphs to identify properties and relationships
- apply algebraic methods to solve a variety of real-world problems

National Mathematics Curriculum Standards Grades 9-12

Standard 8: Geometry from an Algebraic Perspective

- deduce properties of figures using transformations and using coordinates;
- analyze properties of Euclidean transformations and relate translations to vectors;
- deduce properties of figures using vectors;
- apply transformations, coordinates, and vectors in problem solving.

Standard 5: Algebra
- represent situations that involve variable quantities with expressions, equations, and inequalities
- solve equations and inequalities

Standard 9: Trigonometry
- apply trigonometry to problem situations involving triangles

Material Failure

The first experiments include the use of various-sized, latex rubber tubing. Two or more lines are inked onto the tubing to establish the gage lengths while relatively small weights can be used to stretch the tubing. A series of tests vary both the gage lengths and the cross-section. An analysis of the axial load deformations obtained from different cross-sectional members allows students to discover the concepts of stress, strain, and proportional limit.

Balsa/bass wood cantilever beams are used to determine the effects of beam width and height along with load position on the load carrying capability. The controlled experiments are used to hypothesize a relationship between the variables and load capability. The flexure formula is introduced along with yield and ultimate strengths. The concepts are extended to structural materials.

A wooden apparatus was fabricated for beam testing in order to obtain the Euler buckling load. The apparatus is a tabletop sized, and it is adjustable for different column lengths. The effects of column length and beam cross section are explored and quantified. Plastic I-beams and rectangular beams available at hobby shops are used in the experiments.

National Mathematics Curriculum Standards Grades 5-8

Standard 7: Computation and Estimation
- compute with integers and rational numbers
- develop, analyze, and explain methods for solving proportions

Standard 9: Algebra
- understand the concepts of variable, expression, and equation
- analyze tables and graphs to identify properties and relationships
- apply algebraic methods to solve a variety of real-world problems

National Mathematics Curriculum Standards Grades 9-12

Standard 8: Geometry from an Algebraic Perspective

- deduce properties of figures using transformations and using coordinates;
- analyze properties of Euclidean transformations and relate translations to vectors;
- deduce properties of figures using vectors;
- apply transformations, coordinates, and vectors in problem solving.

Standard 5: Algebra

- represent situations that involve variable quantities with expressions, equations, and inequalities
- solve equations and inequalities

Standard 9: Trigonometry

- apply trigonometry to problem situations involving triangles

Shear

A small wooden rectangular frame is pinned at the corners. The students stiffen the panels using both tension members (string is used as a tress) and shear panels (paper or cardboard). Latex tubing is used to illustrate the shearing action in torsion.

National Mathematics Curriculum Standards Grades K-4

Standard 9: Geometry and Spatial Sense

- investigate and predict the results of combining, subdividing and changing shapes
- relate geometric ideas to number and measurement ideas
- recognize and appreciate geometry in their world

National Mathematics Curriculum Standards Grades 5-8

Standard 12: Geometry

- explore transformation of geometric figures

National Mathematics Curriculum Standards Grades 9-12

Standard 12: Geometry

- explore transformation of geometric figures
- identify, describe, compare and classify geometric figures
- visualize and represent geometric figures with special attention to developing spatial sense

Design

Two and five member pinned trusses are analyzed using the method of joints. The engineering uses of trigonometry, simultaneous equations, and equilibrium are highlighted. A Java applet is used to verify the results. The selection of I-beams is conducted using the tensile and compression failure criteria. The applet is used to design a truss with specified span and load and judged on a load/weight criterion.

National Mathematics Curriculum Standards Grades 5-8

Standard 12: Geometry

- explore transformation of geometric figures

Standard 7: Computation and Estimation

- compute with integers, and rational numbers
- develop, analyze, and explain methods for solving proportions

Standard 13: Measurement

- extend students' understanding of the process of measurement
- select appropriate units and tools to measure to the degree of accuracy required in a particular situation
- extend students' understanding of the concepts of area, volume, angle measure, and weight & mass

National Mathematics Curriculum Standards Grades 9-12

Standard 8: Geometry from an Algebraic perspective

- deduce properties of figures using transformations and using coordinates;
- analyze properties of Euclidean transformations and relate translations to vectors;
- deduce properties of figures using vectors;
- apply transformations, coordinates, and vectors in problem solving.

Standard 5: Algebra

- represent situations that involve variable quantities with expressions, equations, and inequalities
- solve equations and inequalities

Standard 9: Trigonometry

- apply trigonometry to problem situations involving triangles

Summary

Elementary and secondary teachers must have practical knowledge of engineering in order to guide their students in exploration of the world of engineering. Including engineering ideas in the existing mathematics and science curricula would provide the students with more options and deeper understandings of these content areas. When students have deeper understandings of

critical areas such as mathematics and science, career doors are opened. Students with greater content knowledge will have more opportunity to make decisions about their own futures rather than finding themselves locked into one lane with a limited view of mathematics and science. And as a result of an increased proficiency among students, the pool of potential engineers, scientists, and mathematicians would be larger, more diverse, and better able to meet the national demand for a greater number of professional workers.

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