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JUNE 22 - 26, 2020 #ASEEVC
Paper ID #29395

Classroom Demonstration Module for Two and Three Dimensional Force Analysis : The Montessori Based Engineering (MBE) Model

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Abstract:
Statics or Engineering Mechanics 1 is a fundamental course for most engineering disciplines and includes topics such as force systems, equilibrium, truss analysis, centroid, and moment of inertia. Statics or Engineering Mechanics 1 is typically taught in the first semester of the sophomore year of the four-year engineering degree. It is usually observed that this is a difficult course for students and the passing rate is 60.7% [1]. The author implemented a variety of methods to reduce the failure rate of students in this class. These methods included some hands-on demonstrations based on the ExCEEd model and the Montessori method of education. Hands-on models when used in combination with other active learning methods are engaging and useful in maintain student interest [4]. The learning materials are one of the two main aspects of Montessori classrooms that are different from the conventional classroom [6]. The use of this method has been limited to K-8 classrooms. In this paper, the authors will describe the classroom demonstration for two- and three-dimensional force analysis, which would be appropriate for use in the Undergraduate Engineering Statics class. Core aspects of the Montessori method, like introducing the color/shape/method scheme with a familiar topic and using the same scheme to introduce a complex topic is done with the intention of making learning accessible to all different types of learners. In this paper the authors introduce the scheme for two-dimensional analysis and then furthers the scheme for three dimensional models. The assessment of this method which shows clearer understanding of the concepts and increased student enthusiasm is provided in this paper. The procedure for making these models, along with textbook examples for use in the classroom are also presented in this paper.

Introduction:
The Montessori method is based on the principle of auto education. When a proper prepared environment is built, the eager mind teaches itself. The learning happens through play, and the result is that the child learns in a way that cannot be forgotten at the end of the semester. This method was developed by Dr. Maria Montessori to teach preschool age children and is a popular method of education in younger children. In this paper, the authors try to bring some aspects of the Maria Montessori method to Engineering Education and call this the MBE (Montessori Based Engineering) Model.

Literature review:
While developing the MBE model, the authors looked at existing models popular in engineering education. This included the active learning model, the flipped classroom model and the ExCEEd model.

Active learning model: In this model, students are active participants in learning. This model has been gaining popularity in engineering education. The MBE model takes the active learning to a new level, with the addition of auto learning concepts.

Flipped classroom model: This model encourages the student to learn the content before class and use the class time for deeper understanding. The MBE model uses the intrinsic knowledge and curiosity of the student. It is heavily based on prior knowledge. However, the student is not required to do mandatory assignments prior to class.

ExCEEd model [2]: is model discourages the use of PowerPoint presentations in class and encourages the use of the whiteboard. The model also encourages the use of in-class demonstrations. The MBE model is based on the ExCEEd model because it uses the demonstrations. However, ExCEEd model does not require any co-relation between demonstrations in the various demonstrations throughout the semester. The MBE model uses the first model to establish the criteria and uses this to further the knowledge throughout the semester.

MBE Model:
The Montessori Method of education, among other things, encourages use of material of the same color, shape etc., while introducing the familiar topic. This is done with the intention of making learning accessible to all different types of learners.

Color scheme for the two-dimensional vector:
In this demonstration, the x-component of a two-dimensional vector was decided as always being the color blue, the y-component of a two-dimensional vector was decided as always being the color yellow. This was done to match with the primary colors, yellow and blue. A vector in the x-y plane would be green in color. This makes it intuitive that a green vector would always have components which are blue (x-component) and yellow (y-component).
This color scheme is gently introduced to the students using problems such as the one given below in Figure 1, 2 and 3

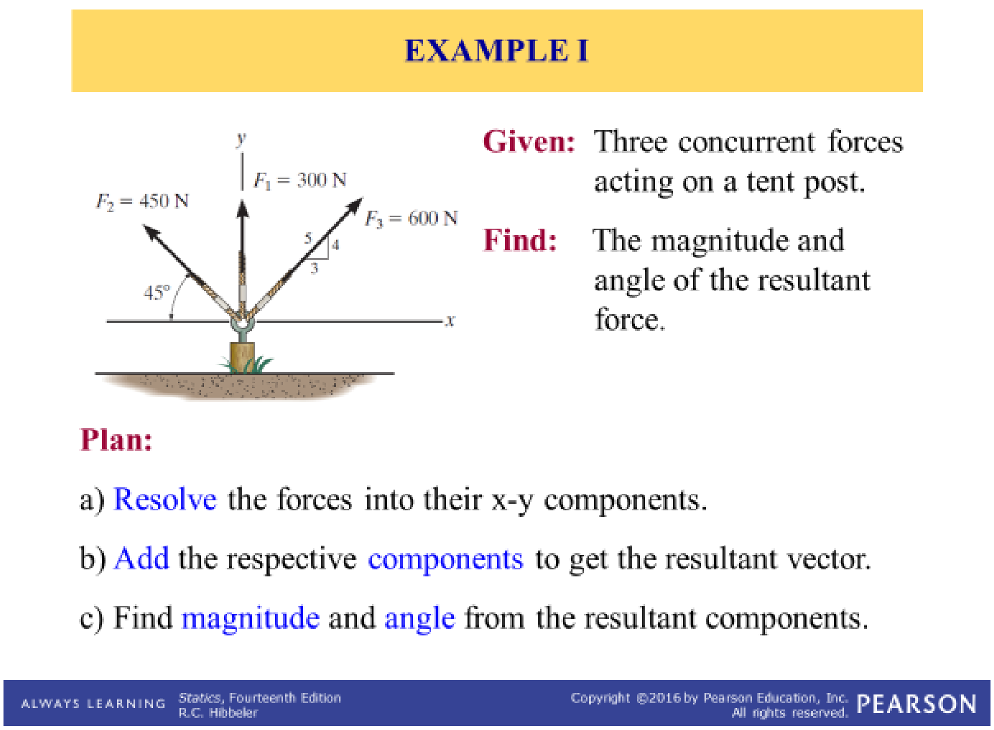

Fig 1: Two dimensional vector problem lecture slide

After introducing the problem, it is solved using the MBE model as shown below:

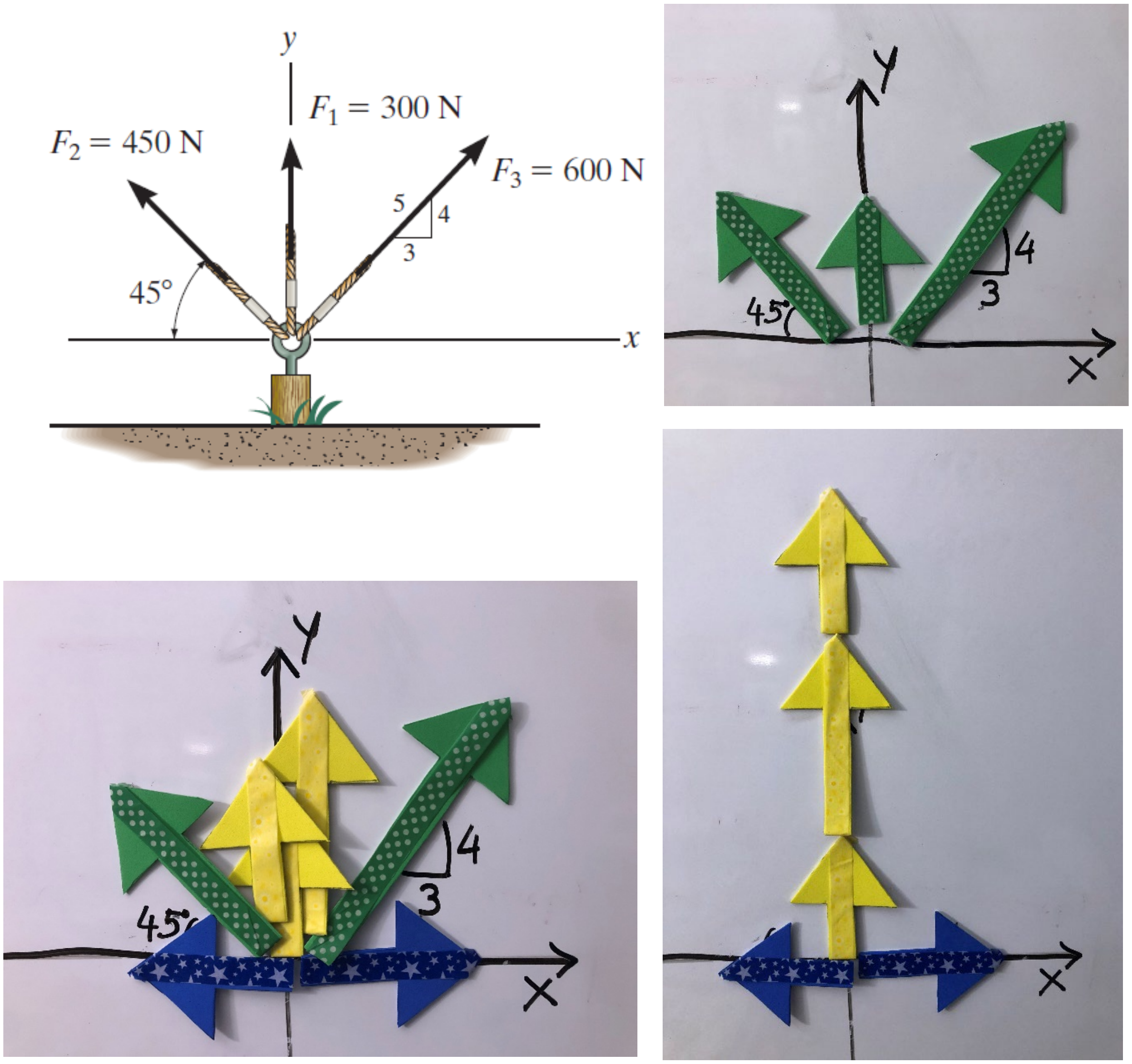

Fig 2: Two-dimensional vector problem [5] solved using MBE model

The traditional calculations are done on the whiteboard and the notes (as shown in Figure 3) are posted on blackboard.

After the students get used to the color/pattern and vector co-relation using the problem concept that they have been exposed to in previous curriculum, the students are introduced to a three-dimensional problem. The three-dimensional vector is made using a glass box and tape.

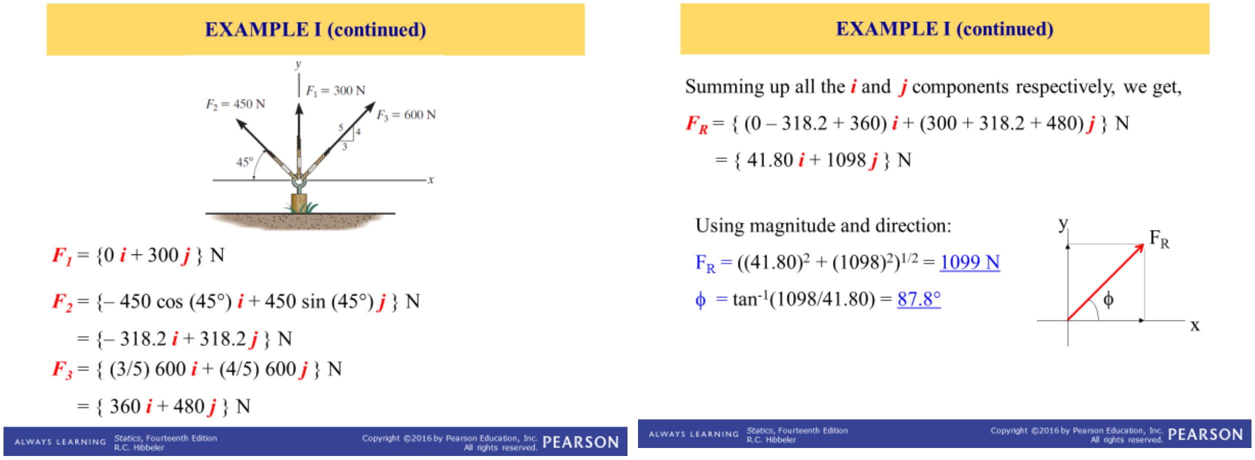

Fig 3: Two dimensional vector problem solved using traditional lecture slides[5]

Glass box

The glass box is made of acrylic, with the brown long diagonal the length of the 3-d vector and the three sides of the box representing the x, y and z components. The diagonals on each plane in green, orange and purple color would represent accurately the projections in the x-y, y-z and x-z planes as shown in the Fig. 3.

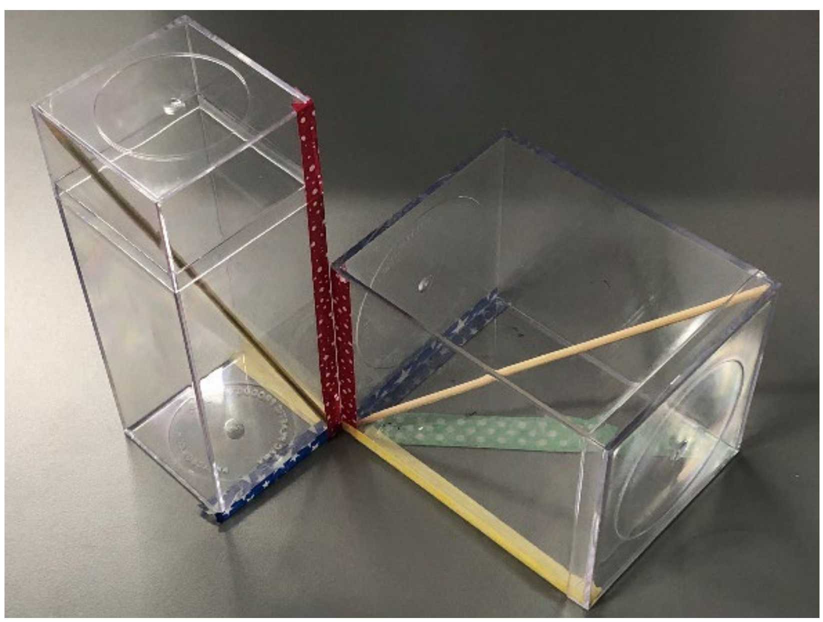

Fig 4: 3 D vectors used in the demonstration

Color scheme for the three-dimensional vector:

The color scheme for the x and y components for the three-dimensional vectors is the same as the color scheme of the two-dimensional vectors. The x-component of a three-dimensional vector is always the color blue, the y-component of a three-dimensional vector is always being

the color yellow. The z-component of a three-dimensional vector was decided as always being the color red. This was done to match with the primary colors, red, yellow and blue.
A vector in the x-y plane would be green in color. This makes it intuitive that a green vector would always have components which are blue (x-component) and yellow (y-component). Similarly, a vector in the y-z plane would be orange and a vector in the x-z plane would be purple. A vector which has x-y-z components would be brown in color which would signify that it has blue, yellow and red color components in it. In addition to color, the components are also denoted by different patterns to accommodate color blind students.

Table 1 : Color coded components in the three dimensional vector

	Notation	Color	Pattern
x-component	$A_x\,\boldsymbol{i}$	Blue	Stars
y-component	$A_y\,\boldsymbol{j}$	Yellow	Flowers
z-component	$A_z\,\boldsymbol{k}$	Red	Little spots
x-y component	$A' = A_X\,\boldsymbol{i} + A_Y\,\boldsymbol{j}$	Green	Big spots
x-z component	$A_X\,\boldsymbol{i} + A_Z\,\boldsymbol{k}$	Purple	Zigzag
y-z component	$A_Y\,\boldsymbol{j} + A_Z\,\boldsymbol{k}$	Orange	Bubbles
3D vector (x-y-z component)	$\boldsymbol{A} = A_X\,\boldsymbol{i} + A_Y\,\boldsymbol{j} + A_Z\,\boldsymbol{k}$	Brown	Solid

While adding vectors, the glass boxes are simply lined up and all the three components can be measured easily. Problems in the textbook, like the one in Fig.5. are explained using this MBE model

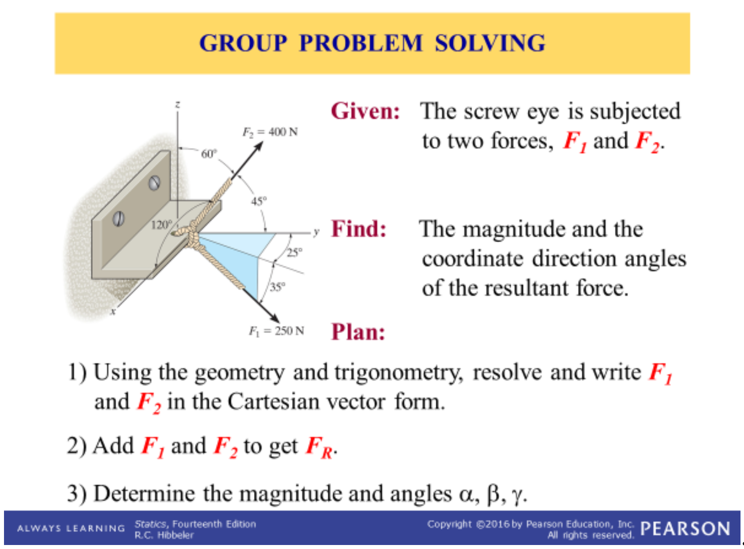

Fig 5. Three Dimensional Vector Problem [5]

Typically two glass boxes are given to students on one table, which is a group of 3-5 students.

The boxes are typically about 4 inches – 8 inches in diameter. They are not too big so carrying it to the class is easy and they fit on the table and in everyone's hands.

The glass boxes were given just for one problem. The authors had a few more examples available but the students were able to solve the problems without any need for hands-on boxes.

Assessment and results:

This model was used in the Statics 1 class at the Authors' university. The students were given a quiz to solve a three-dimensional vector problem, a week after the students were exposed to this method. This result was then compared to the result of a similar quiz in the previous semester, which was used as a control sample. The sample quiz question is given below :

Q3. (20 points) Determine the magnitude and coordinate direction angles of the resultant force , and sketch this vector on the coordinate system.

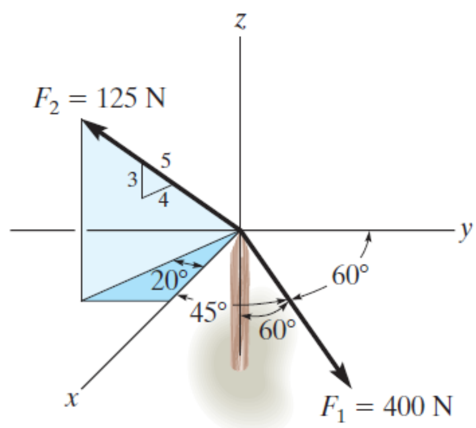

Fig 6. Three Dimensional Vector Quiz Problem [5]

All the students from the class which was taught using the MBE model could solve the problem correctly. One student made a mathematical error and lost some points in the problem. However, all the students were clear in their concepts. This was a trailer class and so had 6 students.

In the control group, 40% of the students solved this problem incorrectly. This class had 26 students.

The students in the control group had difficulty understanding a three-dimensional problem in a two-dimensional space. The students taught using the MBE model were asked if they found it difficult to understand the angles and three-dimensional space on the paper. All the students responded that it was not difficult to understand. It was great to see that the students could not understand why it would be a problem for anyone. The students found it so intuitive and easy that they just could not believe that this has been a difficult-to-understand concept in the past.

While one could argue that the group used for analysis was small, it must be noted that trailer classes historically perform poorer than regular classes. In the previous Spring semester (2019), the content was presented without the MBE method to a 7 person trailer class. Only 2 students could solve the problem correctly. Given this data, it can be seen that the MBE model is effective.

Conclusion:

The Montessori method is a proven method for educating younger students. This method when brought to older students seems to give good results. More studies need to be done to see the long-term retention of this concept in college students.

Citation

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