

A Multimedia Tool to Enhance Visualization and Understanding of Engineering Mechanics Concept

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ABSTRACT - In this paper we describe the development and the incorporation of tweening technique in a multimedia tool to enhance learning, visualization and understanding of engineering mechanics concept based on the equations of equilibrium to analyze engineering structures composed of pin-connected members. Tweening technique allows “in-between” images to be created between supplied key frames using linear interpolation where animations were employed to illustrate motions such as movement of the support and rotation of structure. The study revealed that such a multimedia tool could be implemented using multimedia authoring software rather than high level programming language. Assessment based on learners feedback indicated that the developed prototype tool not only increased the learners level of understanding of the mechanics concept but more importantly it provided the means for visualization of the problem via motion and animation.

Keywords - Engineering, interactivity, multimedia, animation, visualization

1. Introduction

The field of mechanical engineering investigates the structure and function of design, manufacture, test tools, engines, machines, and other mechanical devices. Multimedia has been rapidly used in developing visualization tools that strives to immerse the user completely within an experiential interaction, thereby greatly enhancing the overall impact and providing intuitive link between the computer and the users. Generally in engineering education, the quest to help weak learners visualize engineering concepts has provided the impetus for the development and use of multimedia tools as an alternative teaching aid. Since real machinery can be costly and bulky to be employed in the classroom, multimedia technology has the potential to model experiment in 2D, 3D or virtual reality environment that is difficult to perform using real machines or lab setting. For example, 2D graphics of engineering structures can be analyzed and displayed in multimedia format using ordinary hardware already present in the classroom or at home and the distribution of further copies can be done almost at no cost as long as license permits. It is apparent that such multimedia-based engineering experiments will not be able to replace the experience that would be gained through performing the same experiment using real machinery, however it could certainly accelerate the learning curve of the learner and enhance the

understanding of the various concepts in engineering at an affordable cost. This is evident as multimedia has been applied successfully in diverse areas of medicine, manufacturing, scientific engineering visualization and education ^[1-4].

2. Features and Benefits of Multimedia

The general reasons argued in the literature for using simulations in teaching and learning context are ^[1]:

- Multimedia provides a safe environment within which students can test hypotheses and study outcomes.
- Students can use the software at any convenient time for reinforcement of revision and self-assessment.
- Instructor or demonstrator contact time can be diverted to other tasks.

In the context of engineering, multimedia technology offers added advantages, which include:

- The use of real machinery and accidents can be avoided.
- Multimedia environment enable students to perform sophisticated experiments which otherwise require high level of physical or technical skills.
- Multimedia eliminates the need for physical sets of specialized or expensive lab equipment.

- Body of knowledge can be stored permanently and used repeatedly thus enhancing learning and understanding.
- Dynamic or real time motion such as movement of links, pistons, crank shaft and structures which is difficult to show or visualize during lecture or lab setting can easily be done using multimedia technology.

Multimedia can be used to deliver information in multiple formats i.e. (text, image, animation, audio and video). The delivery of such information, the organization in which it is delivered, and the timing of that delivery can be controlled by the user thus allows the user to engage and interact with the material being presented. This is certainly an added advantage to slow learners. The educational benefits offered by multimedia technology include the ability to take users into environments otherwise inaccessible, the high memory retention of experience as opposed to still observation, and the ability to reach out to visually oriented learners.

3. Multimedia in Engineering

Most varsities and higher-learning institutions have embarked on using interactive multimedia and associated learning technologies [2]. We have developed several multimedia engineering prototype tools for visualizing engineering problems such as structural analysis, kinematics of a particle, motion of projectiles, determination of center of gravity and moment of inertia of engineering structure. These tools have been adopted to supplement teaching of undergraduate engineering program at University Tenaga Nasional (UNITEN). In this paper, the development of a multimedia tool for visualizing engineering structures using 2D graphics is discussed. The ultimate aim of the study is to investigate how to develop optimal 2D high quality interactive animated engineering tool to enhance visualization and understanding of the subject matter.

Previous studies [2] have not dealt with concepts that lend themselves to visualization. By visual, the concept is dynamic and therefore more easily shown on a computer screen where the image can change back and forth between screens.

In this context, the present discussion focuses on the feasibility of using various animation techniques and good quality graphics and color-coding to draw users/learners attention to various engineering concepts. In the initial stage, simple animation of 2D objects on screen was achieved by coloring significant parts of a structural diagram, connecting each part together to form an animation and then returning them to their original state.

The content contained within the tutorials was intended to provide students with better understanding of the theoretical concepts taught in class as well as to enhance their ability to apply mechanics concepts in a variety of engineering design. One common occurrence in the use of such tool is that the users tend to visualize the same material faster when they do not have to spend extra time using these learning aids [3-6]. In addition there is compelling evidence that students develop more interest in the subject matter [7-10].

Mechanics statics like many other engineering subjects is fundamentally about problems solving through the application of scientific principles. However there are many cognitive steps leading from problem to solution and consequently many educational difficulties such as students lack the ability to translate mathematical word problems into the form necessary for effective computation. These engineering problems are often complex, and relationships among the variables of an experiment can be difficult to visualize. Multimedia visualization tool provides an alternative for presenting engineering and scientific information in a way that can be easier for students to understand. For instance, when a 2D image is displayed in the right way, the user often has new insights into the underlying principle being taught.

In general, problems in mechanics statics are presented to the student as a combination of schematic diagrams and text descriptions. In the traditional method of teaching and learning, the student must immediately apply learned knowledge in order to form an internal model of what the problem means. Normally, the shapes, lines and text that make up the schematic diagram of the problem have very specific engineering meanings. Previous experience [2] showed that an average student would be able to solve the problem at the first try but a weak student would require several trials before solving the problem. The weaker students take a longer time to solve the problem mainly because these students lack the understanding of the theory that has been taught during normal lectures. As such, these students would require an alternative method of instruction to enhance their learning skills.

The multimedia tools for mechanics statics tutorials topics currently being developed are listed in Table 1. The aim of these multimedia tutorials is to help learners gain a better understanding of the fundamental mechanics concepts, to resolve forces and moments, and to apply these concepts in solving engineering-related problems. In the subsequent sections, the development of a multimedia tool based on Module 2: Structural Analysis will be discussed.

Table 1. Multimedia tutorial topics under development.

Module 1	Equilibrium of a Body
Module 2	Structural Analysis
Module 3	Centre of Gravity & Centroid

4. General Concept of Truss Analysis

A 2D plane structure, also known as truss, is an engineering structure made of two force members all pin connected to each other. As an example the schematic of a plane truss is shown in Figure 1.

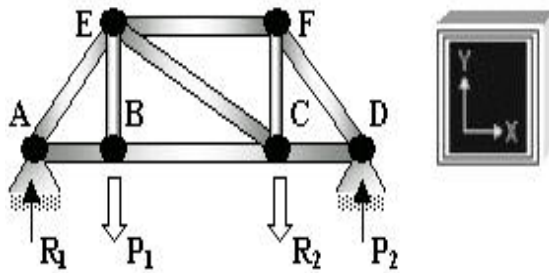


Figure 1. A typical loaded plane truss that is supported at A and D.

The truss in Figure 1 consists of 9 members and 6 joints. For example, there is a member from joint A to B, another from joint B to C, and a third from joint C to D. Due to the external loading (i.e. P₁ and P₂) acting on the truss, each member of the truss will be subjected to internal forces either of the tensile or compressive nature. These internal forces can be calculated by applying any of the three equations of equilibrium with respect to the x-y reference system as follow:

$$\sum F_x = 0 \quad \sum F_y = 0 \quad \text{and} \quad \sum M = 0$$

These equations of equilibrium state that in order for the structure to remain in the state of equilibrium then (i) the sum of all forces in the x-direction must be equal to zero ($\sum F_x = 0$), (ii) the sum of all forces in the y-direction must be equal to zero ($\sum F_y = 0$) and (iii) the sum of all moments about any point on the structure must also be equal to zero ($\sum M = 0$).

Prior to solving the problem, it is normal practice to adopt a reference system such as the x-y system as shown in the top right hand corner in Figure 1. All forces must first be

resolved into their components acting in the x- and y-directions. According to the reference system, force acting in the same direction of the x-axis is taken as positive whereas force acting in the opposite direction of the x-axis is taken as negative. A similar concept is applied to forces acting in the y-direction. As for taking moments about a chosen point, the choice is arbitrary; one can assume that counterclockwise moment is positive and clockwise moment is negative or vice-versa. Thus, the components of any unknown forces can then be determined by applying the equations of equilibrium with respect to this reference system.

As an example for the truss problem shown in Figure 2(a), the students are required to determine the force in each member of the truss and indicate whether the member is in tension or compression.

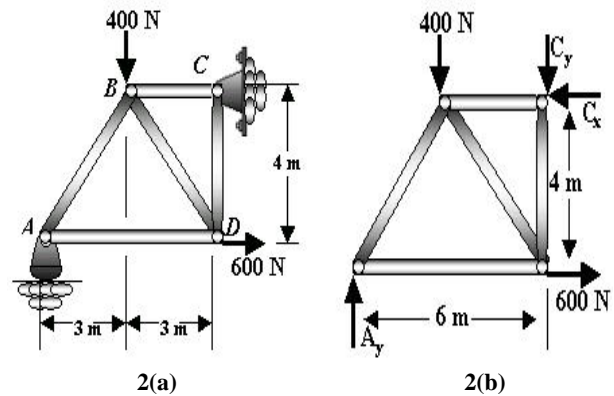


Figure 2(a). A typical loaded truss and 2(b). Free body diagram of the truss.

A free body diagram showing all forces acting on the truss is first drawn as shown in Figure 2(b). The two supports at A and C, are represented by the internal reactions A_y, C_x and C_y as shown in Figure 2(b). These unknown reaction forces can be determined by applying the equations of equilibrium as follow:

$$\sum F_x = 0 : 600 - C_x = 0 \quad \therefore C_x = 600 \text{ N}$$

$$\sum M_C = 0 : -A_y(6) + 600(4) = 0 \quad \therefore A_y = 600 \text{ N}$$

$$\sum F_y = 0 : A_y - 400 - C_y = 0$$

$$600 - 400 - C_y = 0 \quad \therefore C_y = 200 \text{ N}$$

The analysis for the aforementioned problem can now start at joint A or C. The choice is arbitrary, since there is one

known and two unknown member forces acting on the pin of these joints.

Joint A. As shown in the free-body diagram in Figure 3, there are three forces that are acting at joint A. The inclination of F_{AB} and F_{AD} are determined from the geometry of the truss. By inspection, students must apply knowledge gained during lectures on how to assume the nature of the unknown forces. Alternatively, the student can initially assume that all the members are under tension (taken as positive) and if the computed value gives a negative, then the student will understand that the member in question is not under tension but rather under compression. For argument sake, let's assume initially that member AB is under compression whereas member AD is under tension. These assumptions are represented diagrammatically in the free body diagram by the sense of direction of the arrows representing the forces F_{AB} and F_{AD} as shown in Figure 3. If the assumptions are correct, the computed values for both forces will be positive.

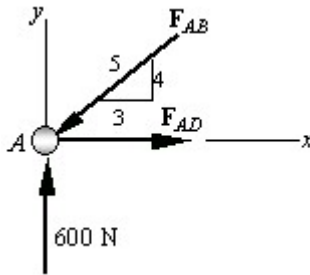


Figure 3. Free body diagram showing all forces acting at joint A.

Thus applying the equations of equilibrium, we have:

$$\sum F_y = 0 : 600 - 4/5 F_{AB} = 0 \quad \therefore F_{AB} = 750 \text{ N (C)}$$

$$\sum F_x = 0 : F_{AD} - 3/5 (750) = 0 \quad \therefore F_{AD} = 450 \text{ N (T)}$$

The letters (T) and (C) indicate tensile and compressive in nature, respectively. Since, both answers are positive, therefore the initial assumption was correct.

Joint D. In a similar fashion, as shown in the free-body diagram in Figure 4, joint D is chosen since by inspection of Figure 2a, the force in member AD (i.e. F_{AD}) is already known. As such, the two unknown forces in member DB (F_{DB}) and member DC (F_{DC}) can be determined. Let's assume initially that both members are under compression. As such, the sense of direction of both internal forces (i.e. F_{DB} and F_{DC}) is as shown schematically in Figure 4. By summing all the forces in the x-direction, we have:

$$\sum F_x = 0 \quad -450 + (3/5) F_{DB} + 600 = 0 \quad \therefore F_{DB} = -250 \text{ N}$$

The negative sign indicates that F_{DB} acts in the opposite sense to that shown in Figure 4 and is therefore tensile in nature (i.e. member DB is under tension). Hence,

$$\therefore F_{DB} = 250 \text{ N (T)}$$

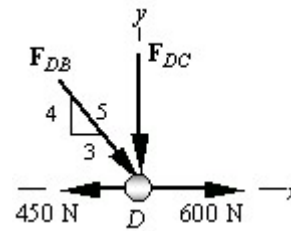


Figure 4. Free body diagram showing all forces acting at joint D.

To determine F_{DC} , the student can either correct the sense of F_{DB} and then apply $\sum F_y = 0$, or apply this equation of equilibrium and retain the negative value for F_{DB} . Assuming we choose the latter option, we have:

$$\sum F_y = 0 : -F_{DC} - (4/5) F_{DB} = 0$$

$$-F_{DC} - (4/5)(-250) = 0 \quad \therefore F_{DC} = 200 \text{ N (C)}$$

Joint C. The free body diagram of all forces acting on joint C is as shown in Figure 5. As can be noted from Figure 5, the only unknown force is the reaction force in member CB. If the student assume that the member CB is under compression, as indicated by the sense of direction of F_{CB} in Figure 5, by applying the equation of equilibrium in the x-direction, we have:

$$\sum F_x = 0 : F_{CB} - 600 = 0 \quad \therefore F_{CB} = 600 \text{ N (C)}$$

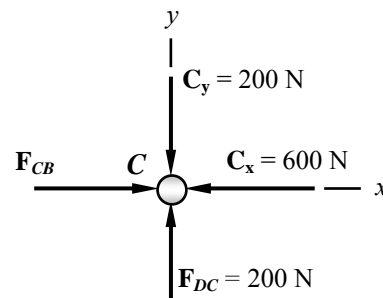


Figure 5. Free body diagram showing all forces acting at joint C.

Apparently this method of teaching can be tedious, difficult, time consuming and requires the instructor to repeat the entire exercise several times until the student understand. Thus, in order to overcome this situation, we have design a multimedia system based on the problem-solving model shown in Figure 6.

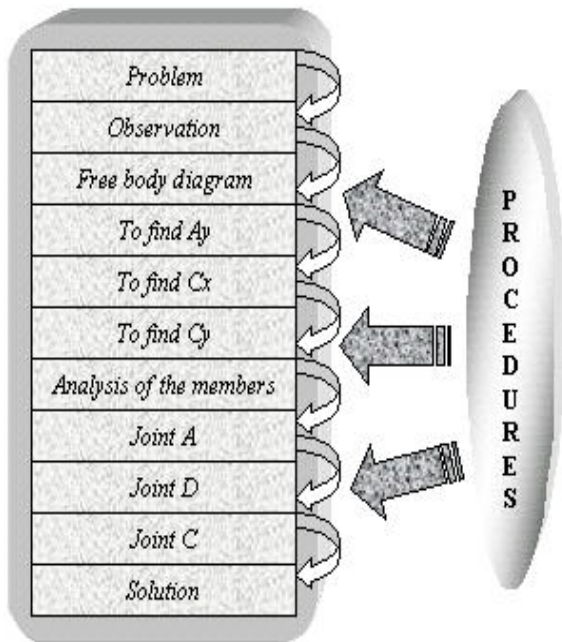


Figure 6. Problem-solving model used to develop the multimedia tool.

The organizational design flow of the problem-solving model shown in Figure 6 can be represented as a list of procedures that must be executed in a serial order which lead from a problem statement to the solution.

Since mechanics statics concepts build in a linear fashion, the software is structured to present information sequentially. In the present work, Macromedia Director™ was used as the main authoring tool. The tutorial contains several sections that are made up of any number of pages/procedures. Each page builds at a time, so that a particular concept is illustrated/explained as the user clicks the "Continue" button. While it is intended that learner will proceed through the content in a linear fashion, the capability to move back and fourth throughout the tutorial is also provided in the multimedia tool. As each page builds, several elements such as text, equations, images, graphics, and animations are displayed and manipulated as typically shown in Figures 7 and 8.

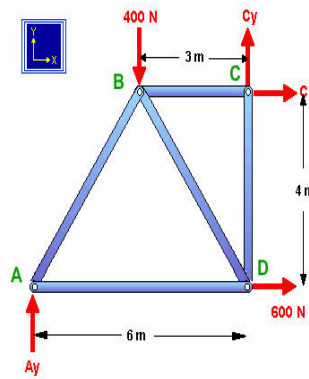


Figure 7. The positive direction of the forces A_y , C_x , and C_y are as shown in the free body diagram. The arrows are colored, e.g. red, as to draw the user attention.

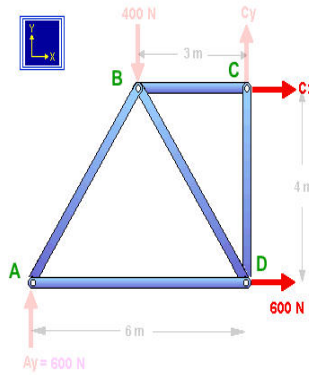


Figure 8. To find force C_x , the forces A_y and C_y are made dim. When the forces in the x-direction are being considered, the computation appears in an animated form, e.g.

$$\rightarrow \sum F_x = 0$$

$$C_x + 600 = 0$$

$$\therefore C_x = 600 \text{ N}$$

At the click of the “Continue” button, the analysis to compute the unknown reactions is carried out in a step-by-step approach as describe in the earlier section using the equations of equilibrium. As the text and figures are written and displayed on the screen, the multimedia system will prompt the students at various checkpoints to see if the student understands the step that has been executed. At this point, if for some reason the student is unclear, he/she can move back to the previous step. Similar approach is adopted to determine the force induced in each member of the truss by considering the respective joints and applying the equations of equilibrium as described in the earlier section. Finally, the solution to the problem in question is illustrated in an animated form as shown in Figure 9.

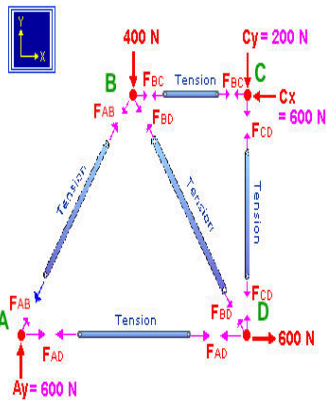


Figure 9. The final solution is analyzed and the correct free-body diagram showing all forces (tensile and compressive) acting in each member is drawn on the screen.

During the development stages of the multimedia tool, it is vital to build a screen sequentially as this allows students to see the steps involve to obtain the solution. For example, as the user clicks the "Continue" button, relevant forces causing moments about C is written on the screen. During the event, the whole sequence is carried out dynamically between each of the screens.

The interface (Figure 10) referred to as the tool, provides an interactive environment in which the students solve the mechanics statics problem. It consists of several electronic turning pages with text, 2D animated graphics and a menu that allows the user to repeat a procedure that is not clear.

5. The use of Tweening Technique

In general, a number of techniques can be used to generate a 2D animation such as cel-based and path-based animation. Animation is done differently in 2D and 3D-based animation, however they have some common properties such as the key-frame holds all the information about the state of the animation at that point in time. Key-frames are renditions of two or more points, usually the beginning and ending frames of a specific animation. In this project, tweening technique has been employed. Tweening is a technique that allows "in-between" images to be created between supplied key frames using linear interpolation. In tweening, key frames are provided and "in-between" frames are calculated to allow smooth dynamic movement of member. The equation for tweening in a linear interpolation (P) is given by equation (1) [3]:

$$P = A(1 - t) + Bt \quad (1)$$

where A is the initial location of the point, B is the final position of the point, and t is the time measured from 0 to 1 seconds.

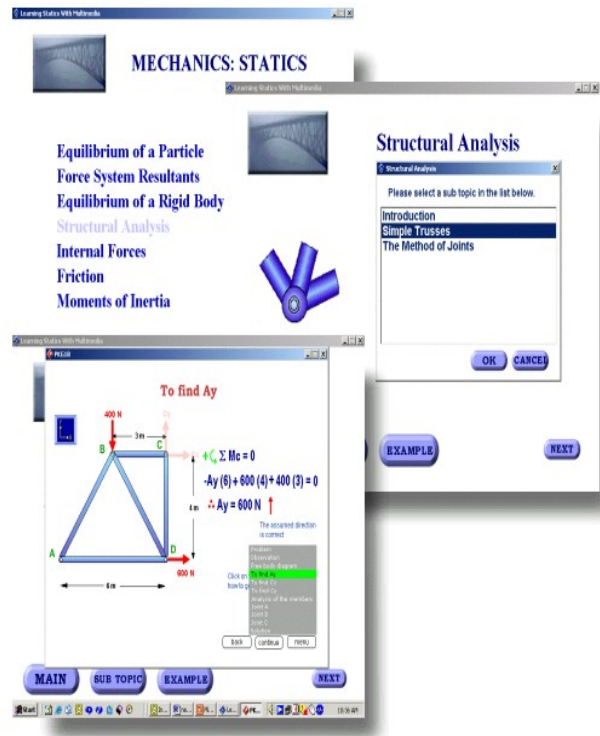


Figure 10. Screen snapshots of the engineering tool.

The points A and B in equation (1) are also referred to as key frames and the linear interpolation creates the "in-betweens". This equation will create a point anywhere on the line that lies between A and B as shown in Figure 11. The images A and B are sets of points. The tween is simply applied to each axis in the n -dimensional coordinate space. In our example of a swinging rocker shown in Figure 11, in-betweens are created from A to B . The resulting 2D animation creates a dynamic rocker that swings from points A to B . The effect of tweening beyond time, $t = 0.1s$, results in what is called interpolation. When $t > 0.1s$, the image results in the tweened points moving beyond B in the direction of A to B . Similarly the same technique is used to analyze the joints at A , C and D . A typical animation sequence for analyzing forces acting at one joint of the truss is shown in Appendix 1.

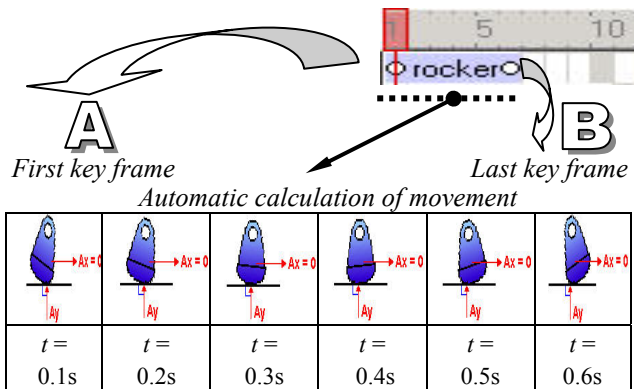


Figure 11. Timeline animation of tweening an image.

In addition to tweening the image's path, the authoring tool was also used to tween the size, rotation, tilt, merge, and change the color of an image to semi-transparent. One advantage of the authoring tool is that it can tween all of these properties simultaneously. To make an image fade, the image merge settings can be made to tween and to make the image spin or tilt, the rotation settings can be made to tween. Similarly to create gradual shifts in color, the color settings can be made to tween. Further work is in progress to examine various animation techniques and to incorporate 3D models in the tutorials.

6. Preliminary Evaluation of the Prototype Multimedia Tool

The assessment was conducted on students taking the mechanics statics course in the university. The objective of the assessment was to evaluate the effectiveness of using multimedia-based tutorials to supplement traditional classroom teaching. The method of evaluation was based on questionnaires administered at the end of the course whereby each student was asked to provide his/her opinion and perception about the use of multimedia-based-tutorials in the course and how to improve the multimedia tool so as to cater towards their needs in enhancing learning.

It was found that majority of the students were impressed by the ability of the tool in enhancing visualization and the students agreed that animation is vital so as to enhance their understanding of various concepts of the subject matter, i.e. in this case, the use of equations of equilibrium. The result obtained from students feedback are as presented in Figure 12. The beneficial effect of incorporating multimedia in teaching mechanics statics has been revealed. In particular, it can be noted that the level of confidence of the students in the subject matter greatly improved with the use of multimedia.

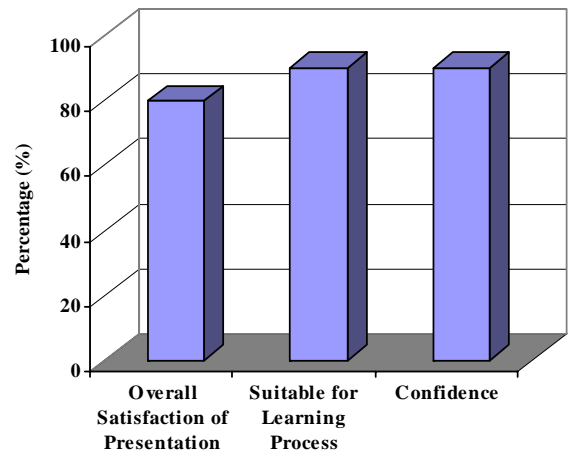


Figure 12. Assessment of the effectiveness of the multimedia tool based on students feedback.

7. Conclusions

In the present paper, the development and implementation of an engineering multimedia tool has been discussed. Initial assessment of the multimedia tool revealed that 2D graphics behavior could appear more natural and predictable than the mono medium style in virtual environments. In addition, the animation that has been incorporated in the tool provided a consistent 'look and feel' to a 2D direct manipulation user interface.

The present work showed that multimedia technology could be employed to aid learning of various topics pertaining to engineering such as the analysis of engineering structures. The developed prototype has been found to be useful in reinforcing understanding of concepts such as equations of equilibrium through animation. In addition, users of the tool found that it was easier to investigate all possible loading conditions of a truss to determine the most severe loading experienced by a truss member. Further work is in progress to upgrade the tool to allow the users to experiment safely by inputting different values for the load and investigate how such changes in the loading influence the internal reactions of the various truss members.

The problem-solving model that was employed to develop the tool was suitable for constructing linear engineering multimedia based tutorials. Tweening technique was found to be very useful as it facilitated and smoothen real-time motion on the computer screen. This technique combined with multimedia features allows the demonstration of boundary conditions, which in turn reinforces mechanics concepts.

Problem solving using powerful multimedia tools permits approaches beyond those traditionally selected because they minimize computational effort. In addition, multimedia technology could facilitate a faster and more complete analysis of design alternatives by providing ways to rapidly create models or prototypes of proposed designs and to then simulate them in a more realistic way.

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Appendix 1. A typical animation sequence for analyzing forces at joint D of the loaded truss.

