Illustrating Engineering Concepts by Employing an Inclusive Pedagogy in Mechanical Engineering

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Abstract

Studies have identified visual cuing as an effective instructional method with the capacity of elevating academic performance in engineering education, engaging students in the classroom, and cultivating an awareness of distinct variables that influences the learning process. In this study, an assorted number of physical models were adopted during lecture sessions as an inclusive pedagogical approach to enhance the perceptivity of rigid bodies in motion and proactively engage students in the learning process. Specifically, three-dimensional models such as a crane, excavator, robotic arm, reference frame, and a swing representation were incorporated to illustrate various geometrical and technical concepts, which are traditionally challenging to visualize by articulation or with common textbook figures. The aim was to recurrently emphasize the visualization aspect of linear/angular motion, directions in vector analysis, geometric configurations, and the incorporation of theoretical concepts in engineering application to cultivate awareness on various technical concepts. In this regard, each lecture session was divided into four segments: introduction, physical model demonstration, theory, and application. A survey was administered to a total of seventy students enrolled in an Engineering Dynamics course to gauge their stance regarding the implementation of the inclusive pedagogical approach. Results indicate that 85% of the participants were able to correlate theoretical concepts with engineering applications with the use of visual cuing. As evidenced by student responses, utilizing physical models during lecture eliminated confusion, increased class engagement, and assisted in understanding motion characteristics.

Introduction

In the 1960s, it was reported that student learning and success were dependent on two variables: instructor's personality, and the students' academic ability and interest in the subject [2]. To this end, various pedagogical methods were implemented to increase academic performance in engineering education. Two of the most common include Problem-based learning (PBL) and Project-based learning, which are traditional instructional tools widely utilized towards promoting student comprehension and scholarship capabilities. PBL, for instance, is geared towards developing self-directed and critical thinking aptitudes through interpersonal and team skills, while Project-based learning focuses on developing professional development via project-based instruction [16], [17], [18].

Decades later, it was reported that student learning and success further depended on being cognizant of students' needs and background [7]. This learner-centered concept is centered on incorporating learning activities as a medium to engage students, eliminate intimidation barriers, and promote student learning. As a result, physical visual supplements have been incorporated during lecture sessions with the intention of simplifying complex themes and conveying real-world applications. Research indicates that incorporating visual during an instructional setting increases student engagements, retention rates, cultivates awareness, and elevates academic performance in engineering education [3], [4], [5], [6], [10]. Visual cueing, according to reported data, is an efficient pedagogical method that allows knowledge to be attained at a faster rate than uncued visualization [1], [8], [11], [15]. In 2019, Marquez and Garcia integrated visual supplements into an Engineering Mechanics course (e.g., Statics and Dynamics) with the intention of developing students' ability to recognize existing real-world designs, and simultaneously identify the type of engineering analyses required for specific applications [9]. It was reported that the integration of visual tools assisted students' understanding of engineering applications, calculation requirements/procedures, design considerations, potential sources of failure, and cost reduction factors [9].

Proposed Work

In this study, an assorted number of physical models were adopted during lecture sessions as an inclusive pedagogical approach to enhance the perceptivity of rigid bodies in motion and proactively engage students in the learning process. Specifically, three-dimensional models such as a crane, excavator, robotic arm, reference frame, and a swing representation were incorporated to illustrate various geometrical and technical concepts, which are traditionally challenging to visualize by articulation or with common textbook figures (Figure 1). The aim was to recurrently emphasize the visualization aspect of 1) linear/angular motion, 2) directions in vector analysis, 3) geometric configurations, and 4) the incorporation of theoretical concepts in engineering application to cultivate awareness on various technical concepts (Figure 2).

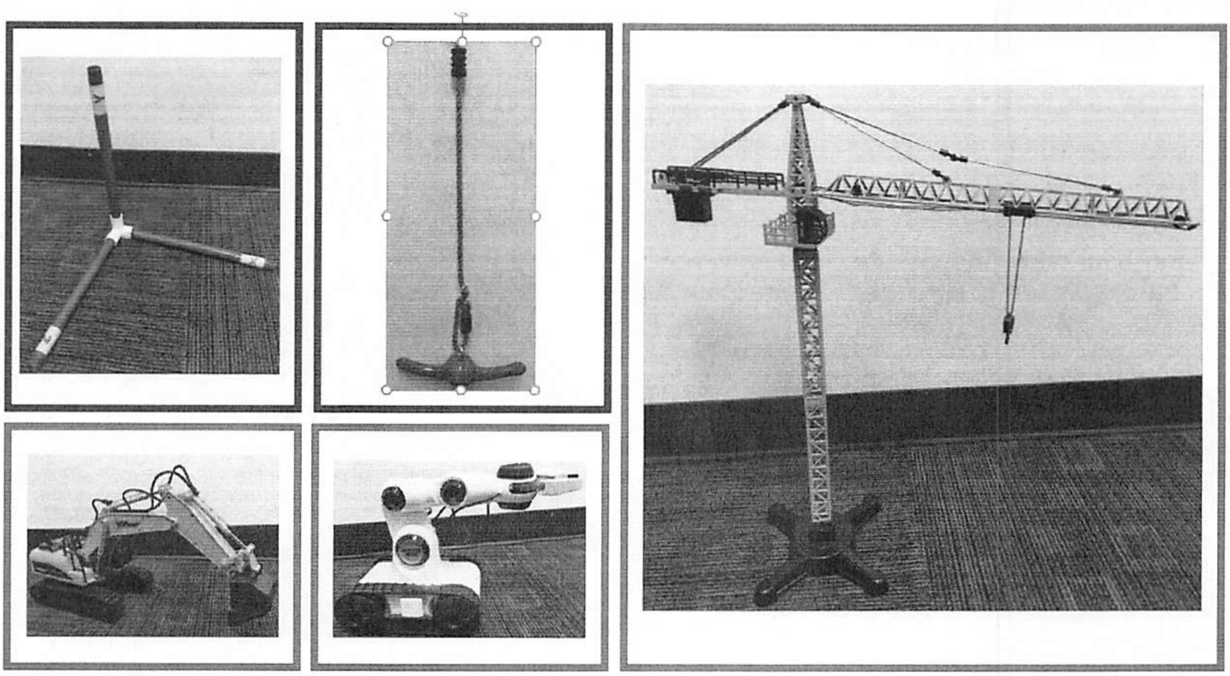


Figure 1: 3D Models: Crane, Excavator, Robotic Arm, Reference Frame, and Swing

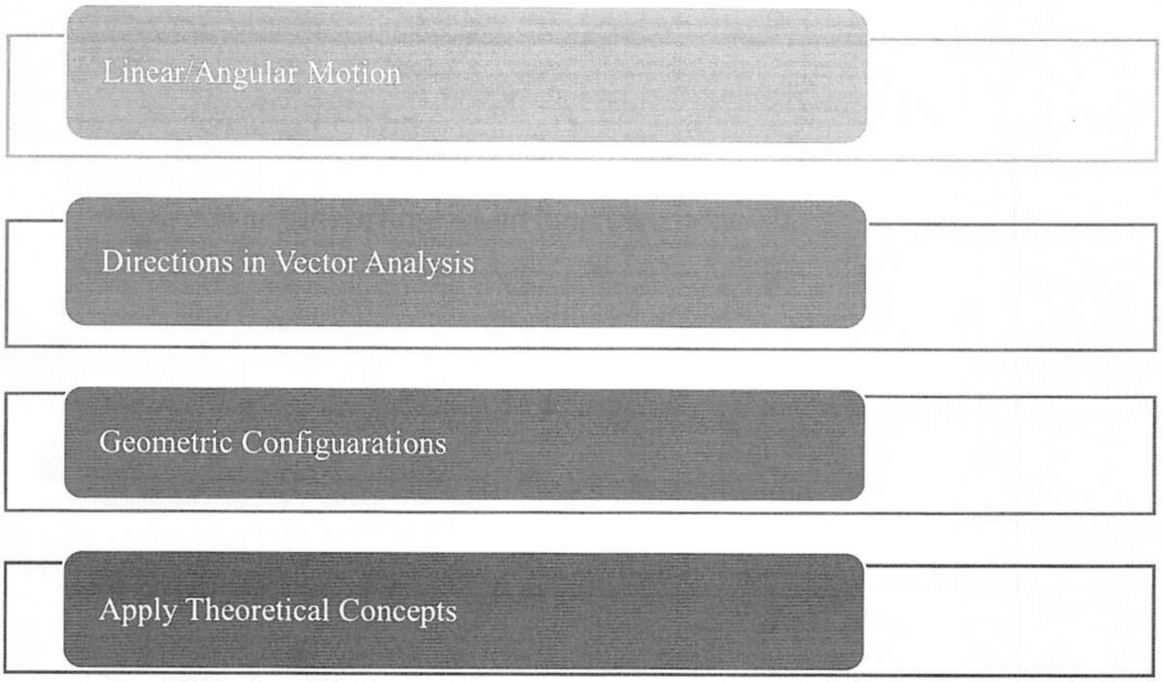


Figure 2: Engineering Principles Illustrated with Visual Supplements in Dynamics

The physical models were incorporated to distinguish between linear and angular motion, which is a concept often difficult to understand by simply adopting textbook or PowerPoint figures. Specifically, linear motion in the *x*, *y*, and *z* directions were emphasized, while angular motion was illustrated with respect to each corresponding axes. Since a vectorial approach was adopted for the course, a physical reference frame – with the corresponding *x*, *y*, and *z* axes labelled – was recurrently utilized during lecture sessions to convey the concept of direction. This model was necessary when elucidating the cross-product between vectors. Additionally, visual supplements assisted when teaching about the various geometrical variations of rigid bodies and their corresponding moments of inertia.

In this regard, each lecture session was divided into four segments: introduction, physical model demonstration, theory, and application. The instructor would initiate lecture sessions by introducing the topic of study and correlating it to relevant engineering applications. Then, a specific physical model would be introduced which correlated with the theme of interest and prompted communication amongst students. Once students would correlate the theme of interest with specific physical models, the mathematical aspects of the theme would be derived and explained.

Methods and Analysis

In this research study, 70 students enrolled in an Engineering Dynamics course were surveyed to better understand gather insights into the pedagogical approaches utilized to engage and enhance student learning. The study sought to examine students' experiences related to the instructional methods that were applied to increase student understanding of engineering related concepts. The sample selection consisted of seventy undergraduate students enrolled at a public Hispanic Serving

Institution in Texas. The authors employed a qualitative research design, and the primary method of data collection was a self-developed survey instrument consisting for four items, two of which were open-ended questions.

The data analysis consisted of an open coding technique to organize data into categories. According to Creswell (2007), open coding "involves taking data and segmenting them into categories of information" (p. 239-240). While all the data gathered from the survey provided useful information, the open coding process was repeated multiple times to slowly reduce the number of categories that became the major themes for each.

Question 1: Visual supplements helps me correlate between engineering applications and theory

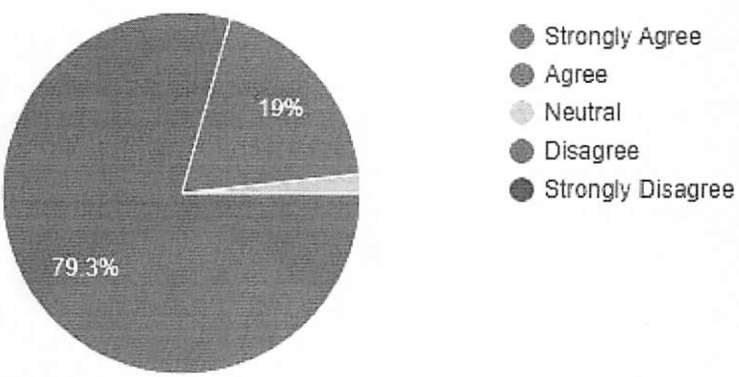
Question 2: The instructor utilizes visual supplements to emphasize design and dynamic factors

Question 3: What is your opinion on the instructor using visual supplements?

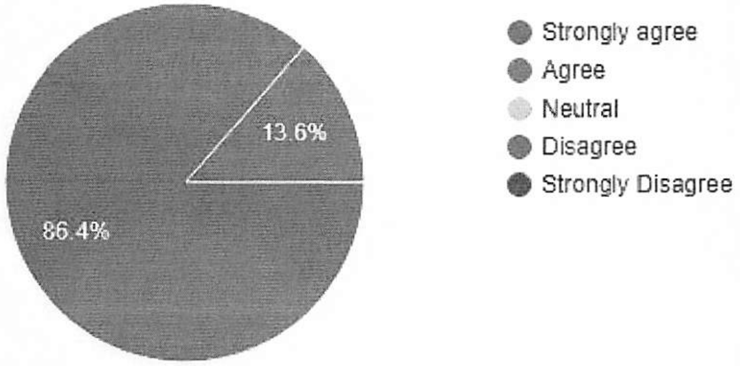
Question 4: Would you be able to visualize Dynamics problems without instructional (visual) tools?

Results

Question 1: Visual supplements helps me correlate between engineering applications and theory



Question 2: The instructor utilizes visual supplements to emphasize design and dynamic factors



Question 3: What is your opinion on the instructor using visual supplements?

Based on the first open-ended question, students shared relevant information regarding their professor's use of visual supplements. Results indicate a positive level of student satisfaction with the implementation of visual and related tools. Data analysis revealed four emerging themes: Increased understanding of course material; real-world connections; limiting confusion; and accommodation of learning needs. The four themes are presented below and supported by corresponding student responses.

Increased Understanding of Course Material

The utilization of visual supplements aided in students' understanding of complex engineering concepts and principles. As indicated below, these tools assisted helping students to better learn course material. Student responses are listed below:

> *"In my opinion, the use of visual supplements is helpful to understand the concept and how things actually work."*

> *"It helps me visualize the concept rather than a drawing on the board to understand its individual components better."*

Another student provided a specific example that highlights the effectiveness of visual supplements:

> *"Visual supplements help me tremendously. For example, reference frames using three markers and sticks to join them together to form a three-dimensional axis. Cranes helped me understand the motions of various components and selecting the proper body to analyze. Robots are similar, all while learning the program runs in the robot and you need dynamics to write that program."*

Connecting Engineering Concepts to Real World Applications

A second theme that emerged from the study is that the use of visual supplements presented opportunities for students to visualize examples of real-world applications of engineering concepts. Student responses addressing this theme are listed below

> *"I think having visual supplements adds more to the learning experience of class, and it can make students think more about real world applications."*

Other students echoed the comment shared above by stating the following:

> *"The visual supplements make the material easier to understand and provides examples of how the material we are learning can be applied in real life applications."*

"The visual aids provide a tangible reference to the theory and mathematical applications being taught in class. This helps cement the understanding of mathematical applications to real world design."

Reducing Confusion and Increasing Engagement

While the use of visual supplements served to increased students' understanding of engineering related concepts, it also helped to reduce confusion and stimulate student engagement. The following responses highlight this theme:

"Visual supplements during lecture help clear any confusion relating to a problem."

"I enjoy that aspect from his teaching. It helps visualize and simplify what could be confusing."

Regarding engagement, several students noted the positive effect this technique had on their learning experience:

"It really does help to keep me engaged as well as explain problem details."

"They make the lectures more engaging and supplement my learning."

Research has revealed that many students struggle with learning certain concepts due to the traditional approaches to teaching utilized by engineering faculty. As indicated by the data above, incorporating visual supplements help to reduce confusion, while making the material more engaging and interesting to the students.

Accommodating Learning Needs

One final and important theme that emerged from the study is that the visual supplements served to accommodate student learning needs. Research has indicated that all students learn and make sense of material differently and that it is vital for educators to be mindful of the diversity of learners in their classroom. Traditional approaches to engineering education have a tendency of presenting concepts in a didactic approach in which principles as purely theoretical, thus affecting students' ability to deeply understand course related material. The following student responses reveal that the visual supplements helped to accommodate specific learning needs:

"It helped me a lot since I am a visual learner. The usage of visual supplements makes the class less boring since looking at these supplements catch more my attention than just hear talk and talk."

"The visual supplements are very nice. The crane example is good, because its intuitive to imagine that a hanging weight will behave in a way that is difficult to determine mathematically, yet also intuitive to our sense of motion."

"I think it's helpful to understand it outside of a 2D perspective coming from the white board. I enjoy it, it helps put things into perspective when talking about more complicated movements."

"Personally, it really helps understand what we're learning otherwise I'm just memorizing terms and formulas but now when I'm solving a problem, I can visualize it in my head operating and can understand how I'm going about the problem."

Research has revealed that many students struggle with learning certain concepts due to the traditional approaches to teaching utilized by engineering faculty. As indicated by the data above, incorporating visual supplements help to increase understanding, reduce confusion, while making the material more engaging and interesting to the students. It also helps to accommodate students' learning needs, which help to ensure that certain learners have access to making sense of the course material.

Visualizing Dynamics Problems (Question 2)

The first open-ended question sought to gather students' insights regarding the instructor's use of visual supplements. The second open-ended question asked students whether they would be able to visualize Dynamics problems without instructional (visual) tools. Results from the study revealed were mixed with most indicating that they would be able to visualize these problems but would require a lot of effort to do so.

Students Who Indicated Yes

Roughly 60% of the students indicated that they would feel confident in their ability to visualize engineering problems without the visual supplements. The students also acknowledged that it would be very challenging to do so. Below are student responses that highlight this finding:

"Yes, but it would only make life harder. The instructor breaks everything down very clearly with his visual examples/ approach."

"I think I can, but it's always better to have a visual aid to understand how a problem is happening, especially when a topic is being introduced for the first time."

"Yes. However, I believe without strong prior knowledge or practice in physics or statics, it's very difficult to visualize problems in your mind without the physical aide. It is a very usual for building up to intuition and I believe everyone deserves to be taught in different ways."

Students Who Indicated No

The other students surveyed in the students indicated that do not believe they could visualize Dynamics problems without the incorporation of visual supplements. Below are a few of the responses that highlight this finding:

"Negative I definitely need them."

Other students echoed the comment and provided specific reasons why it would be challenging to do so:

"No. Without prior practice and knowledge, it would be extremely difficult to develop in depth understanding of problem-solving methods and calculations."

"Probably not since Dynamics problems can be visualized in many different perspectives."

"No then we wouldn't be able to draw them or implement the concept correctly."

The results for question two indicated that more than half of the students feel confident in their abilities to visualize and understanding engineering Dynamics related concepts and principles. These same students acknowledged that it would be challenging and difficult without the visual supplements to help support their learning. The remainder of the students indicated the visual supplements are critical in assisting their comprehension and visualization of Dynamics problems. Based on the responses, the incorporation of these visual tools positively impacts student learning, understanding, comprehension and visualization of complex engineering concepts. It also provides an avenue for making the classroom instruction more inclusive and respond to diverse students' learning needs and style.

Conclusion

Research reveals that numerous students struggle with learning certain engineering concepts due to traditional instructional approaches. In this study, an assorted number of physical models were adopted during lecture sessions as an inclusive pedagogical approach to enhance the perceptivity of rigid bodies in motion and engage students in the learning process. Specifically, three-dimensional models such as a crane, excavator, robotic arm, reference frame, and a swing representation were incorporated to illustrate various geometrical and technical concepts. Results from this study indicate that incorporating visual supplements is necessary to increase understanding and reduce confusion, while making the material more engaging and interesting to the students. It also helps to accommodate students' learning needs, which help to ensure that certain learners have access to making sense of the course material.

More than 50% of the surveyed students felt confident in their abilities to visualize and understanding engineering Dynamics related concepts and principles. However, it was acknowledged that it would be challenging and difficult to support their learning without the visual supplement. Based on student responses, the incorporation of visual tools positively impacted student learning, understanding, comprehension and visualization of complex engineering concepts. It further prompted an inclusive environment which accommodated to diverse students' learning needs and style.

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