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Work in Progress: Visual and Tactile Aids in Multidisciplinary Engineering for Better Learning Outcomes

Dr. K. Jo Min, Iowa State University

K. Jo Min is Associate Professor and Associate Chair, Director of Undergraduate Education in Industrial and Manufacturing Systems Engineering Department at Iowa State University. He teaches courses on production systems, closed-loop supply chains, and engineering valuation. His education research interests include outcome assessment and visualization aids, and his engineering research focuses on application of stochastic optimal control on engineering decision making. He has co-authored numerous papers in The Engineering Economist, IEEE Transactions on Engineering Management, International Journal of Production Research, International Journal of Engineering Education, and other peer-reviewed journals. He has been serving as an ABET program evaluator for EAC and ETAC and as a reviewer for various NSF engineering education panels.

Dr. John Jackman, Iowa State University

John Jackman is an associate professor of industrial and manufacturing systems engineering at Iowa State University. His research interests include engineering problem solving, computer simulation, web-based immersive learning environments, and data acquisition and control.

Ms. Zhuoyi Zhao, Iowa State University

Zhuoyi Zhao is a current Ph.D. student in the Department of Industrial and Manufacturing Systems Engineering of Iowa State University.

Work-in-Progress: An enriched learning environment using visual and tactile aids to support inter-domain learning

Abstract

In this paper, we investigate the impact of visual and tactile aids on the teaching and learning of inter-domain concepts that are related to abstract mathematical models commonly used in engineering education. The context of this study includes industrial engineering, engineering management, and systems engineering, in which there are numerous abstract concepts without physical representations that make it difficult for students to learn. For example, the inventory positions and their cost consequences lead to complicated derivations and complex mathematical expressions with embedded abstract insights, but there are no corresponding physical models like airfoils for aerospace engineering or circuit boards for electrical engineering. Specifically, in this study, we investigate if and to what extent meaningful visual and tactile aids help students increase their learning outcomes.

In multiple domains, we are studying to what extent visual and tactile aids of specific mathematical concepts help students grasp such concepts. The domains in this study include inventory control, integral calculus, and additive manufacturing (AM).

From the integral calculus domain, students will learn multiple ways to visualize the inventory positions and their cost consequences for inventory control. For AM, the same students will learn to produce physical models for these mathematical relationships via AM technologies. Based on these teaching and learning experiences, we plan to show that the

level of students' understanding of the inventory models increases with these visual and tactile aids.

Ultimately, we plan to show how tactile aids produced via AM help students learn the mathematical concepts of integral calculus. We also intend to demonstrate how this calculus provides a way to characterize the variations in products manufactured via AM and enhance the mathematical and statistical aspects of AM for other disciplines. Hence, students' learning critically depends on an inter-domain experience consisting of inventory control, engineering mathematics, and additive manufacturing.

Keywords—Abstract Mathematical Concepts; Visual and Tactile Aids; Learning Outcomes

Introduction

Students have been characterized by their learning styles which affect their ability to learn and the teaching modalities that make teaching effective [1] [2]. The Felder-Silverman model describes learning styles using the dimensions of Active/Reflective, Sensing/Intuitive, Visual/Verbal, and Sequential/Global [3]. The majority of undergraduate engineering students were classified as having an Active, Sensing, Visual, and Sequential learning style as shown in Figure 1, with over 80% of the students indicating that they are visual learners. Kuri and Truzzi [4] evaluated the learning styles of freshmen engineering students and reported similar results.

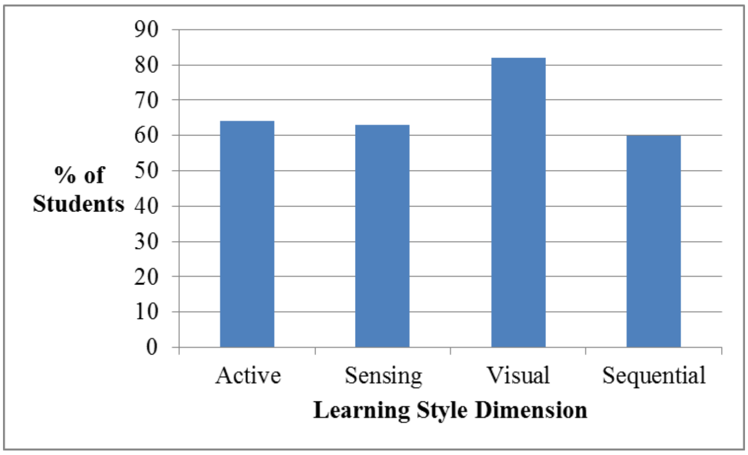


Figure 1 Classification of undergraduate engineering students learning styles [3]

Active learners prefer applying concepts in activities such as problem solving, experimentation, and group discussion. Students in the sensing category prefer learning procedures, methods, and facts. Visual learners need diagrams, physical and graphical models, and figures to learn concepts effectively. Sequential learners like to see concepts presented in an incremental well-ordered sequence. Given the high percentage of visual learners, teaching methods should include frequent use of visual and tactile aids.

In the literature of visual and tactile aids for teaching and learning, there are numerous studies providing supporting evidence that such aids enhance students' learning outcomes as well as possible rationales, for example, aids reduce the burden placed on short term memory for engineering problem solving.

Abstract concepts without direct physical representations can be found in many engineering knowledge domains such as industrial engineering, systems engineering, and engineering management. Domain topics having abstract concepts include supply chains, enterprise computing, and complex engineering projects. Teaching and learning such concepts is difficult, because students are not able to retain the concepts' in long term memory accurately or for a prolonged period of time.

A typical sequence of learning events in the classroom setting can be described by the following.

1. Abstract concepts are often derived from complicated mathematical expressions with solutions implicitly defined by a system of equations and inequalities. To derive solutions, students are expected to use optimization techniques, differential equations, or equilibrium methods, and in many cases, numerical, computational, or simulation steps are necessary.
2. A substantial number of students are unable to explain the meaning of their solutions, the meaning of the relationships among key parameters of the mathematical models, and the ramifications and implications from an economical, managerial, or intuitive viewpoint.

Consequently, we observe that quite a few of our students work hard to derive the correct solutions analytically, numerically, and/or computationally, but do not understand the solutions that they have correctly obtained in the second step above. In extreme cases, they do not know if the solution (obtained through all these numerical and computational steps) is correct, because they follow the prescribed steps mechanically without intuition or insight.

Under the circumstances described above and based on the literature review shown in the next section, we believe that visual and tactile aids are promising learning tools. Therefore, we are interested in the following engineering education research question.

Can meaningful visual and tactile aids help students understand abstract concepts without physical representations often found in the aforementioned engineering disciplines? If yes, to what extent?

To address this research question, in the context of inventory models from the inventory control domain, we propose to construct and analyze evidence-based, in-class examples of visual and tactile aids that support inter-domain learning as shown in Figure 2. These aids are expected to help engineering students develop a better understanding of abstract concepts that are needed in engineering problem solving.

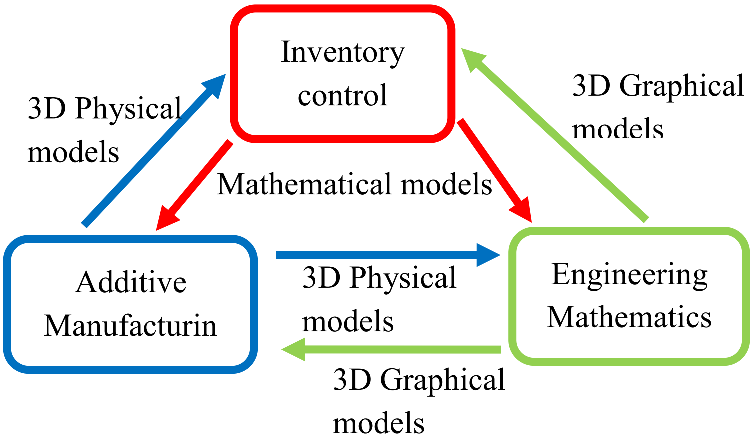


Figure 2 Visual and tactile aids for inter-domain learning

Students will learn multiple ways to visualize the inventory positions in the inventory control domain along with their cost consequences. At the same time, for the additive manufacturing (AM) domain, the same students will learn how to produce physical models of these mathematical relationships via AM technology. We plan to show how tactile aids produced via AM help students learn mathematical concepts of integral calculus from the engineering mathematics domain.

The rest of the paper is organized as follows. First, we present a review of relevant literature. This is followed by the description of the methodology used for this proposed study thus far. As it is a work in progress, we then outline the future plan for this study.

Literature review

Tactile learning aids have been extensively studied in the literature and have been used widely. Learners with a tactile preference learn more effectively when they are involved in making and handling materials (e.g., using sculptures and board games) [5]. Similarly, visual learning aids have also been explored as Zimmerman and Cunningham [6] conducted numerical analysis on the visualization effect of computer on building students' knowledge. For example, Tall [7] found that, when students drew graphs that represented physical shapes, they developed a better understanding of calculus.

The reason why these approaches are effective may be that visual and tactile aids help learners offload part of the conceptual processing required to the visuospatial domain, thus freeing up valuable verbal resources in working memory [8].

In engineering education, there are many examples of visual and tactile aids that have been used to support student learning. Heath et al. [9] claimed that the visual display of performance data was important for student comprehension. Chen et al. [10] studied the effects of using wooden models on student learning in engineering graphics. Students who used tactile wooden models scored higher on a spatial transformation test than students who used non-physical visual aids. The efficacy of visual aids on student learning with respect to learning verbal materials, spatial layout, etc. has been widely studied [11]. In addition, due to its effectiveness in promoting learning, mathematical educators have advocated for the increased use of visual and tactile aids in the classroom [12]. However, visual and tactile aids for abstract concepts in engineering have not been widely adopted.

In industrial engineering, systems engineering, and engineering management domains which share common interests in topics such as supply chains, the impact of visual and tactile aids on learning abstract concepts has not been studied.

Work in Progress

Currently, to answer our aforementioned research question, we are in the process of producing prototype visual and tactile aids which consist of the integral calculus as well as the solid modeling for actual additive manufacturing later. These aids will be evaluated in the context of an inventory control course to determine their effectiveness in improving student learning.

Visual Aids for Integral calculus

We note that integral calculus does resemble additive manufacturing in concept as it produces 3D volumes using many "thin" layers. For example, the 3D shape shown in Figure 3 can be integrated to determine the volume.

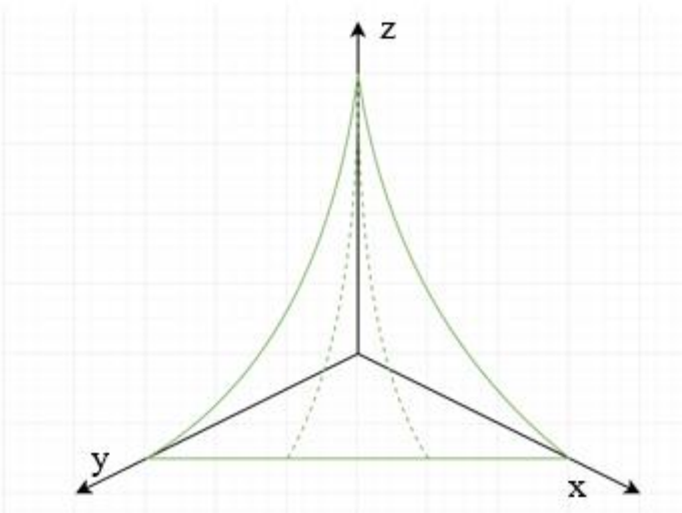


Figure 3: 3D shape defined by the green surface

We can estimate the volume of that object by adding up cubes, or voxels, of defined volume that fill that shape [13]. If we only use a few voxels, we get a rough shape for the visual aid as shown in Figure 4.

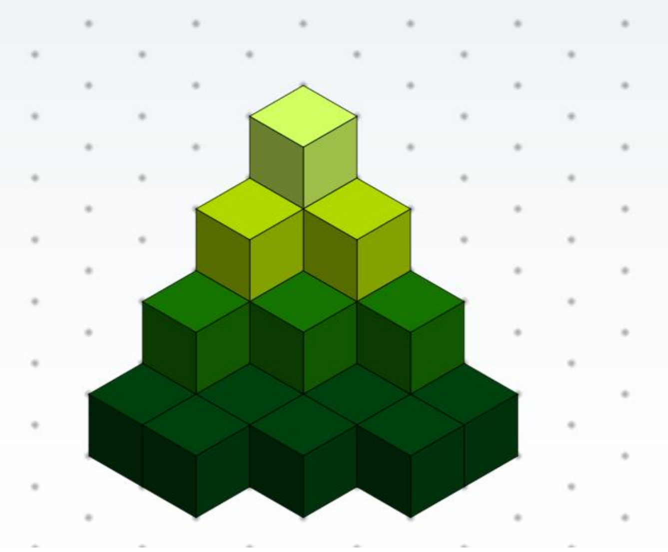


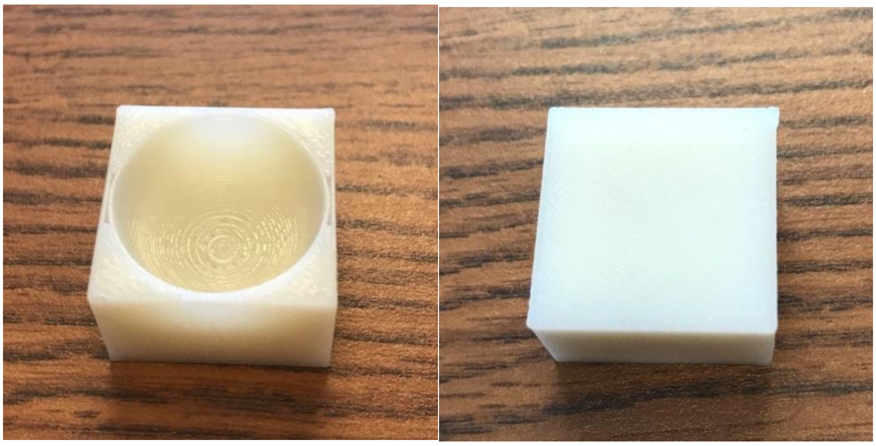
Figure 4: Visual aid using voxels to approximate the volume

Generating Tactile Models (for AM)

To create a tactile model that accurately represents a mathematical model, we use a fused deposition process with acrylonitrile butadiene styrene (a thermoplastic). The fused deposition process is an additive manufacturing technology that produces 3D solids by depositing thin layers of plastic, i.e., multiple 2D cross-sections of a computer-aided design (CAD) model. It should be noted that the resultant 3D representation is an approximation of the original CAD model and therefore, there will be surface deviations in the 3D solid. To understand the nature of these deviations, we describe our method for producing the tactile models.

Given a general function $z = f(x, y)$, we sample a set of discrete points (x, y, z) by varying the values for x and y. A surface representing the function is generated by fitting the set of points using the Scanto3D add-in in SolidWorks. From the fitted surface, a 3D model is generated to represent an (x, y, z) graph of the function. The model is then converted to an STL file which approximates the 3D model using a 3D mesh. The STL file is used in additive manufacturing to create the 2D cross-sections that are used to produce a 3D solid.

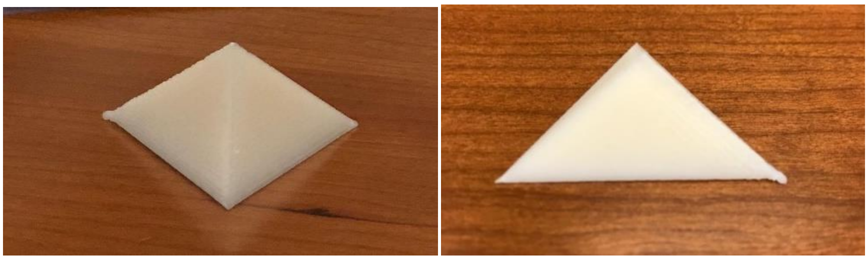
Using a mathematical model for a hemisphere, we produced a tactile visual aid with 3D printing, as shown in Figure 5. This physical model represents the volume of an object and is expected to help students to learn integral calculus.



a) b)

Figure 5: Hemisphere tactile aid: a) top view b) bottom view

To approximate the volume, as has been explained in the previous section, we produced a pyramid-shape tactile visual aid with 3D printing, as is shown in Figure 6. Additional visual and tactile aids like this will be produced in the future for studies that evaluate their impact on student learning.



a) b)

Figure 6: Pyramid tactile aid a) front view b) back view

Future Plan

With integral calculus based visual aids and the tactile aids produced via additive manufacturing, we are formulating pre- and post-test questions to evaluate the effectiveness of the visual and tactile aids in our inventory control course. Examples of our previous assessments can be found in [14] and [15].

The assessment will be designed in the form of multiple choice questions and integration of 3D mathematical models to test how well the students learn the related concepts. Students will be randomly assigned to four groups, those without any aids, those with visual aids, those with tactile aids, and those with visual and tactile aids. Paired t tests will be used to determine the statistical significance of the pre- and post-test differences. Cohen's d will be used to assess the effect size (small to large). The sample size for students in the required inventory control course (about 200 students) should be sufficient to demonstrate any differences between the four groups.

In this study, our goal is to address three types of relevant questions that are related to our primary research question.

1 To what extent does teaching and learning of 3D printing/additive manufacturing help students' learning of additive/integral calculus?
2 To what extent does teaching and learning of additive/integral calculus help students' learning of 3D printing/additive manufacturing?
3 Do visual and tactile aids from additive/integral calculus and 3D printing/additive manufacturing help students' understanding of abstract concepts in industrial engineering, engineering management, and systems engineering?

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