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Work in Progress: Visual Learning and Teaching Aids for Abstract Concepts in Inventory Control towards Better Learning Outcomes

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Abstract

As evidenced by students' inability to explain their solutions, abstract concepts without direct physical representations in engineering are difficult to grasp because they lack direct sensory, physical, or perceptual referents. In this pilot study, we investigate whether visual aids help students better understand abstract concepts and improve their learning outcomes. Specifically, in the context of the (Q, r) model in the inventory control theory, we first develop visual aids for learning and teaching, i.e., the animation of line plots that show the evolution of key quantities in the (Q, r) model over time. We then plan to use a paired t-test to see if there is any difference between the students' scores in the pre-test (before introducing visual aids) and post-test (after introducing visual aids), as well as normalized gain for analysis. In addition, as an alternative approach, we discuss tactile learning and teaching aids for the (Q, r) model.

Keywords

Visual Aids, Inventory Control, (Q, r) Model, Abstract Concepts, Engineering Education.

Introduction

Abstract concepts without visual aids can be difficult to comprehend because they lack direct sensory [1], physical, or perceptual representation [2]. In engineering education, some students struggle to find solutions or are not confident in explaining their solutions even if the solutions are correct, perhaps because they mechanically follow problem-solving steps without reflection and understanding. Hence, this research aims to expand our understanding of how visual aids can contribute to the comprehension of abstract concepts and improve learning outcomes in an engineering course.

Specifically, in the context of inventory control theory, the continuous review inventory control approach (Q, r) model is one example of abstract concepts. The objective of the (Q, r) model is to find the order quantity (Q) and the reorder point (r) that minimize the long-term expected total cost per time unit. Under the (Q, r) policy, when the inventory position falls to r units, an order of Q units should be placed, which arrives after a certain lead time. It is also considered the most critical inventory model as numerous deterministic and stochastic inventory models are special cases of this general model. Meanwhile, the derivation process of the optimal (Q, r) policy is quite extensive because the demand is assumed to be stochastic over time. In the (Q, r) model, the order quantity Q is a natural number in on-hand inventory that can be measured in the real world, such as by counting the number of units on a shelf. In contrast, the reorder point r is measured in the inventory position, an abstract number that cannot be directly measured in the real world, by adding on-order quantity to on-hand inventory minus backorder quantity. Besides, when the difference between on-hand inventory and backorder quantity is zero, the on-hand inventory and inventory position align. Given these potential confusions, the (Q, r) model can be challenging for students to understand. The (Q, r) model is important in inventory control and production planning. Lack of a good understanding may result in less economical decisions leading to a high holding cost or unmet demand, etc., which brings undesirable economic consequences.

Under such a framework, we propose visual aids for the (Q, r) model as a teaching tool and explore their efficacy. By visual aids, we mean the animation of line plots that dynamically show how the key quantities in the (Q, r) model evolve. Each frame in the animation represents the current levels of key quantities at a specific time. The visual aids will be implemented in a video format, which allows students to pause at any time and examine the levels of key quantities and their relationships.

Literature Review

Literature has shown that visual aids help students comprehend abstract concepts and enhance learning outcomes. For instance, Stokes reviewed studies investigating the effects of instruction incorporating varying degrees of visual components (no visual support, still visual aids, and animated visual sequences) [3]. The author found that using visual elements in teaching and learning generates positive results. Moreover, Mayer et al. reported that students have better learning outcomes when the instructor draws graphics on the board while lecturing than, for example, without the instructor drawing graphics, which is referred to as the dynamic drawing principle [4]. Ismail et al. studied the use of multimedia elements based on animated videos developed for engineering drawing subjects. They found that the multimedia element for animation videos could increase students' imagination and visualization [5]. Furthermore, Berney and Bétrancourt investigated whether animation is beneficial overall for learning compared to static graphics and found a positive effect of animation over static graphics [6]. We note that visualization aids themselves are not new (e.g., [7] where the emphasis is on the 2-dimensional static figures and self-efficacy).

Work in Progress

We will conduct our experiment on students in online and on-campus sections. The workflow is shown in Figure 1. Specifically,

1. Students learn the (Q, r) model (i.e., the abstract conceptual, analytical algorithm)

2. Students apply their knowledge to homework problems.

3. Students will be asked to complete a simple pre-test on the concepts of key quantities in the (Q, r) model.

4. We will introduce the visual aids (i.e., the animation of line plots) and teach them how to use the aids in differentiating the key quantities for deeper understanding through a video clip. The number of students involved in this study is approximately 50 students.

5. After introducing the visual aids, a simple post-test will be conducted, zeroing in on the concepts of the key quantities in the (Q, r) model.

6. Both tests will be graded based on the correctness of the answers, and initial statistics will be compiled accordingly. The tests from the two sections will be graded based on the same grader under the same rubric but will not be compiled together to ensure no other variables are introduced (e.g., online learning vs. traditional classroom environment).

7. A paired t-test will be used to test if there is any learning gain attributable to the intervention of the animated visual aids.

8. Normalized gain, the (post-test – pre-test) divided by (100 – pre-test) [8], will be used to analyze the difference between the grades in the pre-test and post-test.

9. In the end, the test results will be summarized.

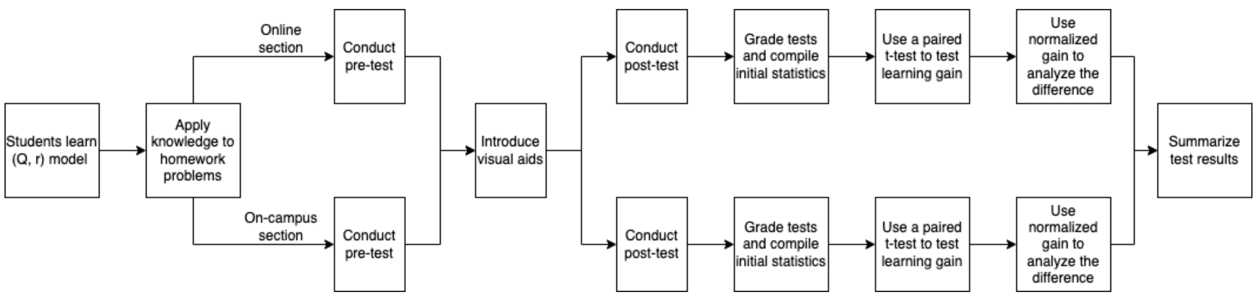

Figure 1 Workflow

Traditionally, we can differentiate the control group and experimental group by randomly assigning students who consent to participate in this project to one of the two groups. Meanwhile, an alternative approach is to use all students who consent to participate in this project and use the pre-test grades as the control group and the post-test grades as the experimental group. We choose the second approach to ensure a large sample size and an equal number of participants in the control and experiment groups, considering some may not consent to participate in this project.

The visual aids we have been developing for the (Q, r) model are the animation of line plots that show the evolution of key quantities in the (Q, r) model over time (e.g., on-hand inventory, inventory position, on-order quantity, backorder quantity, net inventory). The animated visual aids will be provided in a video format, where each frame represents the levels of key quantities at the current time point. Students can pause at any time and observe the levels of key quantities in the (Q, r) model and the relationship between them.

In the case of on-hand inventory vs. inventory position, a screenshot of animated line plots using the default parameter values is presented in Figure 2. The time granularity is a month, so a lead time of 6 means the lead time is six months. The monthly demand follows a normal distribution with a mean and a standard deviation and is rounded to the nearest integer. Students can change the parameter values and the seed number that generates random monthly demand to explore different animated line plots.

The first plot (solid line) shows the evolution of on-hand inventory, and the second plot (dash line) shows the evolution of inventory position. The horizontal dotted line in each plot is the reorder point. For any given time, the current value of on-hand inventory is shown below the first plot. Similarly, the calculation of inventory position is shown below the second plot: on-hand inventory plus the on-order quantity minus the backorder quantity. This way, students can better understand the (Q, r) model as inventory position is an abstract number that cannot be measured in the real world. For instance, if the reorder point is 500, and the on-hand inventory position is 100 with an order quantity of 50, then some students may be worried that the reorder point may never be reached by ordering 50 units.

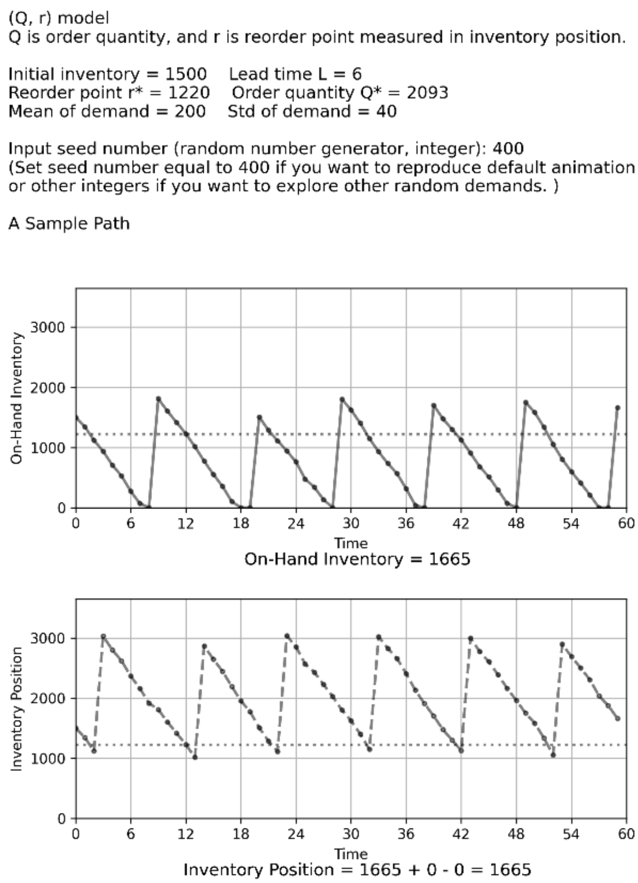

Figure 2 Screenshot of (Q, r) model visual aids (on-hand inventory vs. inventory position)

We are also developing the pre-test and post-test questions to assess how well students understand the (Q, r) model. The questions include but are not limited to how key quantities change when an order is placed or arrives after the lead time, the relationship, the difference between the key quantities, etc. Sample questions are as follows.

1. Which statement is correct given a reorder point r* = 1220 and an order quantity Q* = 2093?

   a) If the on-hand inventory hits 1220, place an order with an amount of 2093.
   b) If the on-hand inventory hits 2093, place an order with an amount of 2093.
   c) If the inventory position hits 1220, place an order with an amount of 2093.

d) If the inventory position hits 2093, place an order with an amount of 2093.

2. Which statement correctly describes the change of on-hand inventory and inventory position before and after the placement of the order?

   a) The on-hand inventory continues to decrease; the inventory position increases by Q*.
   b) The on-hand inventory increases by Q*; the inventory position continues to decrease.
   c) Both the on-hand inventory and the inventory position continue to decrease.
   d) Both the on-hand inventory and the inventory position increase by Q*.

Discussion and Future Research

For the next step, we will follow the workflow and experiment with the visual aids. If this study shows significant learning gains, we will extend our study to tactile aids for the (Q, r) model. Tactile aids have been a useful tool to help students understand abstract concepts. For example, the crocheting of hyperbolic planes has been successfully used in many high school and college geometry classrooms for decades [9]. Moreover, even though deoxyribonucleic acid (DNA) structure is not directly observable, the corresponding tactile aids have been widely applied in biology, medicine, and health sciences [10, 11]. We will continue searching for alternative tactile aids as teaching tools for better learning outcomes considering the abstract concepts are often confusing [12].

Inspired by classical integration calculus, tactile aids have been explored in [13]. As an extension of using the dynamic animation as the visual aids, we will explore tactile aids directly depicting inventory behavior. In the context of the (Q, r) model, we have produced tactile aids for a two-layer on-hand inventory vs. inventory position case with 3-D printing. We chose this combination as our initial attempt because on-hand inventory and inventory position are the most important yet confusing quantities in the (Q, r) model. Specifically, as mentioned previously, on-hand inventory is a natural number, while the inventory position is an abstract number and cannot be directly measured in the real world. Also, they align with each other when the difference between on-hand inventory and backorder quantity is zero.

As shown in Figure 3, the yellow layer represents the on-hand inventory, and the blue layer represents the difference between inventory position and on-hand inventory. To use the tactile aids, a student should first place the two layers of tactile aids in the positions shown in the left two figures in Figure 3. Next, with the left hand holding the yellow layer (on-hand inventory), the student should hold the blue layer (difference between the inventory position and on-hand inventory) with the right hand and attach it to the top of the yellow layer. Students will better understand the critical time points by observing the evolution of the on-hand inventory and inventory position over time. For instance, an increase in the blue layer indicates an order is placed, while an increase in the yellow layer implies an order arrives.

We note that the case of on-hand inventory vs. inventory position is our initial attempt at producing tactile aids for the (Q, r) model, and we anticipate more creative combinations of key quantities in the (Q, r) to be produced in the future study. For example, cases can be generated such as 1) a single layer case showing the difference between inventory position and on-hand inventory, or 2) a three-layer case showing on-hand inventory, on-order quantity, and backorder quantity, respectively, and a single layer case showing the inventory position. We will explore various combinations to obtain better-performing tactile aids as teaching tools.

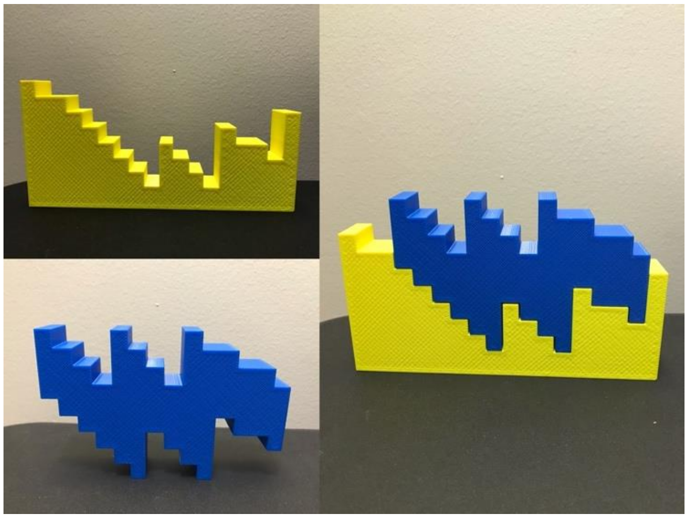

Figure 3 (Q, r) model tactile aids

This project is expected to serve as a basis for enhancing several critical courses in the industrial engineering curriculum. As it focuses on abstract concepts without direct physical representation in the (Q, r) model, it is ubiquitous in engineering education. The approaches and findings of this research should be readily transferable to other engineering disciplines (e.g., systems engineering, requirement engineering, and multidisciplinary design optimization). By that, we mean we hope that this research will improve the teaching of abstract concepts starting with Industrial Engineering in the context of Inventory Control and Production Planning, and similar applications can be extended to the teaching of Industrial Engineering as well as other abstract engineering disciplines such as Systems Engineering, Engineering Management, and even business.

Acknowledgment

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