SIMULATION BASED MODELING OF WAREHOUSING OPERATIONS IN ENGINEERING EDUCATION BASED ON AN AXIOMATIC DESIGN

Rafael S Gutierrez[a], Sergio Flores [b], Fernando Tovia[c] , Olga Valerio [d], Mariano Olmos[e

[a] The University of Texas at El Paso
[b] Universidad Autonoma de Cd. Juarez
[c]Philadelphia University
[d]El Paso Community College
[e]El Paso Community College
[a]rsgutier@utep.edu,

ABSTRACT

Many engineering students have difficulties to resolve real life problems through a traditional instruction. Most of them do not apply the fundamental science-math knowledge to construct a functional understanding. A mathematical modeling learning approach named *Axiomatic Design* represents a didactical alternative to achieve not only the scientific skills but also the ability toward the design, creativity and innovation of engineering processes based on an adaptive expertise for learning using mathematics and physics principles. We present an axiomatic design application in the context of a block stacking situation and the corresponding learning outcomes.

Keywords: axiomatic design, mathematical modeling, space utilization, geometric reasoning

1. INTRODUCTION

Most of students have learning difficulties with science-math fundamental concepts in the engineering courses. A possible reason of this understanding problem is the traditional instruction. Through this educational approach, many students do not develop a functional understanding Flores et al. (2004) of the basic scientific knowledge they need to succeed in their engineering courses and a professional life. This kind of instruction is characterized by the use of: 1) textbook-like exercises, Flores.(2006) 2) a few of didactical strategies, 3) an unidirectional teacher-student communication system, and 4) lectured-based class sessions. Although several efforts have been made to improve engineering understanding through a technology-base instructional modification, they have not been enough to develop a students' integral education. In the sense, we claim the necessity to include a science-math industry-base projects learning alternative to improve engineering students' academic preparation.

Ohland et al. (2004) report that among engineering programs, there is a consensus that mathematics (Calculus I and II) is the largest obstacle causing dropout in the freshman year.[3] To overcome the burden of mathematics and science in the freshman engineering curriculum, integration of science courses with engineering, and project- or problem-based teaching has proven effective in helping students to overcome these barriers (Bernold wt al. (2000) , Dichter (2001), and Dym et al. 2005). In addition, Prince and Felder (2006) state that learner-centered teaching methods (inductive teaching) supported by research findings have shown that students learn by fitting new information into existing knowledge structures that are unlikely to learn if they do not make the connections to what they already know and believe Gutierrez(2003).

In this article, we describe the General Framework of Warehousing and how we may teach warehousing operations using White et al. (1981), a typical sequence of events is to move unit loads from a packaging station, which and how we may teach warehousing operations, a typical sequence of events is to move unit loads from a packaging station, which has followed production operations, to temporary finished goods rack storage. Then, upon demand, the unit loads are retrieved and moved from storage to shipping. This paper focuses on how the objectives of participating students and academic institutions are to provide the engineering students with a new pedagogical approach to understand and apply mathematics and science as a cognitive tool in the context of Engineering. This approach increases the recruitment of community college students and university undergraduates toward engineering with the required skills to succeed and graduate.

Section 1 describes the general framework of supply chain using axiomatic design, defines the general domains-of-use design problem. Section 2 explains how to maximize warehouse space when retroffiting is not an option.

In Section 3, we review the most relevant literature, definitions. Section 4 presents a general warehousing design model formulation . The development of block stocking model is describe in section 5. Finally section 5 provide recommendations for block stocking.

2. GENERAL WAREHOUSE DESIGN PROBLEM AND DESIGN WORLD DOMAINS

2.1 Axiomatic Design Framework

Figure 1 provides a conceptual view of the general design problem for warehousing operations at the warehouse level that is compatible with an integrated supply chain strategy. The management of warehouse resources planning with incoming customer orders are relied on the knowledge of warehouse experts. There are two design applications for warehousing operations: (1) retrofitting of existing facilities and (2) construction of new facilities. Retrofit is the more typical and challenging case.

The main thrust of the paper is to describe a general framework of warehousing on helping students to develop skills and an adaptive expertise for learning using mathematics and physics principles.

The basic postulate is that there are two fundamental axioms that are always present in good design such as product, process, or systems design. ***The first axiom is called the independence axiom, which states that the independence of functional requirements (FRs) must always be maintained***, where FRs are defined as the minimum number of independent requirements that characterize the design goals. ***The second axiom is called the information axiom, which states that, among those designs that satisfy the independence axiom, the design with the highest probability of functional success is the best design.***

The design world of the axiomatic approach is made up of four domains: customer domain, functional domain, physical domain, and process domain. The domain structure is illustrated in Figure 1. All design tasks are contained in these four domains. For example in figure 1, in the case of warehousing systems, customer attributes (CAs) may be the attributes desired by all customers; functional requirements (FRs) may be flexibility, efficiency and controllability; design parameters (DPs) may be the layouts and design of the supply chain elements themselves as composed of physical elements; and process variables (PVs) may be machine tools, people and material handling and so on. The capacitated location/allocation block on the right represents the proposed design solution of how we choose to satisfy the requirements specified in the left block.

It is mandatory for matching functional requirements with parameter design. It is mandatory to explain the axiomatic design procedure for definition and design information required to matching functional requirements with parameter design and improve the satisfaction of the original need through the evaluation of the information content.

1.1 Physics –Mathematical Modeling Cycle

Physics – Mathematical Modeling Cycle provides useful information of our model describing how we use mathematics in physical systems as it is shown in figure 3. Math modeling cycles are applied between the different domains we described before in the figure 1 as mapping and data. Our process of math modeling cycles begin in the lower left corner by choosing a physical system we want to describe.

It is mandatory for matching functional requirements with parameter design and also
It is mandatory to explain the axiomatic design procedure for definition and design information with parameter design and improve the outcome.

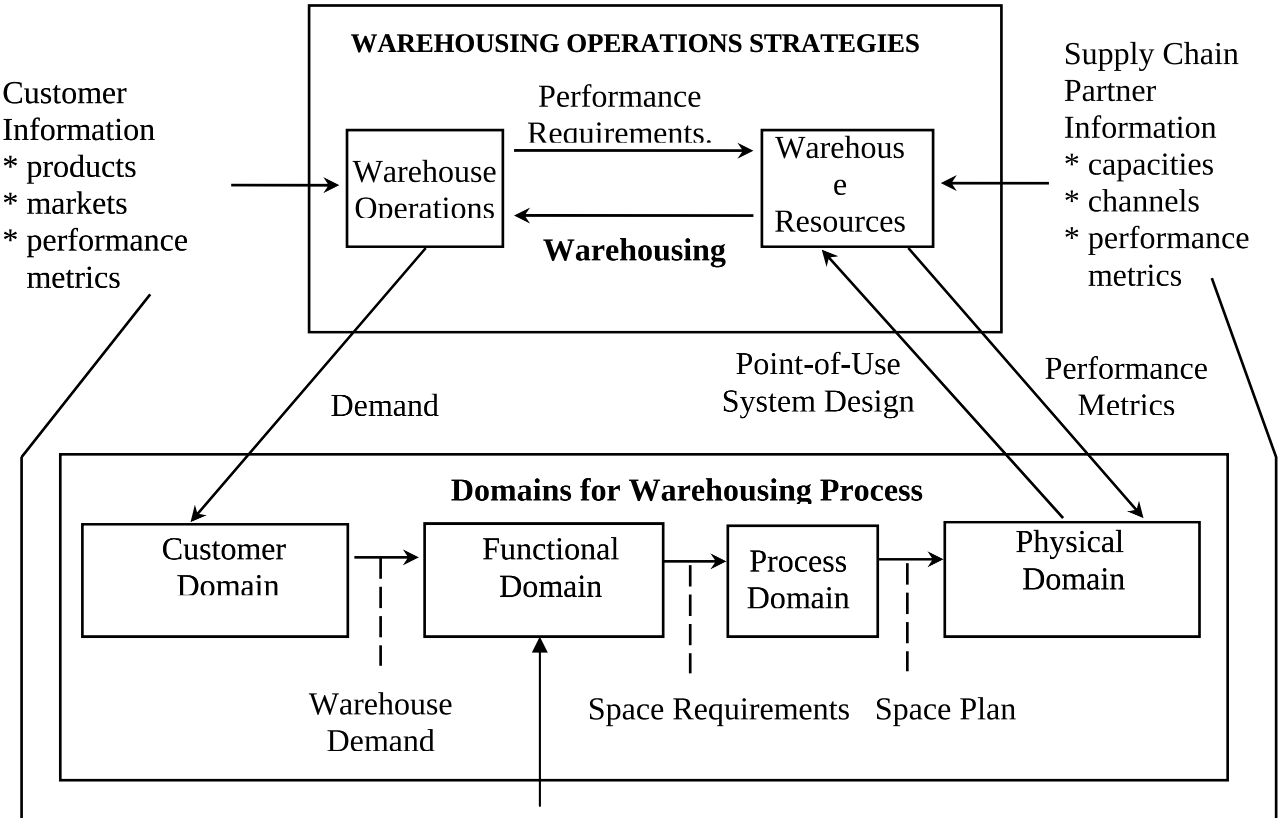

Figure 1 Warehousing Process at the Planning and execution level

1.1 Physics –Mathematical Modeling Cycle

Physics – Mathematical Modeling Cycle provides useful information of our model describing how we use mathematics in physical systems. Math modeling cycles begin in the lower left corner by choosing a physical system we want to describe. Within this box, we have to decide what characteristics of the system to pay attention to and what to ignore once. We have decided what we need to consider, we do step 1 called mapping. We map our physical structures.

According to Redish (2005) – Mathematical Modeling Cycle provides useful information of our model describing how we use mathematics in physical systems as it is shown in figure 3. Math modeling cycles are applied between the different domains we described before in the figure 1 as mapping and data. Our process of math modeling cycles begin in the lower left corner by choosing a physical system we want to describe.

We have decided what we need to consider, we do step 1 called mapping. We map our physical structures into mathematical ones. To do this, we have to understand what mathematical structures are available and what aspects of them are relevant to the physical characteristics we are trying to model following this modeling process. After we have mathematized our system, we are ready for step 2 called process. At this level, we may solve an equation or deriving new ones. We still have to do step 3 called interpretation. We see what our resources tell us about our system in physical terms and then do step 4 called evaluation. We have to evaluate whether our results adequately describe our physical system or whether we have to modify our model.
Our traditional approach does not help our students focus on some of these important steps. We tend to provide our students with the model ready made, and we rarely ask to our students to interpret their results and even less often ask them to evaluate whether we have to modify our model.

1.1 **Physics** After we have mathematized our system, we are ready for step 2 called process. At this level, we may solve an equation or deriving new ones. We still have to do step 3 called interpretation. We see what our resources tell us about our system in physical terms and then do step 4 called evaluation. We have to evaluate whether our results adequately describe our physical system or whether we have to modify our model.

Our traditional approach does not help our students focus on some of these important steps. We tend to provide our students with the model ready made, and we rarely ask to our students to interpret their results and even less often ask them to evaluate whether we have to modify our model.

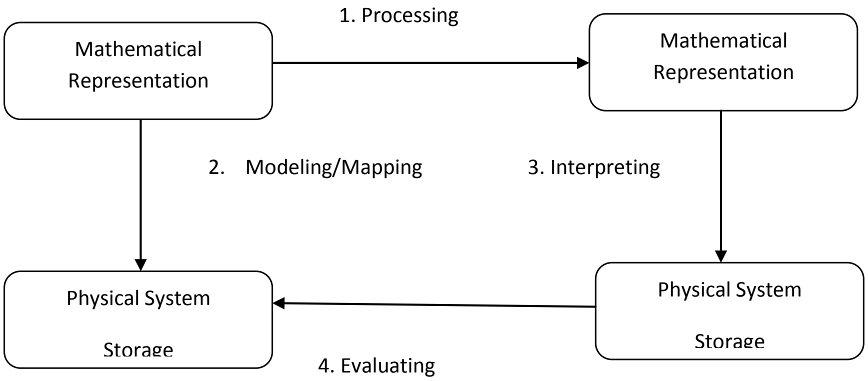

Figure 2 Evaluation process of the information content

When Retrofitting is not an option

A warehouse will normally run out of space due to rapid growth, seasonal peaks, large discount buying, planned inventory builds for manufacturing shutdowns, facility consolidation, or even a slow sales period.

Generally there are three types of space deficiencies that occur in a warehouse. The first type results from simply having too much of the right inventory. The second is the result of having too much of the wrong merchandise, and the third comes from using the existing warehouse space poorly.

We will focus on the space deficiency due to the poorly use of the existing warehouse space. This condition is usually caused by steady growth, changing storage requirements (change in product mix) and ever increasing service requirements. Poorly utilized space is a common occurrence that happens in all warehouses occasionally and is non-exclusive of the inventory type or storage conditions in the warehouse.

Traditionally, warehouses are built to handle projected volumes , a set number of products and limited unit loads. Then they are expected to adjust to customer demands as well as be more efficient over time. To accomplish these conflicting goals, warehouses generally accept long-term penalties to accomplish short-term goals like creating customized floor-ready customer's merchandise at the piece level, or creating mixed loads to simplify customer processing when goods traditionally ship in full case or full pallet quantities. All of these customization steps take valuable floor space and labor from primary warehouse functions. Other common instances of poor space utilization include low vertical space utilization, wide aisles (over nine feet), and multiple products in single bin locations and/or partial unit loads being stored in full unit load locations. These types of problems should be addressed with physical layout and workstation design changes.

3.2 Warehouse Redesign

Most of professionals working in industry consider that the warehouse redesign process is more art than science and more common sense than theory. The primary objectives of warehouse redesign are to:

- Use space efficiently
- Allow for the most efficient material handling
- Provide the most economical storage in relation to costs of equipment, use of space, damage to material, handling labor and operational safety
- Provide maximum flexibility in order to meet changing storage and handling requirements
- Make the warehouse a model of good housekeeping
- Provide maximum flexibility in order to meet changing storage and handling requirements
- Make the warehouse a model of good housekeeping

Eight steps are required to make this happen:

1 Measure the space you have to work with
2 Define the fixed obstacles (columns, walls, doors, clearances, etc.)
3 Understand the product stored and handled
    - Define storage condition zones
    - Throughput/replenishment requirements
    - Unit handling loads
4 Establish the material flow paths
5 Determine auxiliary facility requirements (offices, dock staging, hold and inspection, etc.)
6 Generate alternatives
7 Evaluate alternatives
8 Recommend and implement improvements

All alternatives must consider not only space, but also material handling, and impacts on labor.

4.0 Introduction to the Mathematical Modeling for Block Stacking Design Problem: the case of finite production rate

4.1Warehousing stocking Definitions and processes

Unit load is a term that is well known, to persons involved with material handling mainly with warehouse activities. Perhaps the most common example of a unit load is an arrangement of cartons, stacked in layers, on a pallet. The typical sequence of events is to move unit loads from a packaging station, which has all unit loads produced White J.A (1981.
Block stacking involves the storage of unit loads in stacks within storage rows. It is one of the most frequently used when large quantities of a few products are to be stored and the product is stackable to some reasonable height without load crushing. Frequently unit loads are block stacked 3-high in rows that are 10 or more loads deep. The practice of block stacking is very common for food, beverages, appliances, and paper products, among others.
Among the most important design questions, there is a fundamental question of how deep should the storage rows be, block stacking is typically used to achieve high space utilization at a low investment cost. Hence, it is often the case that storage rows are used with depths of 15, 20, 30 or more.
During the storage and retrieval cycle of a product lot, vacancies can occur in a storage row. To achieve FIFO lot rotation, these vacant storage positions cannot be used for storage of other products or lots until all loads have been withdrawn from the row. The space losses resulting from unusable storage positions are referred to as “honeycomb loss or vertical losses”; block stacking suffers from both vertical and horizontal honeycomb loss. Figure 4depicts space losses resulting from honeycombing.
The ***design of the block stacking storage system*** is characterized by: the depth of the storage row (x), the number of storage rows required for a given product lot (y), and the height of the stack (z), where the decision variables, x, y, and z, must be integer valued. If the high of the stack is fixed, the key decision variable is the depth of the storage row.
For a single product, factors which may influence the optimum row depth include the lot size, load dimensions, aisle widths, row clearances, allowable stacking heights,

storage/retrieval times, and the storage/retrieval distribution.

4.2 Initial steps for collecting drawings and data gathering

The goal of the Texas College and Career Readiness Standards (CCRS) is to establish what students must know and be able to succeed in entry-level courses offered at institutions of higher education Texas of Higher Education Coordinated Board (2010)

Using Geometric Reasoning will initiate to construct and use drawings to represent the block stacking modeling problem. Figure 4 describes the block stacking process as the storage of unit loads in stacks. The use of unit loads represents the basic element of our process such as pallets, boxes, etc. We describe palletization as an example because it is the most common and universally accepted technique of unitization. A pallet is simply a platform upon which material is placed to form a movable collection of items. Figure 5 shows the rack dimensions that are considered for the modeling of the block stocking analysis.

Let assume that a production order for Q units will arrive in the inventory system as a lot size of Q units. We will assumed that every unit load produced go directly to the warehouse. The factory is set up to produce a lot. The production rate is P units per hour and the demand rate is D units per hour. For simplicity we should assume that the production rate and the demand rate leave a fixed rate of unit loads in the warehouse of one unit for analysis only. Therefore unit loads of one unit are received in the warehouse every hour until the warehouse capacity is reached until the level of Q unit loads of inventory. During the periods when the factory is not producing these unit loads, there is a rate of outflow of one unit load until the inventory reaches a level of zero unit loads.

The basic assumptions of our analysis are: the storage is selected on random basis, the first in first out (FIFO) lot rotation is used for moving the unit loads in the warehouse, no re-warehousing of stock, and known lot sizes remain the basic assumptions of this study. The following additional assumptions are made to facilitate analysis of the product design problem.

1. The storage retrieval distribution for the product is characterized with a uniform production and withdrawal rate, no bulk withdrawals, zero safety stock, and no lot splitting.
2. For simplicity, identical load dimensions and clearances (L,W, and C) are assumed for all products. However, Z_i represents the number of stacking levels for product i, is determined by the characteristics of the individual product.
3. The space required for cross-aisles and staging will not be considered in this analysis
4. The number of lanes of each depth to be provided in the block stacking design is exactly equal to the maximum number required. That is, storage lanes will be available so that each product can be stored immediately after its arrival and at its optimum depth.

$$S = \frac{y}{2Q-1}(w+c)(0.5A + xl)(2Q - xyz + xz - 1)$$

Our decision variable is x because Z is restricted to the conditions of the ceiling height of the warehouse and the characteristics of the product in stock. Y is defined as $\left\lceil \frac{Q}{xz} \right\rceil$. Therefore, the optimization problem is:

4.3 .Block Stacking Model

4.3.1 Notation

S : Average floor area required for block stacking
X: Storage lane depth (integer number of unit loads)

Y: Maximum number of storage lanes required
Z: number of storage tiers
Q: Lot size (integer number of unit loads)
L: length or depth of the unit load
W: Width of the unit load
C: clearance between lanes
A: aisle width

We shall assume that $Y = \left\lceil \frac{Q}{xz} \right\rceil$

Where $\lceil . \rceil$ the smallest integer than or equal to $\lceil . \rceil$

4.3.2 The development of a block stacking model

The model considered is shown in figures 4 and 5. The characteristics of this distribution are:

1. Uniform storage and withdrawal rate
2. A storage and withdrawal size of one unit load.
3. Safety stock equals zero.
4. All storage lanes for a product lot are restricted to be of equal depth

The average floor space required for block stacking over the life of the product is given by the following equation,

$$S = \frac{y}{2Q-1}(w+c)(0.5A+xl)(2Q-xyz+xz-1)$$

Our decision variable is x because Z is restricted to the condicions of the ceiling height of the warehouse and the characteristics of the product in stock. Y is defined as $\left\lceil \frac{Q}{xz} \right\rceil$. Therefore, the optimization problem is:

$$Minimize$$

$$S = \frac{y}{2Q-1}(w+c)(0.5A+xl)(2Q-xyz+xz-1)$$

$$s.t. xyz \geq Q$$

$$x, y, zare\,\mathrm{int}\,egers$$

Table 1 is shown an example of how lane and space requirements vary over the entire life of the product, and it is shown the space utilization for the same example.

The space utilization formula for a given inventory level is based on the following expression.

$$Ut = \frac{100 I_t WL}{Z(ww+C)(0.5A+xL)}$$

5.0 Determination of space requirements as a main function in the analysis using Algebraic Reasoning

Review of single product model assumptions the major step in the analysis of block stacking designs for one product is the specification of aggregate floor space requirements. For a single product k, the optimum design was determinate by minimizing S_k the average floor space required during the life of the product lot. The specification of average space requirements followed from the assumption that a storage lane is is charged to an individual product lot until all units of the lot have been withdrawn.

5.1 The development of a block stacking model

The model considered is shown in figure 1. The characteristics of this distribution are:

- uniform storage and withdrawal rate
- a storage and withdrawal size of one unit load
- safety stock equals zero
- all storage lanes for a product lot are restricted to be of equal depth

Using geometric reasoning, our students make connections between geometry, statistics and probability. We compute probabilities using as a reference the number of events (possible solutions) and we scatter plot and use it to make predictions such as probability of having 6 or more pallets in the stockroom. Likewise students and instructor should measure, compute and use measures of spread to describe data. Assume linear approximation in this analysis and draw floor space utilization for this product and answer the following questions,

How the space utilization that rises when a lane is receiving items for stock, and decreases whenever a new storage lane is beginning to get used?
How the space utilization rises whenever a storage lane is freed and decreases as honeycombing occurs?

storage lane; the lane is available for storage of any other product or lot.

Using geometric reasoning, we apply right relationships for definition purposes of the definition of average space requirements for an individual product k implicitly assumes that a storage lane will be immediately required by or charged to our product as soon as all units of product k have been withdrawal

Does space utilization rises when a lane is receiving items from stock, and decreases whenever a new storage lane is beginning to use?

We have the opportunity of computing the empirical probability of an event and its complement.

Table 1. Total number of feasible system states

Inventory Level	Number of lanes required	Total of space required	Probability of inventory level	Contribution to average space	Percentage utilization
1	1	62.111	1/17	3.653	11.74
2	1	62.111	1/17	3.653	23.48
3	1	62.111	1/17	3.653	35.22
4	1	62.111	1/17	3.653	46.96
5	2	124.222	1/17	7.307	29.35
6	2	124.222	1/17	7.307	35.22
7	2	124.222	1/17	7.307	41.09
8	2	124.222	1/17	7.307	46.96
9	3	186.333	1/17	10.960	35.22
8	2	124.222	1/17	7.307	46.96
7	2	124.222	1/17	7.307	41.09
6	2	124.222	1/17	7.307	35.22
5	2	124.222	1/17	7.307	29.35
4	1	62.111	1/17	3.653	46.96
3	1	62.111	1/17	3.653	35.22
2	1	62.111	1/17	3.653	23.48
1	1	62.111	1/17	3.653	11.74
Average number of lanes		27/17	1.5882		
Average space		98.640			

We have the opportunity of computing the empirical probability of an event and its complement.

Solutions obtained with the model

As we observe the model obtained is nonlinear with integer decision variables. The table 1 is shown an example of the model obtained. The solutions are shown that the function S is non-convex with respect to X therefore , it is required to enumerate over values of X in order to identify the global minimum. In the example it was assumed Xmax equals to 15. The optimal value is X equals 8. It was assumed Z equals 3, lot size equals 147 and Y equals 7.

5.2 the development of a block stacking model

The model considered is shown in figure 1. The characteristics of this distribution are:

- uniform storage and withdrawal rate
- a storage and withdrawal size of one unit load
- safety stock equals zero
- all storage lanes for a product lot are restricted to be of equal depth

In summary a block stacking representation has been developed and the independence axiom has been applied to it. This application of the independence axiom has led to the establishment of an uncoupled design for the example of block stacking. The definition of the FRs and DPs has led to the identification of two constraints relating to storage retrieval process. An application of the information axiom is now required to allow the alternative supply chain structures to be evaluated further.

6.0 Conclusions

The axiomatic design is a relevant instructional tool. Through this learning methodology students can understand the fundamental mathematical modeling steps and the corresponding skills in the context of several engineering situations. It represents an opportunity to apply mathematical concepts in real-life situations. Moreover, it is a high cognitive contribution to develop design-innovative process understanding for both, introductory and advanced engineering courses. In addition, many learning engineering situations can be adapted to a lab-based axiomatic design instructional micro-curriculum. The major contribution of this paper is the understanding of axiomatic design block stacking design problem as a math-context tool for the development of guidelines for industry to design inventory systems along the supply chain network. Finally, we will conduct an investigation based on the analysis and categorization of the students' understanding effectiveness of this proposal in introductory engineering courses.

ACKNOWLEDGMENTS

Our sincere appreciation to Dr. Jessica O. Matson for her advice and support

REFERENCES

1.- S. Flores, S. Kanim and H. Kautz, "Students use of vectors in introductory mechanics", Am. J. Phys. **72** (4), 460-468, (2004).

2.- S. Flores, "Students use of vectors in mechanics", PhD. dissertation, Department of Physics, New Mexico State University, 2006.

3.- Ohland, M. A., Yuhasz, A. G., and Sill, B. I., "Identifying and Removing Calculus Prerequisite as a Bottleneck in Clemson's General Engineering Curriculum,", Journal of Engineering Education, Vol. 93, No. 3, 2004, pp. 253-257.

4.- Bernold, L. E., Bingham, W. I., McDonald P. H., and Attia, T. M., "Influence of Learning Type Oriented Teaching on Academic Success of Engineering Students", Journal of Engineering Education, Vol. 89, No. 1, 2000, pp. 191-199.

5.- Dichter, A. K., "Effective Teaching and Learning in Higher Education with Particular Reference to the Undergraduate Education of Professional Engineers," International Journal of Engineering Education, Vol. 17, No 1., 2001, pp. 24-29.

6.- Dym, C. I., Agogino, A. M., Eris, O., Frey, D. D. and Leifer L. J., "Engineering Design

Thinking, Teaching, and Learning," Journal of Engineering Education, Vol. 94, No. 1, 2005, pp. 103-120.

7.-Gutierrez, Rafael S., "Experiences in the Use of Integrative Manufacturing Software in Closing Professional Gaps in El Paso/ Juarez Industry," in INEER Special Volume for 2003 to the titled: "Engineering, Education, and Research- 2002: A Chronicle of Worldwide Innovations," (Eds.: W. Aung, M. Hoffmann, R. King, W.J. Ng, and Luis M. Sanchez), Chapter 25, pps. 247-255, 2003. ISBN 0-9741252-0-2.

8. Gutierrez, Rafael S., "Mathematical Models for the Optimization of Storage System Design Problem. The Case of Finite Production Rate, Working Paper, 2009

9. White J.A, Demars, N.A. and Jessica O. Matson, Optimizing Storage System Selection, 4th International Conference on Automation in Warehousing, Tokyo Japan September 30-October 2, 1981

10.Nam P. Suh, The Principles of Design (New York: Oxford University Press, 1990).

11. Prince, M., Felder, R., "Inductive Teaching and Learning Methods, Definitions, Comparisons, and Research Bases," The Journal of Engineering Education, Vol. 95, No. 2, 2006, 123-138.

12. Redish, E.F., " Problem solving and the use of math in physics courses", Proceedings of the International Conference on Physics Education in 2005, Focusing on Change, Delhi, August 21-26, 2005

13. Texas Higher Education Coordinating Board, "Texas College and Career Readiness Standards,"Texas- HECB