Applying Cognition and Learning Principles in Multimedia Tools Development: Materials Handling Systems

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Abstract — In this paper, we describe aspects related to learning and learning assessment including pedagogy, cognition, pilot study and results from the study. This study is conducted for an educational module on “10 Principles of Materials Handling”. This module along with another titled “Analysis and Design of Integrated Material Handling Systems” constitute a system of multimedia educational tools for use in material handling classes.

Index Terms — Assessment, Cognition, Interactive Multimedia Educational Tools, Learning, Materials Handling

INTRODUCTION

The National Science Foundation (NSF) funded a project at Rensselaer Polytechnic Institute in Troy, NY for the development of interactive, multimedia based educational tools for use in material handling classes. The Material Handling Industry of America (MHIA) and numerous companies and Universities from around the world participated in the development of the products. Materials handling is an important part of Facilities Design courses which are required courses in many Industrial Engineering programs. Global manufacturing and distribution of goods in the 21st century poses increasing challenges for materials handling engineering. Students of this discipline need opportunities to practice integrating the selection of technology with engineering analysis so that they will be able to solve the range of problems they are likely to encounter. The traditional way to impart this knowledge is to use illustrations, photographs, slides and video tapes of various types of materials handling systems (MHSs) and their applications, a taxonomy, definitions, a statement of the principles are covered. This is followed by general guidelines on design, implementation, operation and control of MHSs and specific models for design and operational analysis. Due to technological constraints, important material is typically introduced in a sequence without much integration. The multimedia based educational modules mentioned in this paper were developed by a team consisting of experts from several fields to overcome many of the constraints in the learning of materials handling engineering.

A major learning objective of the multidisciplinary team designing the multimedia tools was to encourage students to consider simultaneously both the analytical and the technology-based paradigms of materials handling engineering. The more these analytical and technological models are brought together, the more students will begin to integrate design and analysis tools with the applicable technologies. The design team attempted to create opportunities for users to examine decisions about the design and building of material flow systems and to analyze the application of materials handling principles to specific, real-world problems.

THE MULTIMEDIA MODULES

The two modules developed as part of the project are titled “10 Principles of Materials Handling” and “Analysis and Design of Integrated Materials Handling Systems”. The focus and structure of the two modules are quite different from one another. The “10 Principles” module teaches the ten principles of materials handling, namely: Automation, Environmental, Ergonomic, Life Cycle Cost, Planning, Space Utilization, Standardization, System, Unit Load and Work principles. It focuses on basic knowledge and principles surrounding the design, analysis and operation of MHSs. It uses a layered approach. The four layers – Discover, Explore, Contrast and Extend, contribute to users' understanding by structuring and supporting "deep processing" of the principle. In addition, the student can test his/her understanding of the ten principles by exploring an Integrate layer. The Introduction, Glossary, Help areas are also available to guide the user (Figure 1). The information design was completed with the help of the content development team, cognitive psychology expert and undergraduate students.
The Discover Layer frames the principle by showing it in action in the context of a warehouse. Situating the principle in this manner helps users visualize its use and observing the actions also serves to elicit questions from the viewer. Inquiry approaches to learning make every effort to open up topics and phenomena to students’ questions. In posing questions, learners connect to the information. Research on the "self-reference effect" shows that recall improves when people encode information in relation to themselves [22].

The Explore Layer identifies the components or "key aspects" of the principle elaborating each component with examples. This layer features playspaces (Figure 2) where the user is able to actively engage in a problem and receive feedback on his or her actions. The design team also offered perspectives --idealized work roles of Engineer, Manager, Professor, and Student-- that presented different views of a problem and modeled different approaches to its solution (Figure 3). Throughout the Explore Layer the user can rely on visuals--pictures, animations, videos, graphs. Visuals offer a change of pace from text on the screen and from the narrative. They focus the learner’s attention, and help conceptualize information presented through the examples. The Explore Layer incorporates widely held beliefs that learners:

- engage material actively in order to form schemes [21],
- learn from models with whom they can identify [2],
- use visual information to form mental images of objects, activities and their spatial relations,
- work back and forth between concrete, familiar examples and more remote abstractions [8], [19], and
- benefit from multiple examples in forming a concept.

The Contrast Layer focuses on applying the principle in real settings. In this layer positive and negative exemplars are presented to support the learner in distinguishing appropriate from inappropriate applications of the principle [5]. The narratives, "Stories with Pictures," provide enough information for users to follow decisions that had been made and to construct meaningful schemas of the problem. In addition, experts comment on the application providing another model for integrating technical and analytical problem solving. Following the narrative accounts, questions are posed that ask the user to review the situation identifying what had been omitted from the decision making. Posing questions and prompting review helps clarify misconceptions in applying the principle. Through the example and counter example, learners can modify their schemas and correct misunderstanding. The Extend Layer prompts users to think about the principle in a different context. Generalizing what one learns, recognizing a principle in a different setting takes guidance as well as practice. This layer challenged the design team's understanding of the principle. The goal was to select examples that support connections to the key aspects of the principle.

The main objective of the “Analysis and Design of Integrated Materials Handling Systems” module is to integrate knowledge of material handling technology with modeling skills. It makes use of self-paced, multimedia supported exercises to increase knowledge of automated storage and retrieval systems (AS/RSs), conveyors and palletizers. It also illustrates material handling applications of analytical modeling through hands-on design and problem solving. The module is targeted to three groups of individuals: a) intermediate level learners including juniors and seniors in undergraduate engineering programs, b) learners with strong modeling skills, but limited knowledge of technology, and c) working professionals without adequate modeling skills, but strong knowledge of current technology and practice.

Exercises are introduced via a virtual facility which is modeled after a real world distribution center (DC). The DC belongs to a national chain of teen fashion clothing retailer (figure 4). The DC ships to 2250 stores nationwide on a weekly basis. 430 pallets of garments are received on 43 trucks and unloaded daily. 28000 totes containing individual stock keeping units (SKUs) must be stored in the AS/RS system. 450 store orders must be assembled and loaded on 45 trucks daily. The primary receiving functions in this DC include unpacking, inspecting, and storing SKUs. Shipping functions include picking, consolidating, palletizing and dispatching store orders. There are several ‘areas’ in this DC where different material handling functions are carried out. For example, in the deunitizing area, the material flow functions are, receive, unpack, inspect, sort tote and store in the ASRS (figure 5). Similarly in the kit assembly area, kits must be cartonized and orders assembled; in the pallet storage area, outbound pallets must be staged and shipped.

The pedagogical approach follows three levels of analysis for each of several exercises in each of the five areas. Each area includes three layers – Select, Configure and Analyze. A learner is asked to select the appropriate technology, configure it and analyze the design created so that it works well during peak as well as off-peak periods. The second layer permits progressive design refinement and analysis of unit materials handling operations and the third requires performance based design validation. For example, in the deunitizing area, the level 1 interactive exercises require the user to specify conveyor technology including model selection, carrier Spacing and speed determination. The level 2 exercises relate to the conveyor operations and focus on planning of secondary handling systems. Level 3 exercises relate to conveyor performance and this is where the student must use analytical models to determine optimal or near-optimal throughput, utilization and cost under different system conditions. The student has rich material including three-dimensional and two-dimensional animations as well as text and narratives to guide him/her in the selection of the appropriate technology.
COGNITION, LEARNING AND SOFTWARE DESIGN

A major goal in designing the software was to provide instructors and students with a single platform to seamlessly combine descriptive, factual material with analytical models. The modules include [12]:

- tools for direct comparisons of the performance of alternative MHSs;
- animated illustration of the effect of a decision on system performance;
- simulations of various dynamic processes involved in materials handling;
- animations and/or simulations of real-world implementations of engineering designs;
- interactive ‘playspaces’ which include temporal, spatial, mechanical and material variables, that can be manipulated by the student in order to critically analyze and design MHSs; and
- case study to help the learner test understanding of the principles, models, design and analysis of MHSs.

Bransford et al., [4] describe how computer-based technologies can be effectively used for pedagogy and learning support, in addition to providing rich source of information. They examine the role of the new technologies in five areas: incorporating real-world problems into the curriculum and instruction, scaffolding learning, providing feedback to enhance reflection and revision, expanding the community of learners, and extending resources for teachers to learn. Taking up the last two areas first, during the design process the team focused on the kinds of users --students, field engineers, and instructors--who might benefit from the product. Learners in different disciplines, from novices to experts in understanding materials handling, contributed to the design process. In providing examples the team made an effort to reflect the international nature of materials handling thus appealing to a wider community of learners. At different points during production, the team sought and received feedback about the usefulness of the product from engineering professors, their students, and the Materials Handling Industry of America, a trade group representing consultants, manufacturers and users of MHSs. Features offered by multimedia, knowledge of the learning process, and experiences of the role of the social environment in teaching and learning were incorporated into the educational modules by a design team. Members of the team met in various configurations as well as all together to compose and to review the various components of the modules. A list server facilitated creation of a virtual community of learners and enabled thousands of electronic messages to be exchanged throughout the modules development.

LEARNING RESOURCES

The 10 Principles module and its companion module, Conveyors and Automated Storage and Retrieval Systems (AS/RS), offer users multiple resources for learning [20]. We have organized these in the chart in Table 1.

Multiple Features of Multimedia - Cognitive Style and Learning Strategies: Cognitive / learning style is a slippery notion that wiggles out of one's grasp even as one tries to pin it down [9], [13], [17], [23]. Still as learners, teachers, and researchers we know intuitively that cognitive or learning style is a cover term that captures the different ways learners approach tasks and internalize knowledge. Multimedia, as a presentational form, makes it possible to provide a variety of features that users with different cognitive styles can access.

Each layer of the multimedia modules employs basic techniques suggested by cognitive research. Cognitive approaches to learning focus on experiences needed in order to build a robust conceptual structure of the target topic. Learners need to internalize more than a definition of a principle; they need to develop a schema of the principle which can "hold " what they know as they "add" to their understanding. Building a schema from multiple examples increases its flexibility.

Elaborated or deep processing refers to thinking about an idea in an active, meaningful way in contrast with repeating its definition multiple times or focusing on surface characteristics. When people use deep processing of words, they remember information better [7]. “Deep processing” of complex ideas involve models of semantic memory organization. Words and concepts are organized in multiple ways with many links to other ideas so that the individual can access the retained knowledge through different routes [1], [6], [14], [15], [16]. However, just as the absence of connections can leave a learner stymied, so can too many connections. The key is organization using applications that guide differentiation, not just connections.

PILOT STUDY

As the modules were developed, an assessment of the features that helped users in their learning was made. We conducted three pilot studies during the development of the “10 Principles” module with a total of 80 participants as well as an exercise in a small graduate class. We conducted two pilots during the development of the “Design and Analysis of Integrated Materials Handling System” module with 22 students participating. In each of the pilot studies, the participants were students in Industrial Engineering classes. They participated voluntarily in the study as an optional class activity. These pilot studies
gathered self-report data on participants working through the layers of specific principles, solving problems and estimating values, or responding to questions about a case study.

**Affordances Offered by Multimedia:** We wanted to know whether participants found the range of features the multimedia offered useful in their learning. The studies reported in Tables 2 and 3 include the following constraints. First, participants were not asked to use the "Notebox" feature. A number of participants experienced technical problems with the sound stream, reporting that they could not hear the "Role Perspectives" and that the sound was "choppy." Participants also reported that they had difficulty activating some animations and playspaces. There is noise in these data, and they will need tuning as technical problems are solved. On the other hand, these data do suggest that participants were able to navigate the module with ease. The mean rating in response to the question, "Within each layer, how easy was it to follow the sequence of actions?" was 4.0 on a 5-point scale in which "1" indicated "not at all easy" and "5" indicated "very easy." (N=40).

Participants made use of the range of features offered within each layer. Following their completion of working through a specific principle, participants were asked to rate design features on their usefulness in learning. Specifically, "How useful to your learning was ______?" Again, participants used a 5-point scale in which "1" indicated "not at all useful" and "5" indicated "very useful." The average ratings for two pilot studies (N=40) are shown in Table 2.

These ratings correspond with the checks made by participants (N=28) on those features they found useful as they worked through the different layers. Every feature did not appear in every layer, and the checklist was not relevant to the Discover Layer.

**Autonomous and Designed Navigation:** In one of our pilot studies, we asked participants (N=30) to work through the layers for two of the principles, responding to questions following their completion of each layer. Participants were assigned to work through the layers of one principle in the "design order" and another principle in any order that they chose, the "free order." We asked participants in this study to rate the usefulness of "moving freely from layer to layer in any order they wished." There was no statistical difference between the ratings of the group (N=10) that worked first in the design order and the group (N=10) that worked first in the free order (\(\chi^2\), df=4=2.3). We also found no statistical difference in changes in participants' descriptions of the principle before and after working through the layers as a correlate of using the "design" or the "free" order (\(\chi^2\), df 1=0.394). One participant wrote, "I liked moving around, but liked the order of when we had to do." On the other hand, a participant working in the "free" order who chose Extend, then Explore, wrote in response to the Extend probe (In what ways did the principle become clearer as you thought about applying it in a different situation?) that "It didn't really help. Mostly because I did it with no real knowledge."

We also asked participants to respond to the following question: "In what ways did the principle become clearer as you thought about applying it in a different situation." One participant, responding to Unit Load, wrote, "It made me think of it [the principle] in things I can understand and see such as Panda and cars rather than a warehouse." Another participant wrote, "It really makes you think about efficiency! Also think more about cargo not getting abused." In responding to the Extend Layer of Automation, a participant wrote, "It's a concept that is very relevant to real life--we all have dealt with baggage claim." Another participant wrote, "Security at airports, makes you really understand importance of efficiency and accuracy--can relate to airports."

Behavioral approaches to learning have shown that performance on a task is optimal when the learner has a model, is motivated to perform, and practices [11]. The design team envisioned the multimedia modules as a supplement to class instruction. Presenting an actual case study often serves as a useful diagnostic tool for learners and instructors as students can compare their responses to the instructor's as novice to expert.

To gauge the effect of using the module alone on students' understanding of materials handling operations, twelve graduate students were asked to respond to the same question before they worked through the case study, focusing on a particular principle assigned to them, and after. The before/after responses showed little or no difference. In another, smaller, graduate seminar, students were assigned specific principles to work through. Then, in pairs, we asked them to review the case from one of the idealized role perspectives. Their written responses, suggest that during the perspective-pair exercise, students did consider the principles and tried to apply them. The responses provided the basis for the whole class discussion of the case study. In an undergraduate class, the case study was given as a written homework assignment to be graded. Of the 38 assignments returned, seven students failed to refer to the 10 principles in their responses. Instead they referred to specific problems and issues in less technical language. The student responses can provide the instructor with useful information about students' understanding. The Planning principle, although it may be taken for granted, was identified by only 61% of the students; whereas Space Utilization, although not applied explicitly in this case study, was recognized by about 80% of the students. Students were most likely confused about the Work principle because about one-quarter of them responded that it was applied in this case. Students correctly identified Ergonomics, Environmental, and Life Cycle Cost as the principles that had not been considered in the case study. We asked the 12 graduate students, whose responses to the case study are reported above, how they approached the task of analyzing the case study. Their responses indicate a range of approaches.
The fact that these participants report working through the principle in different layer orders suggests that autonomous navigation is a useful feature.

**CONCLUSION**

We have not been able to determine what, how much, and how well students have learned the principles. This would have required a finished product as well as proper controls and benchmarks for comparison. Now that the modules are complete, it will be possible to test students’ understanding of the principles as a correlate of using them. In what ways do students who work through the module, in contrast to students who do not use it in studying materials handling, perform better on particular measures, e.g., a typical test, analyzing a case study? Do students who use the multimedia module feel more confident in analyzing materials handling situations than those who have learned the material in the traditional fashion? Do instructors who prepare their lectures after working through the multimedia module, in contrast with those who do not use the module as a resource, provide better examples of integrative analysis in materials handling? We have found that students appreciate many features afforded by the multimedia, and they believe these features are helpful to their learning. Importantly, different learners select different features to use. They seem to assemble the tools in a configuration that supports their understanding of the learning task and their familiarity with the multimedia features.

**ACKNOWLEDGEMENT**

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**REFERENCES**


TABLE 1

<table>
<thead>
<tr>
<th>Design Feature</th>
<th>Learning Resources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Layers</td>
<td>The four layers of the 10 Principles, Discover, Explore, Contrast, and Extend, provide different kinds of information about each principle and challenge learners in different ways. Learning tends to be domain specific, and expert and novice learners approach and work problems differently based on their different knowledge bases, formulation of the problem space, and memory organization [10], [18]. Experienced learners can select different routes and features, tailoring their use to the requirements of the learning task, as they perceive it. Novice learners can follow the design sequence, and try out the various features provided.</td>
</tr>
<tr>
<td>Pathways</td>
<td>Navigation is autonomous. The learner or instructor can select any entry point and personalize the path depending on need. Multiple pathways allow users to regulate their own sequence in working through the content based on interest, focus of the investigation, and time available.</td>
</tr>
<tr>
<td>Examples in Actual Contexts with Real-world Problems</td>
<td>Actual contexts—a warehouse for the 10 Principles and a distribution center for Conveyors and AS/RS—were selected as presentation environments. These are authentic situations in which learners can see and make use of the real work that gets done in materials handling operations. These actual contexts keep the complexity of materials handling operations in front of the learner. This foregrounds a major learning objective; namely, that materials handling engineering requires a process of integrative decision making tailored to the problem at hand.</td>
</tr>
<tr>
<td>Orientations</td>
<td>The user is encouraged to consider multiple orientations to problems posed by materials handling operations. Idealized work roles of engineer and manager maintain the actual context of the example. The orientations help to establish a sense of the materials handling industry as requiring communication between diverse people with different work roles in a range of materials handling operations from small, local activities to large, global material handling systems. The student role gives the user a sense of the kinds of questions different learners ask, and the professor role models expectations for understanding and provides appropriate responses.</td>
</tr>
<tr>
<td>Multiple Actions</td>
<td>The user coordinates different modalities and engages in different cognitive activities in working through the module. The user may inspect a visual representation of an activity, explore a play space, estimate a value, calculate costs, listen to different perspectives, compare positive and negative instances of an application and respond to questions focused on different levels of knowledge acquisition [3].</td>
</tr>
<tr>
<td>Assessing Understanding</td>
<td>The modules support different instructional environments from individual to team problem solving. In addition to the problems and questions presented throughout the module, the Integrate feature of the 10 Principles presents a case study along with questions probing the problem the situation poses. It asks the user whether the ten principles have been applied appropriately in the situation. Individual users might want to begin their work with this feature so that they can gauge their study time efficiently. They might choose to focus on those aspects of materials handling where their knowledge is weak. Instructors might use students' responses to the case study to determine how much time to devote to a particular content area. This feature provides an opportunity for assessing conceptual understanding at the level of practice.</td>
</tr>
</tbody>
</table>
TABLE 2
AVERAGE RATINGS OF DESIGN FEATURES

<table>
<thead>
<tr>
<th>Feature</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>real-world examples</td>
<td>4.60</td>
</tr>
<tr>
<td>visuals--animations, pictures, videos</td>
<td>4.25</td>
</tr>
<tr>
<td>stories contrasting appropriate and inappropriate applications of the principles</td>
<td>4.03</td>
</tr>
<tr>
<td>on-screen text</td>
<td>3.90</td>
</tr>
<tr>
<td>Playspaces</td>
<td>3.40</td>
</tr>
<tr>
<td>auditory narrative stream</td>
<td>3.35</td>
</tr>
<tr>
<td>hearing different role perspectives</td>
<td>3.23</td>
</tr>
<tr>
<td>questions and notebox</td>
<td>2.73</td>
</tr>
</tbody>
</table>

TABLE 3
LEARNING FEATURES (CHECKED BY PARTICIPANTS WITHIN LAYER*)

<table>
<thead>
<tr>
<th>Feature</th>
<th>Explore Layer</th>
<th>Contrast Layer</th>
<th>Extend Layer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animation, video</td>
<td>89%</td>
<td>59%</td>
<td>68%</td>
</tr>
<tr>
<td>Pictures, charts</td>
<td>55%</td>
<td>61%</td>
<td>57%</td>
</tr>
<tr>
<td>Text on screen</td>
<td>75%</td>
<td>59%</td>
<td>57%</td>
</tr>
<tr>
<td>Auditory Narrative Stream</td>
<td>41%</td>
<td>41%</td>
<td>41%</td>
</tr>
<tr>
<td>Playspaces</td>
<td>25%</td>
<td>4%</td>
<td>11%</td>
</tr>
<tr>
<td>Hearing Role Perspectives</td>
<td>20%</td>
<td>18%</td>
<td>11%</td>
</tr>
<tr>
<td>Review Instructions and Questions</td>
<td>20%</td>
<td>13%</td>
<td>13%</td>
</tr>
<tr>
<td>Responding to questions in writing -- Notebox</td>
<td>4%</td>
<td>4%</td>
<td>6%</td>
</tr>
</tbody>
</table>

*28 Participants; Table 2 expresses the ratio of checks made to possible checks as a percent.

FIGURE 1
INFORMATION DESIGN OF ‘10 PRINCIPLES’

FIGURE 2
INTERACTIVE PLAYSPACE