AC 2009-390: TECHNOLOGY-ENHANCED INSTRUCTIONAL DESIGN IN CONSTRUCTION: FRAMEWORK AND CASE STUDY

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Technology-Enhanced Instructional Design in Construction: Framework and Case Study

Abstract

Teaching construction at the university level is a challenging task due to the complexity of construction activities and the logical/temporal/spatial interdependencies among them. Technology-enhanced instruction, if properly designed, has a great potential for helping students to reduce the tremendous amount of cognitive load when learning about the construction process and keeping them actively engaged for high level tasks such as evaluation and decision-making. This paper outlines a design framework that can be used to develop technology-supported teaching tools that will help achieve the desired learning objectives for any subject matter. The framework is built by integrating the existing well-established literature in instructional design with the commonly accepted strategies in active learning and interaction design. Its student-centered approach to design is reflected in the incorporation of students' learning style within the design process. To illustrate, the framework was applied to develop hypothetical software that would be a material management learning module. This was then compared to an independently created learning module that used mobile technologies – tablet PCs and sensors – to simulate a virtual jobsite and served the same learning objectives as those of the hypothetical module. Evaluation of the learning module was performed using a small but representative sample. The evaluation includes student performance data, student feedback, and our observational data. The paper will also conclude with lessons learned and considerations for additional development of mobile technologies for instruction.

Introduction

Construction as a discipline is difficult to teach in the traditional classroom as much pedagogy concerns spatial reasoning about the layout of job sites, materials flows, work areas, etc. Furthermore, construction projects are large, always changing, and, at least for students, inherently unsafe for much more than a field trip. With the advancement of modern technology, this challenge can be overcome by creating a learning environment that virtually expands the classroom beyond the walls of the engineering school building. A simulated jobsite on a computing device equipped with good visualization and manipulation capabilities will provide students with virtual but meaningful learning experiences. Such a technology-and-content-rich environment is also a great condition for active learning – an instructional approach that has been warmly embraced by and desired among educators due to its teaching effectiveness.

The promising potential of an effective technology-supported classroom only becomes reality if properly designed instruction is in place. This requires not only effective pedagogical design but also an efficient and innovative interface design. Instructional design in itself is a difficult task, especially for a domain complex as construction where any learning goal is a multifaceted goal that requires students to understand both the various components of the physical environment and the way these components relate to and react with one another in space and over time. Technology adds one more dimension of complexity to the design problem due to its engaging but very often distracting power. There are many human interface design guidelines to guide the development of a technological platform as well as a considerably large number of instructional strategies that support active learning. However, there has been no consolidated literature that assembles these bodies of knowledge into an operational framework that can be used as a practical design toolkit to create technology-enhanced active learning tools.

Let's take a problem at hand to examine what steps, and what specific knowledge at each step, are involved in the design process of such a tool: how to teach students about material management on a construction jobsite? As for any other method of instruction, the process has to start by identifying the desired learning outcomes for this module, and the metrics for learning outcomes: What do we want the students to know about materials and their role in the construction process? How do we know students have learned the concept after taking the lesson, or using the tool? An active learning strategy will then have to be adopted, which will help us design student activities or exercises, the sequence in which these should be carried out, and the supporting knowledge and environment for those activities. Finally, how should the technological platform be designed to simulate these actions truthfully? Which specific human interface design principle or principles should be emphasized to create the desired impact on learning?

To combine all the different perspectives involved in this design process, we proposed a framework that systematically integrates all aspects of design in an iterative procedure. Such a framework will help instructional designers to navigate the body of knowledge in active learning in a purposeful way and always remain faithful to the original pedagogical goals. By relating interaction design principles and active learning strategies in a structured manner, the framework enables designers to make sensible and logical choices of design features for their interface. The framework has a built-in mechanism for incorporating lessons learned and research findings through testing into the design cycle, which makes the validation and optimization process efficient.

To present the foundation for the framework, a brief review of the relevant background literature will be presented. The framework will then be described and illustrated by using material management as a design case study. The outcome of this hypothetical design will be compared with a learning module we developed independently of the framework. A discussion then follows to highlight the lessons learned and potential improvement to both the frameworks and the learning module. Finally, the next steps section identifies further studies and testing that will improve the framework.

Background literature

Regardless of how active learning and interaction design might seem to become the focus of our design problem, it is important that the central task remain instructional design. It has to be the core upon which the framework is built and expanded to incorporate certain specific perspectives. A literature review on instructional design is therefore in order. Selected strategies in active learning that are most suitable for technological applications will be introduced as the starting point to build our design toolkit. Relevant interaction design guidelines that can be capitalized on to create potentially stimulating learning conditions are another critical component of our toolkit and hence will be described. The following section on the design framework will explain what specific items to pick from this toolkit for a certain design problem.

Instructional design

Instructional design is a systematic approach to instruction. A tenant of instructional design principles is to "start with the end in mind", or "backward design" as described by Wiggins and McTighe[1] (Figure 1). This tenant is analogous to purposeful task analysis. With instructional design, assessment of learning is designed at the beginning rather than at the end of the process. Once the learning outcomes have been determined, measurement methods are created to assess the effectiveness of teaching. These measurements can be made more specific as learning exercises are developed in greater detail in the process.

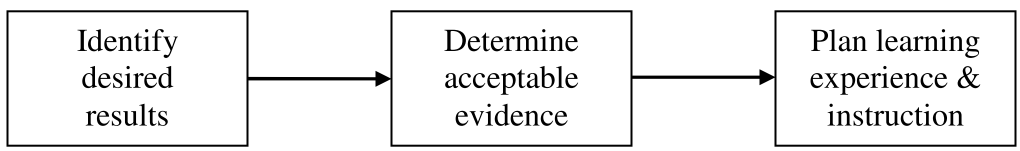

Figure 1. Stages in the Backward Design Process[1]

To help with identifying the learning outcomes, Bloom's taxonomy[2] of educational objectives is often used (Figure 2). Both the cognitive and affective domains are relevant in the design of technology-enhanced teaching tools. While cognitive behaviors are directly related to the understanding of a subject matter, the affective behaviors play an important role in shaping the attitude of students toward technology and this can greatly impact learning effectiveness. The behaviors in the cognitive domain involve knowledge and the development of intellectual skills. This taxonomy is an essential guideline for designing actions that help achieve the desired learning outcomes. The behaviors in the affective domain involve a learner's emotions when dealing with the learning environment. As technology is such a different medium from the traditional learning context, students might have feelings, motivations and attitudes that interact with their learning in unexpected ways. This awareness of the students' perceptions helps to design effective tool evaluation for the learning module.

Active learning

Active learning is defined as any kind of instruction that engages learners in activities that require them to actively take action and think about what they are doing. This engagement is the core element of the whole active learning process. Prince (2004) presents a comprehensive review of the literature in active learning and states that there is a strong base of supporting evidence for the effectiveness of active learning in the literature, although the support is not even for all methods of active learning.

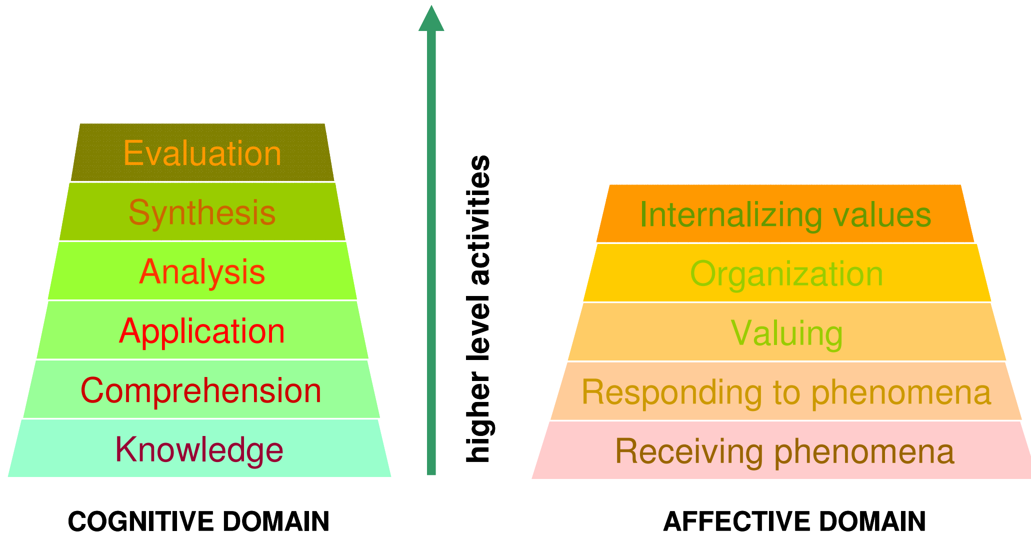

Figure 2. Bloom's taxonomy of educational objectives

Most educators assume that learning is inherently active; yet research suggests that for students to be actively learning, they need to do more than just listen. They must be actively engaged in tasks and in thinking processes. In other words, it is more critical for students to be cognitively active than just behaviorally active[1]. This is an important criterion for us to select active learning strategies for our toolkit among hundreds of strategies and techniques that have been developed over the years. Among these strategies, some can become significantly more effective when supported by a technological platform, especially those that are geared toward self-directed, group or limited-instruction learning. This is another factor taken into consideration for the selection of learning strategies. The initial result of this selection process is presented in the first column of Table 1. It should be noted that the list is not supposed to be exhaustive and just serves as the starting point for framework development. It will change as the framework gets validated and refined and more active learning strategies are revealed to be effective through testing, observation and extended literature review.

<u>Interaction design guidelines</u>

Several guidelines exist for graphical user interface (GUI) design and have been widely embraced by most well-known industry software and hardware designers such as Apple and Microsoft. While most of these guidelines are not specifically developed to guide the design of learning tools, many of them will inherently lead to the creation of interactive, friendly and flexible interfaces which are extremely supportive learning conditions. For any interface, there are qualities that are commonly desired such as readability, aesthetic integrity, or reliability. To support the creation of an active learning environment, we purposely focus on interaction design principles that will help create interfaces that are particularly engaging, stimulating and cognitively supportive to the learning process.

Table 1. Initial input to design toolkit: Active learning strategies and Interaction design guidelines

Active learning strategies [4,5,6]	**Interaction design guidelines**[7,8]
Video critique. Students watch a video of a real-world scenario and analyze the situation to enhance understanding.	**Consistency.** Make objects consistent with behaviors. Make options consistent with uer expectations.
Mind-mapping. Create a tree-like map to generate ideas around one or more central themes.	**Feedback and Communication.** Keep users informed about what's happening by providing appropriate feedback and enabling communication with application.
Immediate feedback by electronic polling. Students use handheld or web-based tools to answer assessment questions as the lecture is presented. Useful to show real-time engagement and immediate understanding.	**User control/Direct manipulation**. Allow users, not computer, to initiate and control actions, avoid dangerous and irreversible actions.
Simulation. Students learn by seeing reproduced processes and concepts of an organization or system in action.	**Forgiveness.** Make most actions easily reversible. Anticipate common problems and provide timely alerts.
Role-playing. Students assume a role in a simulated or imaginary context and learn through dramatic interactions with the simulated environment and other relevant imaginary characters/roles.	**Anticipation.** Anticipate users' want and needs
Case studies. Students learn about an actual event related to subject matter, then analyze and discuss many aspects of the problem.	**What You See Is What You Get**
Concept clouds. On a prepared handout of key concepts to be learned, students visually highlight best understood concepts, then compare with instructor's expectations.	**Explorable interfaces**. Provide multiple options, paths. Always allow "Undo". Offer solutions in all cases.
Clarification pauses. Mini breaks within a lecture/lesson for reflection and quick quizzes.	**Metaphors**. To create visible pictures in the mind, grasp finest details of conceptual model.
Recap viewlets. At the end of lecture, review keypoints visually by creating a flow of snapshots.	**Modelessness.** Give users total control at all time. Avoid modes that lock users into one operation with no exit option.
Leading question. Ask students an interesting/controversial question related to the subject matter at the beginning of a lecture to stimulate thinking and engagement.	**Reflect the user's mental model.** Built on user's real-world experience to meet expectations about task logic and flow.
	Explicit and implied actions. Explicit actions clearly state the result of manipulating an object. Implied actions convey the result of an action through visual cues or context.
	Effortless. Don't make users think.
	Don't let users make mistakes
	Learnability. Products should have no learning curve.

The goal of a commercial user interface is to eliminate the need for thinking about the interface as much as possible on the user's side. The goal of instruction, on the other hand, is to focus thinking and cognitive processes on the subject matter to be learned. As a result of this discrepancy in purpose, some of the existing GUI "golden rules" might not work as well in an educational setting as it does in the original setting. Through carefully designed experiments using our existing and future learning modules, some of these subtle impacts can be detected which helps develop a more thorough set of interface design guidelines for pedagogical tools. For the purpose of initial framework development, the set of guidelines in the second column of Table 1 has been selected from a large body of knowledge in interaction design.

Design framework illustrated

This session will describe how the input from the literature is integrated in the design framework we developed, and what additional actions and thought process an instructional designer has to perform besides using our framework and toolkit. To illustrate the steps involved in this process, we will use the material management problem as our case study design. The outcome of applying the framework to this problem resulted in "ideal" learning module software. We will compare this "ideal" design with a previously designed module that was not based on the framework and examine the gaps between the two. The graphical presentation of our framework in Figure 3 will be followed by detailed explanations for every step.

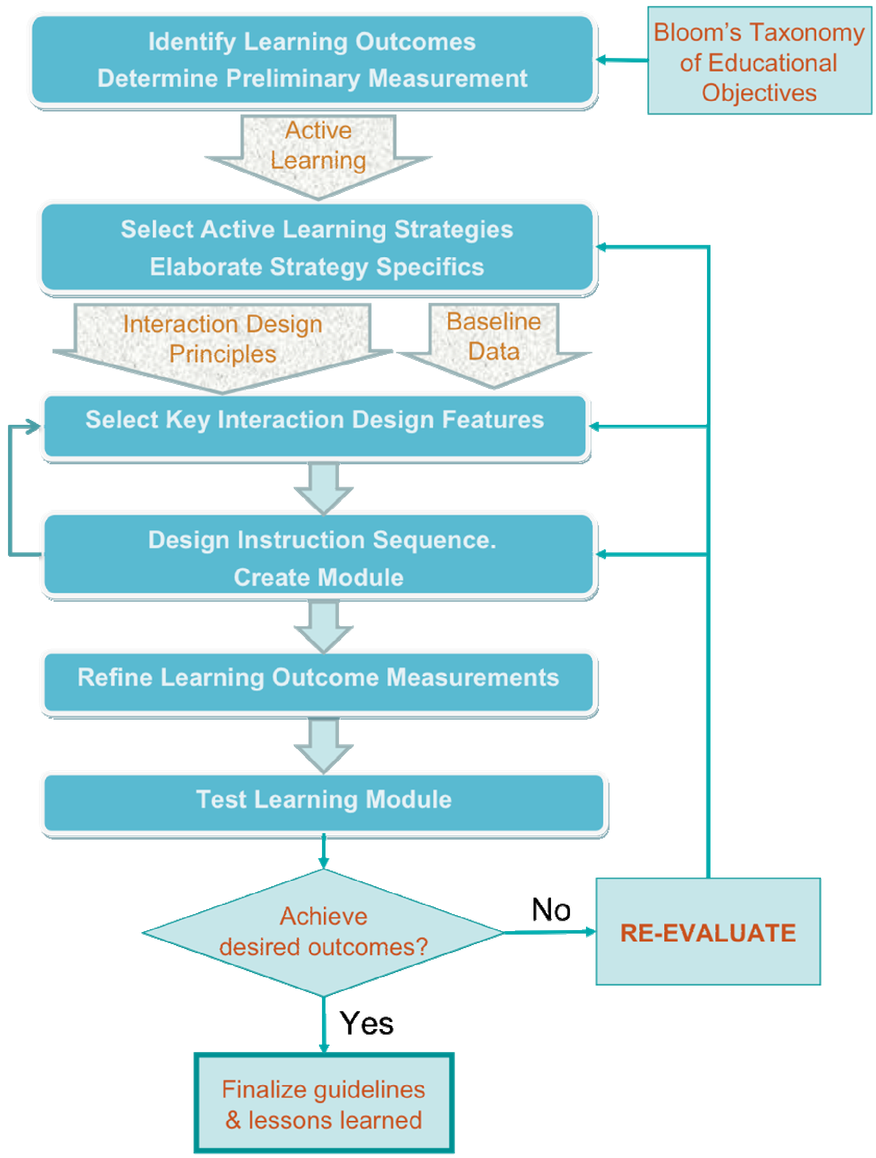

Figure 3. Design framework for technology-enhanced teaching tools

Step 1. For the topic to be taught, determine specific Learning Outcomes (objectives) guided by Bloom's taxonomy of educational objectives presented in the literature review. For our case of the material management module design, five cognitive and three affective learning objectives were identified as shown in Table 2. It is the instructor's subjective decision as to what learning objectives are the most important.

Step 2. Determine preliminary learning outcome measurements for teaching effectiveness assessment. These metrics might change when detailed instruction is created. The technology platform when completed might enable additional parameters to be recorded within the software. Observations of students using the software might provide more evidence for the design's effectiveness or the lack thereof.

Table 2. Learning outcomes and outcome metrics for material management learning module

Learning Outcome	Domain	Level	Learning Outcome Metrics
Material identification	Cognitive	Knowledge Comprehension	Percentage of materials identified
Spatial reasoning	Cognitive	Comprehension Analysis	Percentage of materials located Ability to identify spatial conflicts
Resource comprehension	Cognitive	Comprehension Application	Percentage of materials correctly associated with activities
Spatial-time integration	Cognitive	Analysis Synthesis	Ability to adjust schedule to avoid time/spatial conflicts
Logical reasoning	Cognitive	Evaluation	Ability to make logical schedule adjustments
Response to missing information	Affective	Responding to phenomena	Percentage of missing materials correctly identified
Response to technology failure	Affective	Responding to phenomena	Ability to realize technological failures Observational data of student reactions Student feedback
Valuing of human independence in decision making	Affective	Valuing	Ability to make sound judgment and logical decision when technology fails Student feedback

Step 3. For each of the identified learning outcomes/objectives, select from the Active Learning Strategies component in the toolkit (left column in Table 1) the best-suited strategy (or strategies). It should be noted that not all strategies in the toolkit are of the same level of complexity or specificity. Some are specific activities that do not require a much more elaborated action design, such as mind-mapping, leading question, or clarification pauses. Other strategies such as simulation, case studies or role-playing are just generic techniques that can be operationalized in various ways. Among the many active learning techniques, we chose simulation and role-playing as our desired methods to teach students about such complex reality on construction sites given the fact that we cannot always have access to actual job sites. We wanted them to play the role of a site superintendent whose major task is site management, which would serve our teaching purpose well. We wanted to create software that can communicate with mobile devices such as sensors to collect data on materials, and hence created a simulated jobsite within our engineering building. The goal was that after using the module, with a construction schedule in hands, the students should be able to walk a jobsite, comprehend the material availability status for all construction activities, their relative locations on the jobsite, to diagnose any spatial or availability conflicts and make necessary adjustments to the schedule. These objectives were aligned with the cognitive learning outcomes previously determined.

Step 4. Determine Specific Strategy Actions for the chosen active learning strategies that will help create the necessary learning conditions, if necessary (for generic strategies that lack specific action guidelines). Since both simulation and role-playing can be created in several ways, we needed to determine what qualities a simulation product would have to possess or what action it should enable to recreate a construction jobsite realistically. The ability to replicate the physical and functional constraints of a construction jobsite and to reflect accurately the cause and effect relationships of construction processes were deemed important in our simulation. To create a meaningful context for role-playing, the simulated system would have to allow interactions that reflect truthfully the responsibilities, authorities and relationships practiced by a superintendent. This is a step that might not be performed easily just by selecting items from our toolkit (although many strategies will be analyzed for the purpose of our framework development and therefore will be available for use).

Step 5. By consulting the "database" of interaction design guidelines in our toolkit (right column in Table 1), on an individual basis compare the Interaction Design Features to the Specific Strategy Actions and select them as key features to focus on in the interface design if they are consistent with the Active Learning Strategies and Learning Objectives. This process requires common sense and a good understanding of what each design principle or guideline is about and what implications it might have on learning.

Also in this step, if the information about the student audience is available, it can be used to identify additional desired design features as audience need analysis is a critical part of the student-centered approach to instruction. For example, we collected the learning style data from 57 civil engineering students in different schools, and the results showed that among our sample, a vast majority of students are visual (88%) and sensing (81%) learners with a slight preference of active (52%) over reflective reasoning. They also seem to be more comfortable with sequential (63%) than global (37%) learning. The design implication of this might be the importance of a highly visual interface with a right balance of degrees of freedom and structured instruction where students can explore and learn by discovery without getting lost.

Figure 4 illustrates one possible path from step 1 through step 5 for one of the learning objectives that we had for the material management learning module. It should be noted that the path determination is subjective, and different learning objectives might have overlaps in their paths, which indicates that certain learning strategies or design guidelines are really relevant to the achievement of the overall learning goal. This path can be used as a visual tool to select the learning strategies and design features in a systematic and cognitively supported manner.

It should be noted that this tool is not automatic and several of the steps involve subjective decisions based on personal experience and knowledge, but each column in the filter constrains the next, thus narrowing the path that will be taken. In this iterative process, as the investigation advances, it is expected to solidify the foundations of the interaction design with the outcome of the Learning Modules.

Step 6. Design Instruction (Learning) Sequence and create the detailed learning module. This is where the bulk of software development is done. It is possible that not all the desired interaction design features can be realized in the interface, and changes might have to be made to the design of the lesson, including the learning activities and sequence. The learning sequence for our case study is shown in Figure 5.

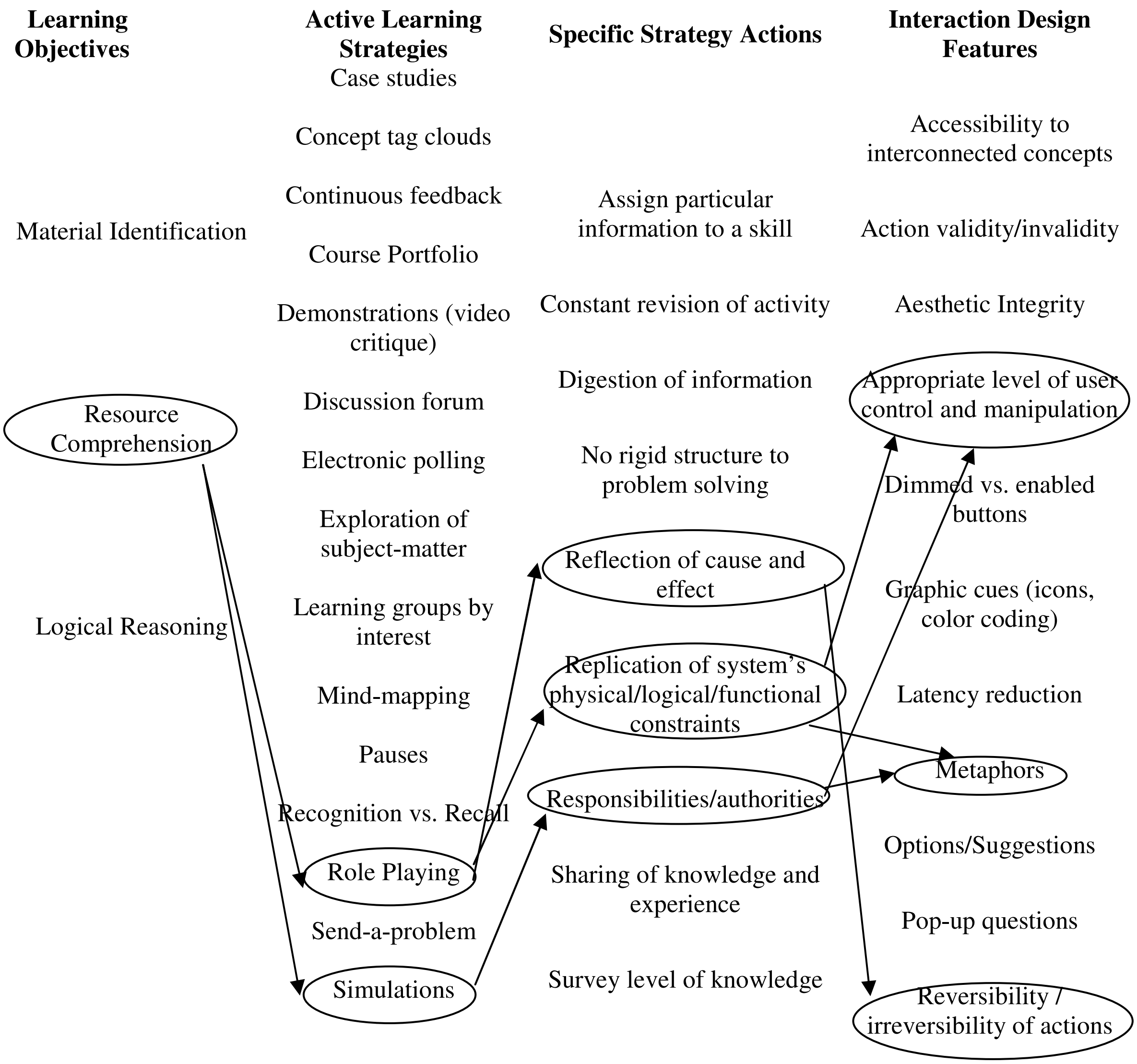

Figure 4.Visual tool for identifying active learning strategies, specific actions and interaction design features

Step 7. After the module's interface is created, we can refine the learning outcome measurements to reflect the additional capabilities of the technology in improving learning assessment. For example, we can record the number of mouse clicks for each action, or capture the screenshots when the students use the application. Observational data can be effective metrics to measure the affective learning outcomes as well.

Step 8. Software/Tool Testing. Using a representative sample, test the interface developed, and collect data for both instructional assessment and tool usability assessment.

The module testing includes learning assessment, learner perceptions and usability testing. The most important indicator of a successful design is the satisfactory achievement of the desired learning outcomes. If the learning module fails to achieve the outcomes, we have to go back and re-evaluate every step after the identification of learning outcomes. Failure might lie in the instructional technique chosen, the outcome measurement design, or the design of the interface itself. Any lessons learned in this process will contribute to the development of a more generic set of design guidelines that is applicable to other teaching tools in different domains.

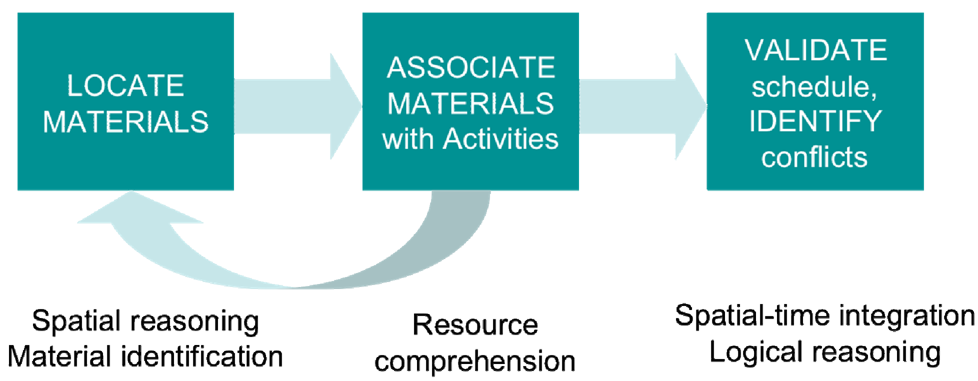

Figure 5. Learning activities sequence and educational objectives

Comparisons with independently developed learning module: Lessons learned

Before the framework was created, we had developed material management software with the same learning objectives and activity sequence as described in the hypothetical design. On a real intelligent jobsite, materials come with RFID (radio frequency identification) attached to them which can communicate with a mobile receiver device to provide all the information on the materials. To recreate a virtual jobsite in the university setting, we used several sensors that could communicate with a tabletPC to generate RFID-like data to feed to the material management software.

In the designed learning module, the virtual jobsite used was the fifth floor of our civil engineering building, with the map shown in Figure 6. The map was drawn purposely like a 2-D engineering drawing with black background and white lines as this would be the kind of drawings used on most construction jobsites. There were offices all around and in the central block. Sensors were hidden in the ceiling along the corridor. As the students carried the tabletPC and walked along the corridor, they had to look for the materials that were supposed to be physically present on the jobsite (which were presented by big paper signs). Live RFID-like data generated by sensors were displayed on the tabletPC (top left corner panel in Figure 6) which allowed students to compare what they saw with their own eyes and what was detected by the tabletPC, and then take actions. They would locate materials by dragging the pins (representing materials) from the RFID data panel and dropping them on the map where they were found. The same drag-and-drop action is used for associating materials with corresponding activities. The final and most difficult task was to evaluate the schedule and make adjustments if certain materials were missing, or a spatial conflict was found. We used several visual cues such as icons, color codes, and pop-up information boxes to help students understand the consequences of their actions.

Figure 6. Material management learning module interface

Prior to using the module, the students were asked to fill out a pre-test questionnaire that included general questions about their educational background and their familiarity with mobile devices as well as RFID technology. After the lesson, the students did a post-test assessment that included both an assessment on the understanding of subject matter as well as their feedback on the usability of the learning module.

Although this is a simple exercise, it demonstrates the attractiveness of technology when incorporated properly in the design of pedagogical tools. The initial feedback we got from students is generally positive. As the exercise content is very relevant to their study, the technology makes more sense, especially when they have a chance to actively carry out tasks that are very interactive in nature.

All the eight students that participated in the testing completed at least 70% of the possible tasks, suggesting a high degree of engagement with the exercise. Students also performed well in the objective section of the posttest questionnaire, demonstrating retention of concepts utilized during the exercise. For most of them it was their first time to use a tabletPC or to have direct experience with sensor technology. The students also found the exercise and the technology relevant to the construction domain and praised its' applicability to the real world. The high level of engagement and relative simplicity of the tools (simple touch interface using a pen) required relatively little orientation for the students despite their lack of previous experience with tablets. Table 3 summarizes the key performance indicators obtained from the testing. For the descriptions with a star (*), it was unclear if the less than ideal performance was caused by the lack of ability to perform the tasks on the student's side or by the flawed design of the interface. It was found from the testing that many of the tasks were repetitive and the duration of the exercise was a little long which caused frustration and led to the loss of interest in some students.

When comparing the actual designed interface to the hypothetical "ideal" design outlined by the framework, there is a great amount successful realization of the supposedly great design features, as shown in Table 4. There were, however, several unexpected lessons learned about how to improve the design, and what else might be included in the framework just by observing eight participants using the module, especially those related to the physical usability of the tool and affective learning behaviors:

- For tools that use tabletPC's, length of the exercise might be the critical factor. The original version of the designed learning module required some students to spend more than 45 minutes to complete the exercise. As the students had to carry the tabletPC (which was more than 2 pounds) and walk the "jobsite" for an extended period of time, their arms got fatigue which was a great demotivator.
- Some students complained about the repetitiveness of a few tasks that were, in their opinion, simple. Once the students reached the learning curve's plateau of the material locating task, for example, they tended to get bored if they had to keep doing it. They wanted new challenges. This is an area where exact replication of the real world is not necessarily a desired feature in pedagogical design. In reality, the number of materials, and hence the number of repetitive material locating task can be hundreds of times bigger than in the simulation. However, the students just want to know how to do the task, they do not want to have to do as much as it requires in the real world (at least for the purpose of learning). Therefore certain simplification of reality is needed to keep students motivated and engaged.
- One of the common beliefs in the interaction design world is that good applications should not make users think what to do; such action should be effortless. For learning purposes, this might not be entirely desirable. We want to free the students of cognitive loading when it comes to operating the application. However, we do want to make them focus on thinking about the subject matter

and reflect on their actions. Effortlessness, therefore, could eliminate the context for real learning to occur. In our module, we could have had a feature where only materials corresponding to a construction activity can be associated with that activity so that students would never make a wrong association. We chose not to do that so that students could make mistakes and then would have to re-evaluate the consequences of their actions when conflicts emerged.

- The students' learning preferences did play an important role in their interaction with the learning module and hence influenced their performance. Some students liked the large degree of freedom that the interface offered; they could go back and forth to explore the relationships between the components of the tools instead of having to follow a rigid procedure to get to the final point. Some students, however, were less comfortable with and less confident in having to guess what to do next. A versatile application should have a mechanism to make sure both styles of learning will be supported.

Table 3. Assessment of designed module against identified learning outcomes

Learning Outcome	**Learning Outcome Metrics**	**Performance**
Material identification	Percentage of materials identified	Excellent. All materials correctly identified.
Spatial reasoning	Percentage of materials located Ability to identify spatial conflicts	Excellent. Most materials found and located. Average*. 50% identified conflicts.
Resource comprehension	Percentage of materials corrected associated with activities	Excellent. Most materials correctly associated.
Spatial-time integration	Ability to adjust schedule to avoid time/spatial conflicts	Good*.
Logical reasoning	Ability to make logical schedule adjustments	Good*.
Response to missing information	Percentage of missing materials correctly identified	Good*.
Response to technology failure	Ability to realize technological failures Observational data of student reactions Student feedback	Good. Most realized failures. Good. Most reacted positively after the first failure incident Positive feedback
Valuing of human independence in decision making	Ability to make sound judgment and logical decision when technology fails Student feedback	Very good. Most proceeded with confidence after realizing something failed Positive and confidence perception of technology

Table 4. Comparisons of actual and hypothetical designs

Expected specific application qualities	**Key guiding interaction design principles**	**Actual features designed**
Reflection of cause and effect	Appropriate level of user control and manipulation	Users able to drop pins to locate materials, delete them if misplaced
Replication of system's physical/logical/ functional constraints	Metaphors	Engineering drawing Sensors to mimic RFID Extended space for virtual site instead of in classroom Drag-and-drop push-pins to locate on map Intuitive color codes and icons
Responsibilities/ authorities	Reversibility / irreversibility of actions	Most actions reversible Ability to make changes to schedule

Next steps

The validation of the developed design framework has to be done through several case studies and carefully designed experiments. In this paper, we described the use of this framework in the design of a hypothetical material management learning module that uses technology to support active learning. We then compared this design with actual material management software we developed independently of the framework but was designed for the same purpose. Initial findings suggest that the framework has a great potential of guiding such technology-enhanced instructional design for a complex domain like construction. Further testing of the existing learning module and development of new applications will help improve the framework and create a more comprehensive toolkit that assists the use of this framework in the future.

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Bibliography

1. Wiggins, G., McTighe, J. (1998). Understanding by Design. Prentice-Hall, Inc. New Jersey, USA.
2. Bloom, B. S., Englehart, M.D., Furst, E.J., Hill, W.H., Krathwohl, D.R. (1956). A Taxonomy of educational objectives. Handbook 1: Cognitive domain. New York, Longmans, Green, 1956.
3. Instructional Consulting Center (2009). Active Learning Strategies. School of Education, Idiana University Bloomington. Retrieved on Feb 3rd, 2009. URL: http://www.indiana.edu/~icy/document/active_learning_techniques.pdf

4. Silberman, M. (1996) Active Learning: 101 Strategies to Teach Any Subject. Allyn and Bacon, Massachusetts, USA.
5. Active Learning Strategies (2009). Clayton University Learning Center. Retrieved Feb 3rd, 2009. URL: http://learningcenter.clayton.edu/cid/active_learning
6. Apple Human Interface Guidelines: User Experience. URL: http://developer.apple.com/referencelibrary/API_Fundamentals/UserExperience-fund-date.html
7. Nielsen Norman Group (2009). Interaction Design Solutions for the Real World. URL: http://www.asktog.com/basics/firstPrinciples.html