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EDDE: A FRAMEWORK TO EXPLORE, DESIGN, DEVELOP AND EVALUATE TECHNOLOGY-ASSISTED INSTRUCTION FOR CONSTRUCTION ENGINEERING AND MANAGEMENT

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SUMMARY: *This paper presents a framework for developing technology-assisted instruction in construction engineering and management. A compilation of instructional principles, as well as interface features, is used to provide a structure for the process of developing instructional tools, and generating recommendations throughout this process. The framework is operationalized through a computer program named EDDEaid. This tool guides and supports users, both theoretically and rhetorically, through the process of designing instruction and generating interface design concepts. This tool is evaluated by application of recommended features for an actual instructional tool, and also by intended users' assessment of the framework's capacity to aid the design of instruction. Results from these evaluations suggest that the tool—and the resulting recommendations—are both useful and usable in the context of construction education,*

KEYWORDS: *Instructional design, user interface design, technology-supported instruction*

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1. INTRODUCTION

The approach of technology-assisted instruction has been applied in construction engineering and management education in order to simulate and represent the interactions found in construction jobsites (Rojas and Mukherjee, 2005; Hildreth and Gehrig, 2009). Reflecting such robust interactions and their outcomes is a challenge for construction educators, as traditional instructional settings do not usually support such an active approach. Activating students in situated learning contexts, such as simulations, is one of the most important aspects for motivation and the overall learning effectiveness (Schroeder and Spannagel, 2006). Advanced technology has the potential to aid the learning process through use of multimedia and interactive interfaces. Meaningful learning experiences can be provided by simulations and other less complex systems—such as games—enhanced by technologies' visualization and manipulation capabilities.

Despite these benefits, the design of instructional tools has not been approached systematically given the large amount of knowledge necessary to improve control over the learning outcomes. In a motivational study presented by Nguyen (2010), a simulation of materials management is used to analyze the process of instructional tool design in the construction engineering domain. This study points out the need to review the literature for aspects of instructional and interface design in the context of technology-supported education. These bodies of knowledge, however, have not been consolidated into an operational framework that can be used to develop technology-supported teaching tools for specific instructional topics, especially for those in the construction domain.

The objective of this research is to create a usable framework to guide instructors through the process of learning tool design for construction engineering education. The framework is grounded in well-established instructional design models and user interface design guidelines. A thorough review of the literature produced such design knowledge. In turn, this knowledge is delivered via a computerized tool that suggests specific features for different learning tools.

This research makes two contributions to the construction education domain; first, the compilation of knowledge that supports the design of instructional tools focused on construction engineering activities. The second contribution is the condensation of this knowledge in a tool that provides specific recommendations throughout this particular design processes.

2. LITERATURE REVIEW

Nguyen's (2010) preliminary research considered basic instructional concepts and interface guidelines for the design of a materials management learning tool. For example, McTighe's (2005) backward design process was used to plan instruction starting from desired learning objectives, and Felder and Silverman's (1988) learning styles index served to account for learners' preferences. The iterative process of refining and testing the tool for learnability and usability revealed critical aspects in the design process. The dual need for adequate instruction and interface design pointed at more specific concepts from the literature. As such, the literature review focuses on four main areas: (1) ways to leverage technological features, for the distinct purpose of engaging students, (2) identification of an instructional design model, which needs to be appropriate for technology implementation, (3) student background, in the particular context of readiness for technology, and (4) user interface design principles, which are propitious to enhance pedagogy.

The current section summarizes and condenses findings in the literature concerning the four areas mentioned. After compiling this knowledge, the present research is expected to serve a theoretical framework to systematically address the instructional design problem for the construction engineering and management domain.

2.1 Learning Strategies

Despite the fact that educators do not believe in the existence of one universally effective formulated method for teaching, there is a consensus about the critical role of engagement in the learning process. Engagement is a key condition that leads to the development of higher-order thinking skills such as analysis, synthesis, and evaluation in Bloom's Taxonomy of Educational Objectives (Chickering and Gamson 1987; Anderson and Krathwohl, 2001). This engagement, as argued by Prensky (2001), is also the single most important factor in improving learning effectiveness for today's students, as it is essential in delivering this content.

In the context of technology-assisted instruction for construction engineering, it is desirable to make appropriate use of the engagement factor, in order to improve the conditions to control the outcomes of learning. This section reviews the potential to enhance the engagement factor through specific learning strategies, as well as technology tools.

2.1.1 Active Learning Strategies and Technology

In recent years, an approach to instruction known as active learning has received enthusiastic support in disciplines across the board because of the benefits educators believe this particular learning method can create. 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 (Prince, 2004). Engagement is the core element of the whole active learning process.

A review of the literature has found that there is a strong base of supporting evidence for the effectiveness of active learning methods (Prince, 2004). Commonly used active learning strategies include games (McKinney, 2009), analysis or reactions to videos (McKinney, 2009), student debates (McKinney, 2009; ICC, 2009), case study analysis (Hansen, 1987; McKinney, 2009; Meyers and Jones, 2009), concept mapping/idea map (ICC, 2009; McKinney 2009), role playing (Meyers and Jones, 1993; Shannon, 1986), simulations exercises/simulation games (Meyers and Jones, 1993), computer models (Meyers and Jones, 1993), and mind mapping (ICC, 2009).

In addition, delivery of content through technology has engaging characteristics itself. Videos, games and real time communication are constant stimuli to which current construction engineering students have been exposed. Delivering active learning instruction through advanced technologies is a powerful couple. In the study of teaching tools by Nirmalakhandan et al (2007), several methods of instruction that promote active learning were identified, most of which are implementations of technology such as computer-based instructional tools, self-paced computerized tutorials, multimedia presentations, hands-on demonstrations, computer simulation models, and Internet-based instruction.

Synthesized from different sources, commonly used active learning strategies include: role playing, simulations and computer models (Meyers and Jones, 1993); games, analysis of videos, student debates, student-generated exam questions, case study analysis and log keeping (McKinney, 2009); Concept mapping, mind mapping, student debates, and concept clouds (ICC, 2009). Many of these strategies can be supported and significantly enhanced by the use of technology. It should be noted that the strategies listed here are not all equivalent in terms of the complexity and scale of the learning activities involved. Some could be part of other broader strategies, and they are not mutually exclusive of one another.

2.1.2 Games and Simulations as Instructional Strategies

In the Technology and Construction Baseline Survey for construction engineering students' background, Nguyen et al (2012) found that simulations were favorable as a learning activity that students would like to see included in classes. They also show a positive attitude toward the use of video and animation technology in class, with more than 75% of students finding it engaging and believing it helped remember and understand learning materials better. With 90% of students reporting playing computer games, this study suggests to leverage students' videogame skills to support instruction.

TABLE 1: Classification of games, reproduced from Teixeira et al (2008)

Teixeira	**Prensky(2001)**	**Battaiolla (2000)**	**Crawford (1982)**
Action	Action	Adventure	Card games
Adventure	Adventure	Education and training	Computer games
Card	Combat	Sports	Board games
Competition	Sports	Strategy	Sports games

Strategy	Strategy	For infants	Children games
Role playing	Interpretation and role playing	Fighting	
Fighting	Puzzle	Leisure	**Caillos (*in* Anjos, 2005)**
Board		RPG	Competition
Leisure	**Johnson *et al*(1985)**	Simulator	Chance
Puzzle	Individual		Simulation
Games of chance	Collaborative		Movement
Simulation			
Educational context			
Sports			
Children			

This suggestion is supported by Prensky (2001), who claims that the cognitive, emotional, psychological and behavioral conditions created or stimulated by games, lead to the voluntary dedication of intellectual energy from players to the learning/playing process. For example, games' rules, goals and outcome components promote conditions of structure, motivation and learning, respectively. According to Gee (2005), popular video games have managed to get players to learn long, complex systems to be successful in the game. This study explains that the reason for these conditions of learning is the set of learning principles embedded in games; for example, video games provide well-ordered problems, progression through cycles of expertise, sandboxes that provide opportunity for practice before risks are faced, among others.

However, despite the full-blown scale and highly commercial nature of the game industry, there seems to be no consistent classification of games in the literature. As shown in Table 1, there have been several classifications of games used in different contexts. These taxonomies are often based more on the nature of the action involved in the games as opposed to the understanding and knowledge the players acquire in the subject domain of the games. As a result, these lists provide little guidance in terms of what platform would be best for a certain instructional goal under consideration.

TABLE 2: Proposed taxonomy of game/simulation-based instructional strategies synthesized and adapted from several sources, as detailed below (extracted from Nguyen, 2010)

Interactive Case Studies (Horton, 2006; McKinney, 2009; Meyers and Jones, 1993) An effective way to deliver a large amount of information to learners through relevant and meaningful context of real world events, processes or systems. Technology provides rich multimedia presentations to help students digest information better and offer interactive features for decent analyses and application. Can accommodate a wide range of learning objectives (facts, theories, systems, judgment, observation). Case studies are normally quite structured and linear, which is suitable for most students except those with highly global thinking style.
Device Simulations/Virtual Products (Aldrich, 2005; Horton, 2006; Wang, 2002) Refer to simulated model of a product or device (or a part of it). Widely used for testing a product design for form, fit, performance, and manufacturability, or serves very well as a study or training tool for perspective users of the actual devices/products. Useful in teaching advanced skills that would otherwise unsafe to acquire using the actual product. Students with low or very low technology background mind find these hard and need training.

Math-based Simulations/ Interactive Spreadsheet/ Guided Analysis (Horton, 2006; Aldrich, 2005; ICC, 2009; McKinney, 2009; thiagi.com) Refer to all interactive analyses that involve complex behind-the-scene mathematical calculations and an interactive interface for results with tools to aid analyses and decision-making. Users input data through relevant variables, the program calculates the desired functions, and results are displayed mostly visually. Suitable teaching accounting, economic problems, structural stability, process systems, physics, etc. Adequate prerequisite knowledge in subject is a must as interface is mostly visual.
Skill Building Simulations (Wohling and Gill, 1980) Involve a simulated environment in which students operate virtual equipment and carry out procedures to learn some desirable skills, mostly technical (as opposed to soft skills, which can be learned through role playing and other management/strategy games and simulations). Used primarily to develop skills in specific procedures, methods and techniques.
Design/ Invention Games (Horton, 2006) Provide the basic building blocks for creating an object or a system that serves a predefined function. The interface provides a wide range of options for basic elements from which users can choose, enforces the most important design principles (such as science), and visualizes as well as evaluate the creation. Usually highly visual and emphasizes impact each component/element has on the whole system. Good for creativity and learning about scientific systems.
Role-playing (Wohling and Gill, 1980; Horton, 2006; McKinney, 2009) Role-playing is an unrehearsed dramatization in which individuals improvise behaviors that illustrate acts expected of persons involved in defined situation. Participants are presented with a realistic or hypothetical situation, in which each of them assumes a role and puts himself/herself in the shoes of that character. They will then have to act and interact with the assumed perspectives and views of the character they are playing. Role-playing helps students understand the perspectives and feelings of different stakeholders in a complex situation of conflicts of dilemmas. Role-playing has two major uses: 1) training people in attitudinal areas, and 2) integrating and applying learning from a variety of sources to deal with problem situations. Students with strong preference for facts (sensing) over intuition might need extra help in role-playing.
Strategy Games/ Management Simulations/ God Games (Aldrich 2005) Refer to the most complex and technologically elaborate simulation platform of all. Can be highly sophisticated in the visual interface, highly interactive and engaging, and cognitively comprehensive. In a game of this type, "learners manage the concepts of exploration, building, defending, logistics and conquering. They need long-term philosophies, not just minute-to-minute reactions. They balance short-term vs. long-term goals. They have to move between the small and big picture, juggling a bigger task of distraction or destruction of a key facility." Students need strong technology skills and good domain knowledge to be ready for this learning method.
Concept/Mind Mapping (Novak and Canas, 2006; Horton, 2006) Concept mapping is a method to create, explore, present, and structure knowledge graphically. In many cases, concept/mind mapping is considered a better alternative to outlines and purely textual hierarchy of ideas. It helps the visual brain process the information and grasp both the meaning of details and the big picture of relevant concepts in a context. Mind mapping is a less fluid version of concept mapping in the sense that it is more like a tree-branching map. Mind mapping are better suited for topics that are more descriptive, while concept mapping works well for more abstract topics. Concept and mind mapping is a simple and useful tool in a wide range of learning activities, such as note taking, brainstorming, idea generation, documenting and tracking team input.
Quiz-show Games (Horton, 2006) Similar to TV game shows, can be used in place of tests official quizzes and exams to test students' knowledge. This will make the task of taking tests less intimidating, more engaging, and more motivating if games are played prior to teaching the subject. Quiz-show games are good for testing factual knowledge, and if done right, will encourage and motivate to learn and improve.

In order to express the relationships between active learning strategies with the types of games/simulations (in Table 1), it is proposed to develop a taxonomy of technology-supported (game/simulation-based) instructional strategies. The resulting taxonomy is presented in Table 2, which was synthesized by Nguyen (2010) from several game classifications. Though the instructional strategies in this taxonomy bear game-like names for a more descriptive distinction, the criteria for classification are based on pedagogical differences between the genres. Each of these game-based instructional platforms also embraces one or more active learning strategies reviewed earlier. The list covers most of the genres that can be easily adapted for educational purposes.

2.2 Instructional Goals

The first step in the instructional design process before any decision is made on what learning strategy to be used, what activities to include, or how to build all these into an interface, is to determine what students are expected to learn. This includes both the broader instructional goal (such as what type of knowledge to be taught) and the more specific instructional objectives (what skills/knowledge students are expected to demonstrate and how to assess their performance). Since the effectiveness of a learning tool is measured by whether or not students learn the intended objectives, learning assessment has to be a critical aspect of learning tool design from the start.

However, for the purpose of this research, it is of interest to observe instructional goals in relation to the use of technology. In the previous section, several learning strategies were identified to have the potential for leveraging the technology skills of construction engineering students. Therefore, this section presents findings about instructional goals related to the learning strategies listed above.

TABLE 3: Taxonomy of instructional goals with examples and suggested learning activities (expanded from Prensky, 2001).

Goal	Examples	Learning Activities	Possible game types
Judgment	Ethics; interpretation of laws, regulations, and codes; assessing impact of changes; hazard analyses; evaluating change orders; resource allocation; dispute avoidance and resolution; negotiation; jobsite inspection; hiring; community/public relations.	Case studies, asking questions, discussions, making choices (practice), feedback, coaching	Role-play games Detective games Multiplayer games Adventure games Strategy games
Calculation Analyses	Apply theories, formulae, procedures to do calculations (engineering, economics, etc.); estimating; cash flow analyses; evaluating economic alternatives.	Reviewing theories, realizing components, substituting variables, comparing results	
Creativity	Apply existing and new knowledge to create a product: marketing; public image; sustainable design.	Play, experimentation, exploration, challenges, idea generation	Puzzles Invention games
Facts	Product specifications; laws, regulations and codes; insurance bonds and requirements; licensing requirements; cost accounting formats; policies; punch lists;	Questions, memorization, association, drill	Game show competitions, flash cards, mnemonics, sports games
Physical Systems	Components of systems in the physical world and the physical and logical relationships among them: spatial relations; site development/organization; product details; machines; site work/excavation; mechanical/electrical systems.	Recognizing components, understanding components and relationships, exposure to various systems	

TABLE 3 (continued)

Procedures	Carry out a certain sequence of activities to achieve a goal: assembly techniques/equipment; steel erection; pipe lining; concrete curing; payment request.	Demonstration, imitation, practice	Timed games Reflex games
Language	Technical terminologies; acronyms; negotiation language; press release protocol; project documentation	Imitation, continuous practice, immersion	Role-play games Reflex games Flashcard games
Theories	Structural mechanics; economics; organizational behavior; management philosophies; how people learn; marketing principles	Logic, experimentation, questioning	Open-ended simulations Building games Construction games Reality testing games
Technical skills	Estimating; budgeting; interviewing; technical drawing; surveying; crane operation; pipe connection; machine operation; scheduling.	Imitation, feedback, coaching, continuous practice, increasing challenge	Persistent state games Role-play games Adventure games Detective games
Behavior/ Soft skills	Leadership; facilitation; supervision; self-control; team building	Imitation, feedback, Coaching, practice	Role-play games
Reasoning/Decision Making	Strategic and tactical thinking; quality analysis; idea evaluation; risk analysis;	Problems, examples	Puzzles
Process	Bidding; procurement; auditing; scheduling; training; strategy creation	System analysis and deconstruction, practice	Strategy games Adventure games Simulation games
Systems	Supply chain; partnership; business organization; refineries; markets.	Understanding principles, graduated tasks, playing in micro world	Simulation games
Observation	Moods, morale, inefficiencies, problems	Observing, feedback	Concentration games Adventure games
Communication	Appropriate language; meeting facilitation; public speaking; face-to-face vs. online communication	Imitation, discussions, practice	Role-play games Reflex games

Prensky (2001) provides a classification of instructional goals, in which fifteen categories of knowledge are provided. These categories, though broad and high-level, are important in making one think about the nature of the learning experience one wants to create. Table 3 extends work by Prensky (2001) on categorization for learning goals and supporting game types. The first and fourth columns in the table are taken directly from Prensky’s (2001). The second and third columns are expanded by the authors to provide examples of common topics in civil engineering and construction management, and additional learning activities that can be used to achieve each goal. Also, two instructional objectives are added, calculation analyses, and physical systems, which were not included in the original table and better support educational objectives in the construction engineering and management domain.

Once the high-level instructional goal has been defined, specific instructional objectives have to be determined. Meyers and Jones (1993) identified "clarifying course objectives and content" as one of the four elements essential to the learning environment. The failure to define specific learning objectives often leads to failure, especially in e-learning (Clark and Mayer, 2003). For this purpose, Bloom's Taxonomy of Educational Objectives has long been used as a practical guideline that helps define a specific level of understanding in a subject matter to be taught. Bloom's Taxonomy is a framework used to classify learning activities in the order of cognitive complexity. This means that the taxonomy is meant to be a linear model; a learner moves up from lower level thinking to higher ones. For example, it is easier to remember an equation than to apply it to a problem; likewise, in order to analyze a context, one has to know the facts and/or the theory. Table 4 lists common verbs that can be used to define learning objectives at each level of the Bloom's taxonomy.

TABLE 4: Bloom's action verbs (synthesized from Overbaugh and Schultz, 2010)

Bloom's level	**Action**
Remembering	Arrange, define, duplicate, label, list, memorize, name, order, recognize, relate, recall, repeat, reproduce,
Understanding	Classify, describe, discuss, explain, express, identify, indicate, interpret, locate, paraphrase, recognize, report, restate, review, select, translate
Applying	Apply, choose, demonstrate, dramatize, employ, illustrate, interpret, operate, practice, schedule, sketch, solve, use, write
Analyzing	Analyze, appraise, calculate, categorize, compare, contrast, criticize, differentiate, distinguish, examine, experiment, question,
Evaluating	Appraise, argue, assess, choose, compare, defend, estimate, evaluate, judge, predict, rate, select, support, value
Creating	Assemble, compose, construct, create, design, develop, formulate, plan, propose, write

2.3 Instructional Design Model

While games and simulations are often designed with several characteristics inherently supportive of the learning process, they may not be intentionally purposed to achieve a set of pedagogical objectives. It is important to base the design framework on a solid instructional design model, as "pouring a solid foundation of good pedagogical design before adding on the layer of technology can become a critical factor in the success rate of technology integration" (Ziegenguss, 2005).

The instructional design model to be selected should serve as the guiding structure for the design of technology-enhanced teaching tools. There are two important qualities sought in such instructional design model. First, the model should be pedagogically sound and based on established research in cognitive processes involved in the human learning process. This assertion is particularly important as when learning with technology, learners have to handle more stimuli than simply listening or reading. These stimuli require simultaneous responses from several senses and might become overwhelming when not handled correctly. Second, the model needs enough actionable details so that linkages can be made between the various components of technology design and instructional design embedded in the framework under construction. Gagne's Nine Events of Instruction model fits these requirements (Gagne et al, 1992) as (1) it has been around long enough to be validated by experts in the field and (2) it is event-based, which is a match for the event-based operations of computer applications. Not only does Gagne's model remain "one of the most significant contributions to instructional design today" (Van Eck, 2007) and is widely used to ensure teaching effectiveness, its framework and details can also be fully supported in good games, and hence in good game-based instruction (Becker, 2007).

TABLE 5: Gagne's nine events of instruction (expanded from Van Eck, 2007)

Event	Descriptions	Game/simulation elements
1) Gain attention	To get students ready for learning and participation. To make them curious and want to learn more about the topic.	• Persistent animations to allure users into clicking • High quality demo videos • Pop-up suggestions
2) Inform learners of objectives	To create the internal process of expectancy and helps motivate learners to complete the lesson. Also to set *benchmarks* for learning assessment.	• Back-story, context setting • Advertising, show case of games/simulations prior to start • Rule setting • Winning state/score definition
3) Stimulate recall of prior learning	To establish links between knowledge to be learned with prior knowledge and personal experience. This is believed to help code information in long-term memory.	• Physical/mental resemblance of interface stimulates recall of prior knowledge about the real world counterpart • Short quizzes prior to start also trigger thinking and recall prior knowledge
4) Present the content	Present new content to learners. This is key for engagement. Content should be chunked and organized meaningfully, and typically is explained and then demonstrated. To appeal to different learning modalities, a variety of media should be used if possible, including text, graphics, audio narration, and video.	• Define goals • Provide support when needed • Offering a hint • Response to a negative action, reward a positive one
5) Provide learning guidance	Additional guidance to facilitate long-term information coding, includes use of examples, non-examples, case studies, graphical representations, mnemonics, and analogies.	• Game players do not use manuals – provide "on site" just-in-time coaching: in terms of guidance and extra materials • Provide examples (multimedia rather than text) • Visual or auditory mnemonics • Metaphors/analogies • Get help from other online users/community
6) Elicit performance (practice)	(Responds to questions to enhance encoding and verification). Learners to practice new skills or behaviors. Eliciting performance provides an opportunity for learners to confirm their correct understanding, and the repetition further increases the likelihood of retention.	• Offer lots of practice with varying content/format
7) Provide feedback	Provide specific and immediate feedback of learners' performance. Exercises and tutorials are used for comprehension and encoding purposes, not for formal scoring (formative feedback).	• Displays, scores, • Queries • System response messages: verbal feedback • Goal reminder: status update
8) Assess performance	Post-test of final assessment of student performance upon completion of learning period, completed independently without additional coaching, feedback, or hints.	• Through scores or expected outcomes • Through definition of winning/pass state

9) *Enhance retention*	Encourage application of newly learned knowledge in different contexts. Develop perspective understanding of subject matter (in relation with other knowledge areas, with the world).	• Graduated challenges and increasing level of complexity/difficulty help retain long-term knowledge • Themes and context in games and simulation support long term retention of materials

The Gagne model (Gagne et al, 1992) identifies nine instructional stimuli or events that create favorable conditions for learning through the activation of various internal mental processes. This model is based on the theory of information processing, which treats the human brain as a computer. The model focuses on intellectual skills and suggests that various types of tasks and learning activities should be included in instruction. The order of the nine events might suggest a hierarchy of learning events for a learning module, which is typically followed in a conventional learning sequence. However, this is not a requirement for applying the model. The role of each of these nine instructional events in the learning process is described in Table 5. This table shows Gagne's nine events in the first column, a description for each event—added by the authors—in the middle column, and related game/simulation elements to each of Gagne's events, as listed in Van Eck (2007). For each of the events, suggestions are also given as to which multimedia elements in a game-simulation platform can be used to create the conditions that facilitate that learning event.

2.4 Student Background

Learning is influenced by what a student already knows when instruction begins, but it is also influenced by learner traits and characteristics. Some researchers believe that instructional design should support learning by matching instruction with students' learning styles, hence providing comfort (Mahlios, 2001; Ogden, 2003; Stanberry & Azria, 2001). This does not imply that instruction should be tailored to fit a certain learning style, but instead must have enough diversity in format and content to support the range of preferences that exist in the student audience.

TABLE 6: Proposed high-level user interface design guidelines

Guidelines	Examples
Consistency	• Visual consistency: Icons, size boxes, scroll arrows, etc. need to appear the same throughout the application • Make objects consistent with their behavior. Make objects that act differently look different.
Provide psychological/emotional comfort	• Appeal to all senses with sounds, visuals, texts, dialogues, feedback. • Use voice/narration where appropriate to create a sense of dialogue. • Allow enough time for users to response.
Support cognitive processing of information	• Small number of rules applied throughout. Use generic commands wherever possible. • Reduce memory load. Front load menu entries. • Use visuals effectively: color codes, design theme graphics,
Simplicity	• Prioritize: most important components must be most visible and prominent. • Modularity of topics: break complex tasks into simpler ones. • Simplicity means visibility. • Focus attention on content delivery, not on fancy media.
Efficiency of users	• Prioritize: optimize for most important tasks, use large objects for important functions. • Typical use cases
Aesthetic integrity	• Graphics: keep simple. Interface should look pleasant on the screen, even when viewed for a long time. • Conventionality: don't change the meaning or behavior of standard items. Try to use metaphors. • Legible text.
Accommodate individual differences	• Vision: avoid confusing colors to the color blinds; flexible font size. • Add sound where appropriate • Content: adapt to different expertise levels of users.
Feedback and communication	• Confirmations: confirm upon receiving input from users. • Informing of progress • Use a mix of verbal (textual or audio) and visual feedback
User control	• User control: Allow the user, not the computer, to initiate and control actions.

	• Help users avoid dangerous, irreversible actions. • Consequences of actions should be immediately visible.
Forgiveness	• Make most actions reversible. Create safety nets, such as the Undo and Revert to Saved commands. • Anticipate common problems and give warnings.
Explorable interfaces	• Stable visual and structural elements to give users a sense of "home" • Level of flexibility: depends on frequency of use for the task. • Menu: should be broad, not deep with many layers of options.
Use of metaphors	• Take advantage of people's knowledge of the world by using metaphors • Use metaphors that represent concrete, familiar ideas, and make the metaphors obvious.

As found from the student background survey results in Nguyen et al (2012), age and gender do make a difference in terms of the technology skills students possess as well as their attitude toward games. Low-scoring students might benefit greatly from multimedia-based instruction but might need significant orientation or training prior to the lesson and frequent feedback (Issa *et al*, 1999). An audience that is not technology-savvy might not feel comfortable handling a complicated simulation, or students with a global learning approach to constructing knowledge will find a structured game boring and limiting. In addition, their knowledge on a given topic may not be adequate for presenting them with advanced concepts.

While all these are not definitive or absolute in any sense, they are realistic observations with research implications that will help make instruction more supportive and effective to all groups in the student audience. Therefore, student background in technology and construction knowledge is considered a binding aspect of instruction and interface designs. The main reference for students' background is the survey instrument presented by Nguyen et al (2012), as it is specific for construction engineering and management students and considers both general construction areas of knowledge as well as current technologies used both in the construction engineering classroom as well as the jobsite.

2.5 Principles of Interface Design

The major difference between a traditional learning method (such as an instructor-led lecture) and a technology-enhanced learning tool is the way information is delivered to the students. In a traditional lecture, information is usually given by the instructor; students do not have significant control of their learning pace or method, at least not in the classroom. In a technology-supported learning environment, learners do not have that human factor when interacting with the medium; however, the sources of information are much more diverse (multimedia) and learners are much more in control of their learning activities.

Several guidelines exist for graphical user interface (UI) 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. For an educational interface, extra attention should be paid to the interaction design principles that help create tools that are particularly engaging, stimulating and cognitively supportive of the learning process.

Table 6 describes twelve interface design principles that are believed to have important implications in instructional design. The descriptions for these guidelines are brief, generic, and synthesized from various sources available (Horton, 2006; Apple, 2010; Asktog, 2010; IBM, 2010; Microsoft, 2010).

3. RESEARCH METHODOLOGY

Once the literature of specific aspects of instructional and interface design have been reviewed, a four part research methodology is followed. First, a conceptual design framework is developed, which consists of assembling the components from the literature review into a design sequence. The purpose of such sequence is to provide instructors with manageable information for design decisions that is logically related. To serve such logical relations, the components of the framework need to be contextually related to each other. Therefore, the second part of the methodology consists of mapping these components and generating textual content to guide transitions from one component to the next. Once these mappings are completed, the third part is to operationalize the framework through a computer tool. This tool was designed to present relevant information for instructors, at each of the decision points in the design sequence. The fourth part is the assessment of the tool for usefulness to support the design decision process. One evaluation consists in showing the results of using the finished tool to make recommendations to an existing design. This design is the materials management application developed by Nguyen (2010) mentioned in the previous sections. The other assessment consists of evaluations generated by intended users of the framework, which are construction engineering professors. Final conclusions of this paper follow the presentation of the four parts described.

4. DEVELOPMENT OF DESIGN FRAMEWORK

The conceptual design framework proposed in this research is founded upon the key components identified from the literature and depicted in Figure 1. The structure of the proposed framework consists of four major steps: Explore, Design, Develop, and Evaluate (EDDE). By relating interaction design principles and game-based active learning strategies in a structured manner, the framework provides users with sensible and logical choices and enough background information to make good design decisions.

This conceptual framework is materialized into a design sequence that takes instructional designers through a step-by-step process, starting with an instructional goal, then navigating through the body of knowledge in interface and instructional design in a structured and purposeful way and arriving at a conceptual design of a game-based learning tool that has enough concrete details to be turned into an effective interface.

4.1 EDDE Framework

The EDDE design process starts with Explore, in which the instructor has to decide what the overall instructional goal is for the topic to be taught and then choose an appropriate game-based instructional strategy to be the format of the learning tool they are designing. The taxonomy of instructional goals previously developed during the preliminary research and literature review phase (Table 3) provides designers with a comprehensive list of goal categories from which they can determine an appropriate goal for the topic they are teaching. It is essential that students' backgrounds in the subject domain, their preferences for learning, and their technology skills be taken into account when deciding what should be taught to them and how. Analyses from the survey study (Nguyen, 2010) suggested several ways in which student background data can impact the choice of interface features and learning strategies/activities. It is expected that the framework can enforce a mechanism that makes instructional designers aware of this impact at every decision point so they can take action to address it where necessary.

Once the instructional goal has been defined and a game-based instructional strategy chosen, the next step of EDDE is Design, where most of the conceptual and content design is conducted, in terms of both instruction and user interface. During this process, Bloom's Taxonomy can be a useful guide for designers, as they consider the specifics of the topic being taught. Gagne's Nine Events of Instruction model is also considered at this stage, as it can provide specific recommendations for each of the game-based instructional strategies.

In terms of user interface design, the choice of instructional strategy dictates what the framework suggests as important user interface (UI) design features, with considerations given to the student background. The focused UI guidelines are chosen from the list of basic UI design principles provided in Table 6. More concrete interface features are also provided to further explain the high-level UIs in the context of the instructional strategy chosen.

For the last two stages, Develop and Evaluate, the involvement, and therefore contribution, of EDDE will be indirect: it helps development by providing theoretical concepts and design requirements and helps evaluation by providing the initial benchmark of what to be expected for the final product.

In the third step in the design process of technology-supported instruction, Develop, software development is expected to take place. The role of EDDE in this stage is to provide the conceptual design to guide implementation. Decisions on functionality and UI design are expected to be based on the specific recommendations made in the previous two steps. However, there might be revisions to the detailed instructional events and specific interface features during interface development when all sorts of constraints start to reveal themselves, such as time, budget, and difficulties in usability and functionality implementations. Therefore, iterations with respect to instructional design are expected at this point, including revisions to the decisions made in the previous two steps, as well as updates to the interface design features initially considered.

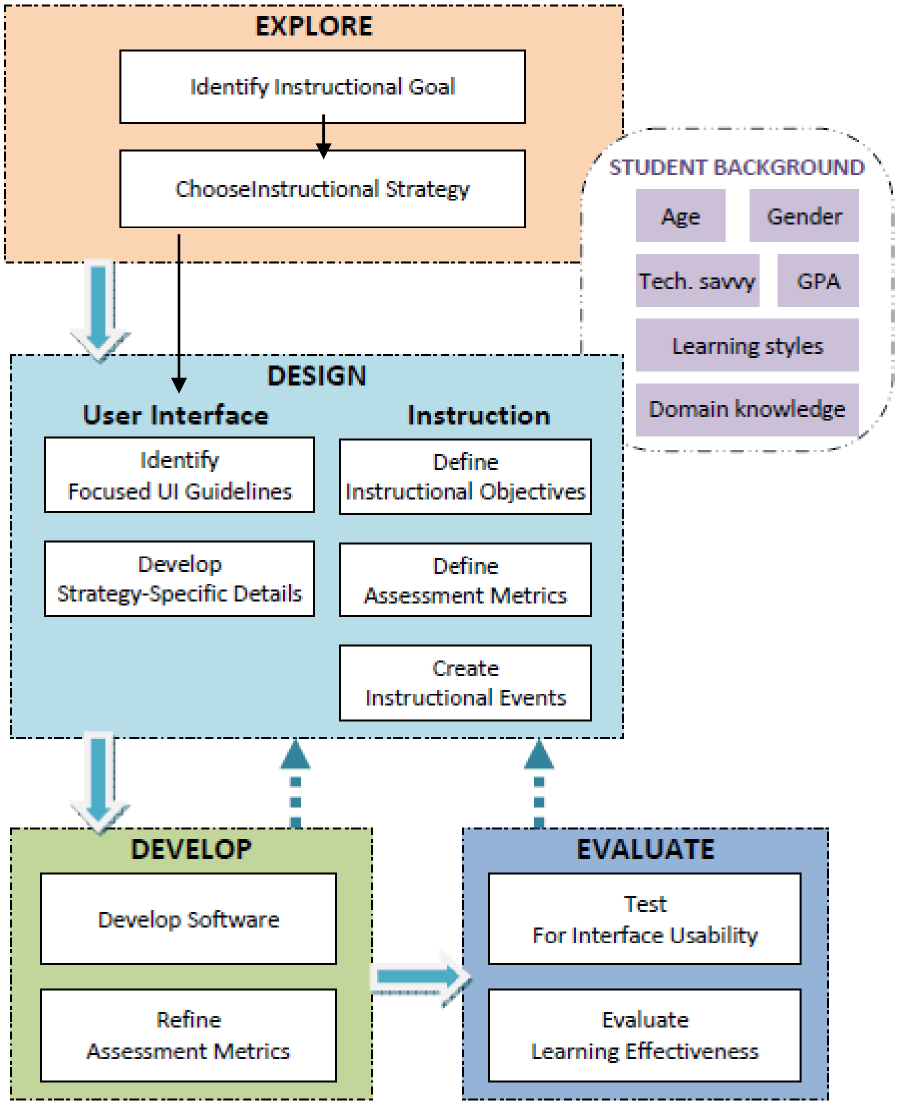

FIG. 1: The EDDE Framework.

The last step of designing a technology-supported learning tool is Evaluate, where testing is done to assess the achievement of learning effectiveness, learner perceptions, as well as the technical usability of technology. This process is done after the software has been designed, but some preliminary evaluation metrics should be initiated during development so that the software is designed in a way that it can be tested later on. The most important indicator of a successful design is the satisfactory achievement of the desired learning outcomes. If the tool fails to achieve the outcomes, the designers have to go back and re-evaluate decisions at every step after the definition of learning outcomes. It is expected that the EDDE framework will be helpful in providing theoretical guidelines to the conceptual and content design of an effective technology-enhanced teaching tool.

To operationalize this conceptual framework, its components and concepts are broken down into a relatively sequential design flow. As shown in Figure 1, the framework imposes a structure on the design process, in which designers have to make decisions at specific points in each stage. For example, identifying instructional goals and choosing instructional strategies are necessary before moving on to designing or developing the tool. The framework proposes an interactive process in which the tool and the users alternately provide choices and make decisions.

4.2 Mapping of components

In order for the framework to give appropriate output for specific user input, a few sets of rules need to be established to operationalize this process. In this sense, there are four sets of connections or rules that need to be developed for operation of the framework. First, the rules that provide instructional strategy options for a certain instructional goal. Second, the selection of user interface design principles related to a specific strategy. Third, are the recommendations for instructional events and activities corresponding to a selected strategy. Finally, the fourth set of rules concerns the design implications of student background characteristics. These four sets of rules/recommendations are the missing connections that need to be generated, in order to complete the EDDE framework.

TABLE 7: Mapping of instructional goals and instructional strategies by author

Goal	Suitable learning strategies/game styles	Blooms' level
Judgment	Interactive case studies, role-playing, strategy/management games	Advanced (evaluating, analyzing)
Calculations/Analyses	Math simulations	Intermediate (applying)
Creativity	Design/invention games, concept/mind mapping	Advanced (creating)
Facts	Quiz-show games, case studies, concept/mind mapping	Basic (knowing, understanding)
Physical Systems	Device simulations, skill building simulations, design/invention games	Basic(understanding)
Procedures	Skill building simulations	Intermediate (applying)
Language	Role-playing, quiz-show games, concept/mind mapping	Intermediate (applying)
Theories	Device simulations/Virtual products, strategy/management games, interactive case studies, role-playing, design/invention games	Intermediate (analyzing)
Technical skills	Skill building games, role-playing, device simulations	Intermediate (applying)
Leadership/Supervision	Role playing games	Advanced (evaluating)
Reasoning/Decision Making	Strategy games	Advanced (evaluating)
Process	Strategy/management games	Advanced (evaluating, creating)
Systems	Strategy/management games, interactive case studies	Intermediate (analyzing)
		Advanced (evaluation)
Observation	Role playing games, interactive case studies, concept/mind mapping	Advanced (analyzing, evaluating)
Communication	Role playing games, concept/mind mapping	Intermediate (applying)

The literature review produced a taxonomy of instructional goals (Table 3) and a taxonomy of game/simulation-based instructional strategies (Table 2). The descriptions of the goals in Table 3 provide reasonable guidelines for instructors to make a sensible decision on the learning goal they want to achieve. There are, however, no direct links between instructional goals and instructional strategies. The taxonomy of game-based instructional strategies was newly developed from the various studies in the literature, and hence there was no research findings directly mapped to it. To create the links between instructional goals and game-based instructional strategies, the following methods of analysis were used:

- Use the possible game types suggested in the original Prensky's instructional goal taxonomy (last column of Table 3) and translate these game types into equivalent instructional strategies (in Table 2).
- Use the examples and suggestions for learning activities in the revised taxonomy of instructional goals (third column of Table 3) to establish connections.
- Based on the descriptions of the instructional goals, they can be classified as belonging to certain levels in Bloom's taxonomy of educational objectives.
- Rely on the definition of the instructional goals and strategies.

This process was done elaborately for all instructional goals and strategies. The results were the mapping presented in Table 7 As the way an instructional designer defines a learning goal can be very subjective, the framework just offers recommendations and provides detailed descriptions for each type of game. It leaves it to the designer to decide which game type or learning strategy works best for the nature of the topic to be taught and the learning goal to be achieved. It explains why this is an exploration process in which the instructional designers can try out different scenarios and find the best (initial) solution to their problem.

TABLE 8: Mapping of learning strategies and user interface design guidelines by author

Learning strategy	User interface guidelines (high-level)
Interactive Case Studies	Feedback and communication, Accommodate individual differences/Provide emotional comfort, Explorable interfaces, Support for cognitive processing of information, Simplicity
Device Simulations/Virtual Products	Consistency, Feedback and communication, Efficiency of Users
Math-based Simulations/ Interactive Spreadsheet/ Guided Analysis	Support cognitive processing of information, Forgiveness, Simplicity, Explorable interfaces
Skill Building Simulations	Efficiency of users, Use of metaphors, Feedback and communication
Design/ Invention Games	Simplicity, User control, Feedback and communication, Efficiency of users
Role-playing Games	Simplicity, User control/Direct manipulation/Forgiveness, Feedback and communication, Provide emotional and psychological comfort
Strategy Games/ Management Simulations/ God Games	Use of metaphors, Simplicity/Efficiency of users, Feedback and communication, Explorable interfaces/Forgiveness
Concept/Mind Mapping	Simplicity, Support cognitive processing of information/Efficiency of users
Quiz-show Games	Accommodate individual differences, Forgiveness, Simplicity, Feedback and communication

The second missing set of connections is related to the rules that map instructional strategies to user interface design guidelines. In the literature there are several separate studies of individual strategies that provide best practices in user interface design for these game types (Horton, 2006; Prensky, 2001; Aldrich, 2005). Through synthesizing and identifying those that have the most pedagogical relevance, a list of best interface design qualities was created for each of the game-based instructional strategies on the taxonomy used in this framework (Table 8). The principles in focus are those with more important pedagogical impact for the game-based instructional strategy being examined and therefore should be the foundational interface design principles to start with in conceptual design.

TABLE 9: Student background implications at key decision points

Decision	**Student background considerations**
Define instructional goal	Goal should be appropriate for background in the domain. • If students have limited prior knowledge, high level goals (judgment, leadership, reasoning/decision making) can be challenging. If must use, make sure to provide lots of background knowledge. • The opposite is true: low level goals (facts) create boredom and demotivate students with substantial background knowledge.
Select instructional strategy	• Students are technology-savvy: avoid simple games like quiz shows. Students are low tech: complex games like device simulations or strategy games might be too challenging. Provide lots of training if must use. • Students with limited/no domain knowledge: avoid or provide enough background knowledge when using strategies that require prerequisites such as math simulations. • Sensing and/or sequential students prefer facts and procedures. Open-ended game requiring intuition such as role-playing and strategy games might create challenges. Include enough instructions and background facts if must use.
Design user interface	• Teaching students with substantial domain knowledge and/or teaching high-level goals: emphasize interactive features and exploration. Provide feedback to challenge or trigger thinking. Teaching students with limited domain knowledge: provide lots of information and educational feedback as instructions. • Sequential students: provide clear/well-structured action sequence. • Low-scoring students: use diverse multimedia. Give lots of feedback. • Reflective students: provide pauses and user control. Active students: encourage actions. • Visual students: icons, buttons, actions should be highly visual, intuitive, metaphorical. Light in text. • Teaching complex subjects to sequential/sensing students: balance user control/explorability with imposed structure. Break down into small steps. • Technology-savvy students: multitasking is possible.
Design instruction	• Low-scoring students: demonstrations are helpful in setting expectations and recall prior knowledge. Also benefit from explicit guidance and teamwork. • Young students have high expectations for engagement: include milestones and attention-grabbing events throughout the lesson. • Experienced or students with substantial domain knowledge: content with real world connections will be engaging. Encourage knowledge sharing and collaborative work. Goal-oriented instruction could be helpful. • Students with limited/no prior knowledge: engage by create curiosity or controversies. • Provide tools to encourage interactions, both in-person and simulated. This is good for all students. • Students with diverse domain background: include tasks of different levels of difficulty.

The generic instructional design model used in this framework is Gagne's Nine Events of Instruction. To make the framework more useful to the users, for each of the instructional strategies, a set of specific instructional activities were developed to address each of the nine event groups in Gagne's model, as were presented in Nguyen (2010). These specific instructional activities were generated through a thorough synthesis of best practices in the literature (Horton, 2006; Van Eck, 2007; Lee and Owen, 2000; Aldrich, 2005) and a conscious effort to include as many active learning strategies. When using EDDE, it is up to the designers to adopt these suggestions, ignore them or modify them to suit their needs. As discussed before, it is not always required to include all nine of Gagne's instructional events in a learning module, as some events might be infeasible to be implemented for some topics, however, these provide the users with a pool of ideas to adopt and develop from. This represents the third connection created for the framework.

As shown in Figure 1, student background, though it does not dictate the choices for instructional goal or strategy, has design implications depending on students' knowledge in the subject domain and their technology skills, as these affect the effectiveness of the strategies and the value of the instructional content. Concerns regarding appropriateness of instructional goals, strategies, events and user interface features have been translated into specific considerations at the key decision points of the framework (Table 9). This is the last mapping demanded by the structure of the EDDE Framework.

4.3 EDDEaid Development

In summary, the EDDE process represents a design framework for technology-supported teaching tools, starting with an idea and finishing with concrete recommendations for a working product. For completeness, the process also includes phases that are beyond the scope of this research—such as software development and user testing—which can range from simple applications (e.g. a quiz game in Power Point) to robust systems (e.g.

immersive simulations). The main content of the framework is reviewed in the previous section. It can be observed that the amount of information in EDDE is quite significant. As the framework draws knowledge from multiple fields to address this interdisciplinary design problem, applying it to a specific problem at hand might be overwhelming due to the sheer amount of information involved in this process. To make this task easier for the users of this framework, a design support software application called EDDEaid was created to help them use the framework efficiently without having to organize and juggle too many pieces of information at one time. All the content and logic of the framework are hardwired in the backend of the application (e.g., Tables 7, 8, and 9). Relevant information is presented only where necessary when prompted by users. It is also designed to be interactive to help trigger the thought process of users and incorporate their input (learning topic, student background, etc.) in the final outcome of the tool.

The information content of EDDE is mainly concerned with the first two steps of the framework, which are Explore and Design (Figure 1). Hence, these two steps are the focus of operationalization of the framework in the EDDEaid tool. The interface of EDDEaid has five different interactive screens that are numbered to guide users through the design sequence. The Explore screen (Figure 2) is where users provide student background input and select the instructional goal and strategy. In EDDEaid, it is an assumption that the designers have basic information on their student audience and provide that as an input to the process, based on which the framework will provide feedback or warning messages for choices of instructional goals or strategies that might have conflicts with the current status of their students. By default, the data provided by the system is the data obtained in the Technology and Construction Baseline Knowledge Survey (Nguyen et al, 2012). Mappings regarding Learning Objectives and Strategies appear in this screen.

The following screens contain the Design section of the framework. The Design User Interface screen (Figure 3) guides users through the user interface design requirements, and shows mappings between Learning Strategies and UI features, as well as recommendations given student background. The Design Instruction (Figure 4) provides a template for creating specific instructional events and includes all the specific recommendations for the events of instruction given any one of the strategies selected. All decisions made by users are recorded in a summary in the Progress Report screen (Figure 5) where they can review, edit and save the output to be used outside of the EDDEaid interface.

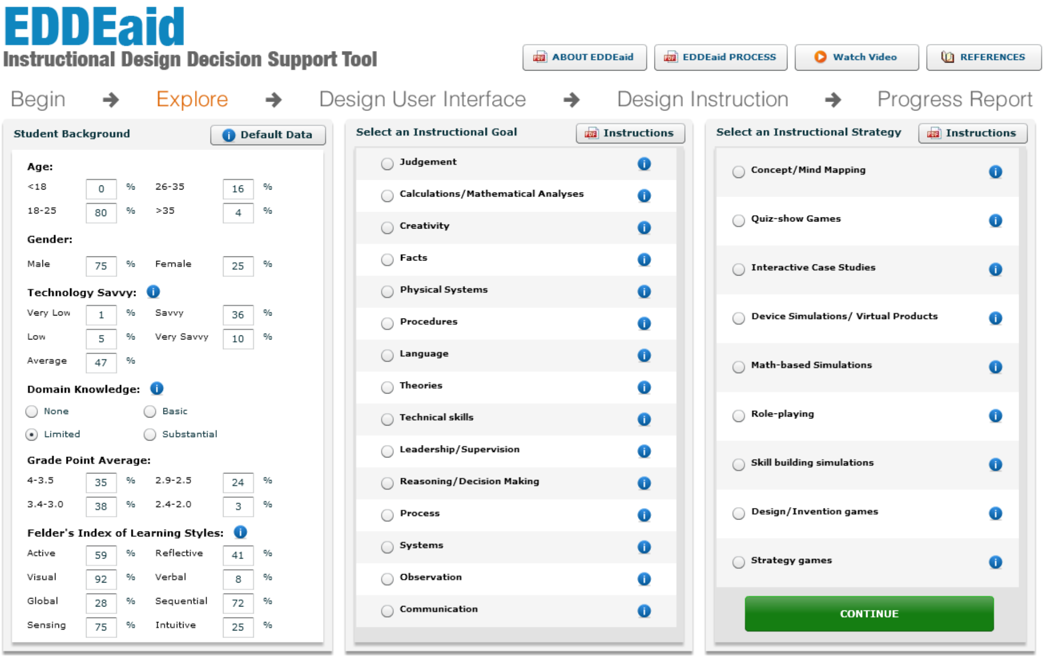

FIG. 2: EDDEaid Explore screen.

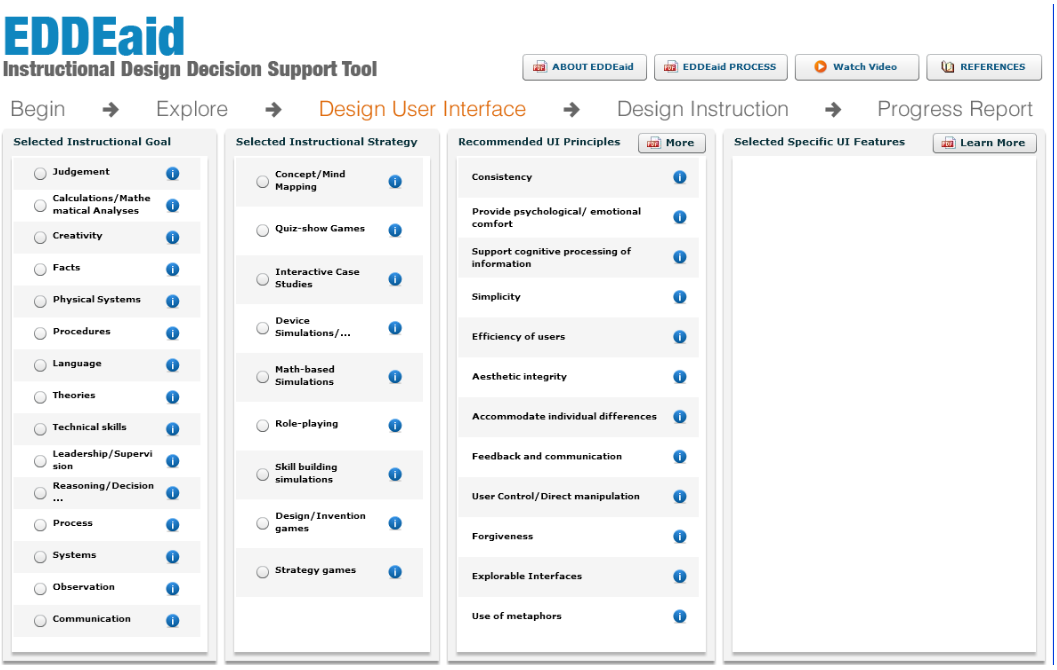

FIG. 3: EDDEaid Design User Interface screen.

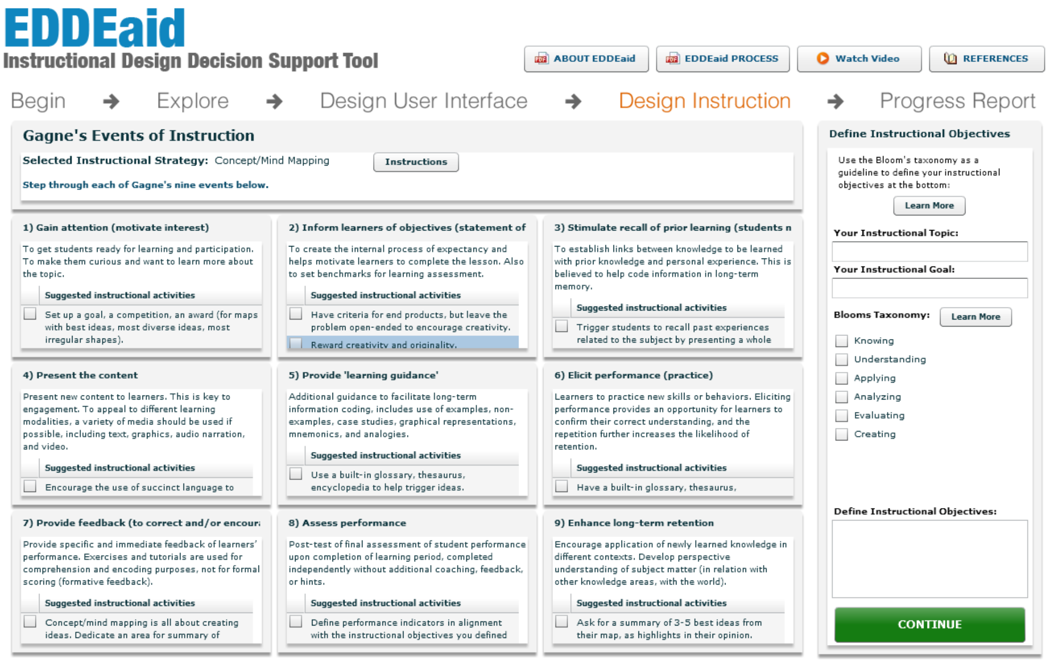

FIG. 4: EDDEaid Design Instruction screen.

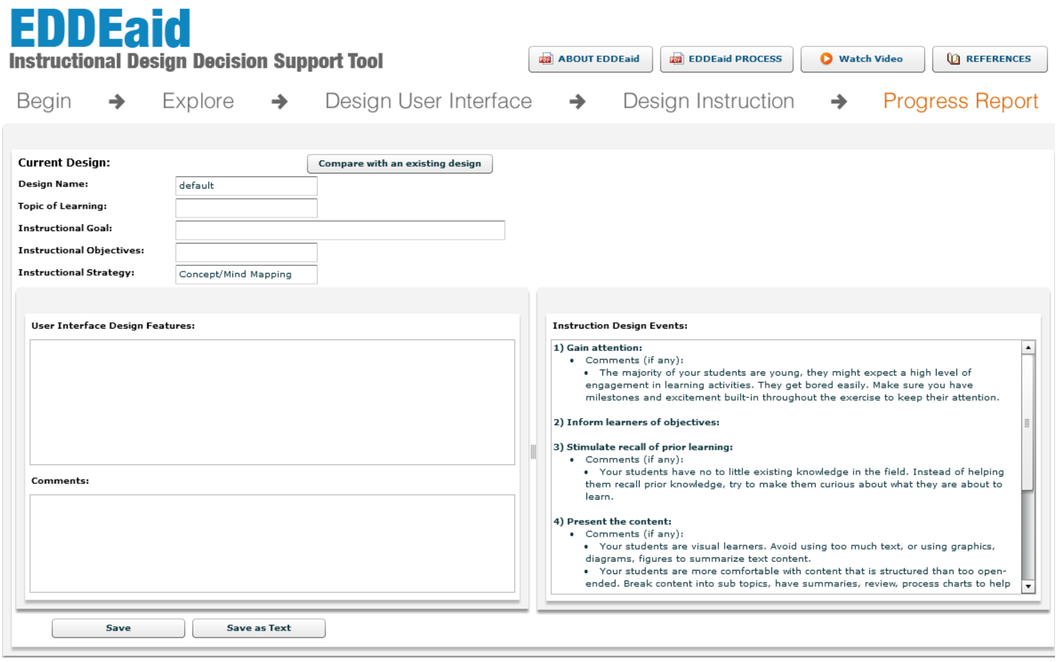

FIG. 5: EDDEaid Progress Report.

5. TOOL EVALUATION

In this section, the evaluation of EDDEaid as a tool for designing technology-assisted instruction is presented. This evaluation has two main objectives: first, to validate the usefulness of the EDDE framework as a whole, through the use of EDDEaid as an instructional design support tool, and second, to identify weaknesses of EDDEaid and ways to improve the framework/tool. As described in Section 3, the evaluation is done in two parts. First, EDDEaid is used to generate recommendations for an existing design, which is a materials management learning exercise supported by an augmented reality simulation of a construction jobsite. Effectiveness of recommendations is then assessed through evaluation of students' learning after participating in the exercise. In the second part of the evaluation, intended users of the framework—in this case, construction engineering faculty members of different American universities—are asked to use EDDEaid to design a technology-supported learning tool to teach a topic of their choice. This evaluation considers users' perception of usefulness, the value they perceive in the designs produced by the tool, their concrete evaluation of specific EDDEaid recommendations, as well as the researcher's observations of users in progress.

5.1 Using EDDEaid to Generate Recommendations for an Existing Design

The learning module described by Nguyen (2010) was based on a tablet PC application that allowed students to process live material data. This was achieved through an array of sensors located in the hallway of a university building, thus constituting the virtual jobsite; sensors were automatically detected when students walked nearby. The three main learning activities were: 1) to locate materials, 2) to associate materials with construction activities and 3) to validate the construction schedule based on material availability. The module was tested by eight students.

*TABLE 10: Specific user interface design guidelines for Skill building simulations**

User's efficiency

- *Gradually reduce learning support: increase the challenge at every step: "show me, teach me, coach me, let me."*
- Offer lots of practice
- Divide big task into smaller tasks and *increment challenges gradually*
- For easy tasks, let users use their intuition. For more complex tasks, demos and guidance are necessary.

Use of metaphors

- Have a "virtual" coach who trains and supports the user. Give a name, a face, and pop him up when feedback is given. But don't be annoying.

- Interface should have moderate fidelity with the real world, but does not have to be total fidelity (simplifications are desirable to avoid distractions and focus on the skill being learned).
- Use visual metaphors for command/action buttons (that mimic/represent the physical action, such as drag and drop for locating, associating, attaching)

Feedback and communication

- *Teach in feedback: give intrinsic and educational feedback*.
- For invalid actions: give explanation
- Indicate progress of tasks by elapsing clock, color coding, etc.

Extra notes relating to student background:

- Your students are visual. Limit text-based content and feedback. *Use voice narration instead of text on screen when possible.*
- *Your students are technology savvy and can handle multitasking*

* *Italic items* indicate features that were not implemented in original pilot design

EDDEaid was used to iterate the design of the tablet PC application. The instructional goal selected was "Physical systems", as the module refers to the physical and logical relationships between construction tasks and required materials. Then, among the instructional strategies suggested by the framework, "skill building simulations" seemed to be the best option, as it provides both a simulated reality and convenient conditions for procedural practice. Finally, the set of user interface design guidelines and instructional events, suggested for the selected strategy, were compared to existing design features. Specific user interface guidelines, as shown in Table 10, indicated that user's efficiency, use of metaphors, and feedback & communication, are relevant for this design. These interface elements were found to be incorporated well in the initial design, although some specific improvement areas were highlighted. The specific recommendations to support the nine instructional events, as shown in Table 11, indicate more possibilities for improvement.

TABLE 11: Instructional events for "Skill building simulations"

Instructional event	Events
Gain attention	• *Set up a challenge, and/or a prize*
Inform about objectives	• Create specific assignments to target specific goals
Stimulate recall of prior learning	• *Have pop-up probe questions to check/confirm mastery of background knowledge during the process, especially after an important decision*
Present the content	• Have a somewhat linear structure to content presentation to provide information gradually. • For highly visual applications that focus on operations: only display the most relevant information on the current task to be carried out. • For complex tasks: provide tools for further research (browsing, searching), or background information
Provide "learning guidance"	• *Apply the personalization principle in providing guidance: conversational style and virtual coaches, rather than text-based information* • In providing feedback and guidance, make explicit references to prior knowledge as well as potential future consequences
Elicit performance (practice)	• Break down learning goals into small assignments • Trigger thoughts: ask questions, or prompt users to self-ask questions. • Have different levels of difficulties of tasks • Offer much practice, but make it optional so that students can choose how much practice they do (to accommodate students with different learning curves)
Provide feedback	• With device simulation, feedback has to be prompt and accurate right after action is taken • *Provide comfort: the modality principle – add sound, narration is generally better than text. This creates a sense of conversation* • Use short quizzes, multi-choice questions as educational feedback and learning guidance.
Assess performance	• Emphasize learning, not acting: the goal is to learn the skills to be learned, not to go through the exercise in the shortest amount of time or the fewest mouse clicks. • Procedural actions can be recorded and use as one assessment criterion • *Provide comprehensive assessment at the end for reflection*.
Enhance retention and transfer to the job	• *Have a report of student performance, what they did well and what they did not do well.* • Relate/compare students' performance to expert performance
<u>Student background concerns</u>	• Your students are visual learners. Avoid too much text, or using graphs, diagrams, figures to summarize text content. • Your students are more comfortable with content that is structured than too open-ended. Break content into sub-topics, have summaries, reviews, process charts to help them understand the material better.

* *Italic items* indicate features that were not present in original pilot design

The recommendations shown in the previous tables were then translated into features for the tablet PC application. This is shown in Table 12 Due to time and resource constraints, only the features in italic were added to the learning module. The refined version was re-tested to validate the value of the new additions.

TABLE 12: Additional features for learning module recommended by EDDE

#	Feature	Description
1	Material location information	• Identify material locations as (x,y) coordinates. Define a square/circle for tolerance.
2	Validation for schedule changes	• Give feedback as a pop-up message when an illogical change is made to the schedule
3	Give landmarks for task completion	• When all activities located or associated, display message in popup to inform learners of task completion and direct them to the next step.
4	*Make visual feedback more informative and educational*	• *Change color code for schedule bar to yellow, light green, dark green with check mark to reflect status* • *Change background color for schedule when locked/unlocked* • *Stronger visual cue to remove pins* • *Upon pin removal, simultaneously remove association and change schedule status color*
5	*Performance statistics*	• *Number of materials to be located and correctly located (x/y materials located)* • *Number of materials to be associated and correctly associated (x/y materials associated)* • *Number of activities ready to be executed with all materials: x/y activities ready* • *Time on task*
6	Confirmation message for unlocking schedule	• When button lock/unlock is clicked, display message "You are about to make changes to the schedule. Please review material availability and locations before proceeding. Pay attention to spatial conflict when changing the schedule."
7	*Hover tooltips*	• *Display information in text boxes when hovering over certain icons (this is already there for the schedule bars)*
8	*Add user info box*	• *To save name/id*
9	*Add Help function*	• *When clicked upon, display a large popup window with brief instruction*

5.1.1 Testing of Revised Learning Module

The testing of the newly updated materials management learning module was with seven participants. The learning objectives of the module, as well as indicators of performance, are presented in Table 13 as defined in Nguyen (2010). The metrics used for learning assessment are listed in the last column of the table. In the new test, additional questions were added to the post-test survey to get users' specific feedback on the newly added features. Complete surveys and quizzes can be found in Nguyen (2010).

TABLE 13: Performance indicators and metrics in relation to learning objectives

Learning objectives	Performance indicators	Performance metrics
Material identification	% task completion	% task completion (electronic)
Spatial-time integration	Schedule adjustment based on material availability	Material availability and status (quiz)
Resource comprehension	Determination of material availability and status	Conflict diagnosis (quiz)
Spatial reasoning	Spatial conflict diagnosis	Conflict diagnosis (quiz)
Logical reasoning	A derivative spatial reasoning	Conflict diagnosis (quiz)
Recognition of technology potential and limitation	Ability to diagnose communication failures	Results from quiz
Operation skill development	Time on task	Time on task

5.1.2 Student Performance

Students participating in the exercise were undergraduate students in a construction-related engineering. Table 14 summarizes the performance of seven participants in the testing of the materials management exercise after recommendations from EDDEaid were implemented. Table 15 shows the results of tests before the recommendations. The most significant improvement noticed by the author was the much shorter time on task for all participants using the improved tool. Overall performance for participants using this tool was also more consistent. They also showed a greater level of enjoyment and less frustration than participants in the previous test. This might be the reason all seven participants completed the task with relative ease and six out of seven made correct observations of material availability and appropriate adjustments to the schedule (only one out of three test participants in the previous test was able to complete schedule validation).

TABLE 14: Student performance in test after recommendations from EDDEaid were implemented

Participant #	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**
Task completion	Completed	Completed	Completed	Completed	Completed	Completed	Completed
Conflict diagnose	4/4	3/4	3/4	3/4	3/4	4/4	4/4
Representations of material availability and status	3/3	3/3	3/3	3/3	3/3	3/3	3/3
Understanding of RFID communication	2/4	2/4	4/4	4/4	4/4	4/4	2/4
True/False questions on RFID and wireless communication	8/8	7/8	8/8	8/8	8/8	7/8	6/8
Time on task	22 min	30 min	27 min	25 min	30 min	24 min	25 min
Schedule validation	*Validated*	*Not validated*	*Validated*	*Validated*	*Validated*	*Validated*	*Validated*

TABLE 15: Student performance in test before recommendations from EDDEaid were implemented

Participant #	**1**	**2**	**3**
Task completion	Completed	Substantially completed	Completed
Conflict diagnose	2/4	1/4	4/4
Representations of material availability and status	3/3	3/3	3/3
Understanding of RFID communication	3/4	2/4	4/4
True/False questions on RFID and wireless communication	8/8	5/8	8/8
Time on task	40 min	1 hour	25 min

5.1.3 Student Feedback

For the improved learning tool, participants were asked to rate the usefulness and effectiveness of nine interface features on the scale from “0” to “10” with “0” being “not useful/effective at all”, “5” being “neutral” and “10” being “very useful/effective”. The results are shown in Table 16. The shaded rows indicate newly added/improved features, while the rest were features present in the previous version of the learning module.

The best rated features among those surveyed were features number 1, 2 and 6, all of which were purely visual feedback and communication. The participants responded strongly (and positively) to the very visible color coding for activity status and the flow of logic when a corrective action was taken, such as the way the association icon and activity status changed when a previously found and associated material was removed.

TABLE 16: Student's rating of interface features (shaded rows indicate new features)

#	Participant	#1	#2	#3	#4	#5	#6	#7
1	Color coding for pins (red for "unfound", green for "found")	10	10	8	10	10	10	7
2	Color coding for activity status (yellow, light green, dark green with check mark)	10	9	8	10	6	10	7
3	User performance statistics	NA*	7	10	NA	6	8	6
4	"Instruction" button	NA	5	10	NA	6	6	6
5	Ability to "lock/unlock" schedule	0	5	10	10	7	7	8
6	Visual feedback (schedule panel changes color when locked/unlocked, activity status changes when pins removed or disassociated)	10	10	10	10	6	8	7
7	Ability to move/remove pins on map	10	9	0	2	7	7	5
8	Hover tooltips	8	9	3	10	10	9	7
9	Ability to sort materials	NA	8	3	NA	10	8	7

*NA: participant did not use the feature. 0 = not useful at all. 10 = very useful.

Another interesting observation was the extreme differences in the way test participants rated some features; features #7 and #5 got both "10" and "0" scores from different users. Two out of seven subjects did not use features #3 and #4, but subject #3 used them and thought they were very useful. For certain tasks the interface offers more than one way to implement recommendations, such as having both the "instructions" button and hover tooltips to explain the functions of the icons, or adding "user performance statistics" to track progress on top of the permanently visible but not easily assessable visual representation. Because of this reason, some features, though useful to those who use them, might not be relevant or even appear useless to those who do not find they need to use them. While avoiding redundancies and noise in an interface is desirable, it is also important to offer various ways to do some key tasks as learners have different preferences and tend to learn in different ways.

The testing of the improved materials management learning module shows that EDDEaid can be used to promote the evaluation of existing instructional designs, and that it is also capable of making practical recommendations for improvement. This is an early validation for the potential of EDDEaid to be useful tool.

5.2 User Evaluation of EDDEaid

Further evaluation of EDDEaid was conducted via several intensive pilot tests with target users. Specifically, university faculty members from different construction programs, with different backgrounds in instructional and technology design, were invited to use EDDEaid. The faculty could either use EDDEaid to do a hypothetical design for a technology-supported tool or use EDDEaid to critique or improve an existing tool they already designed.

The testing procedure starts with a structured pre-test interview in which test participants are asked about their college teaching experience, their background in formal instructional design training/education, and their approach to creating instruction and addressing student's learning needs. Next, the test participants are given an orientation session in which they discussed with the researcher the potential topics of instructional design that will benefit from EDDEaid. Here, participants spend time to explore the actual EDDEaid interface to familiarize themselves with the tool and get further explanations from the researcher until they are ready to start their design problem.

Once the test participants started their EDDEaid session, they were encouraged to go through the design task independently without the help of the researcher. While the researcher was always available throughout the session, participants were expected to carry out the task on their own and only consult the researcher for verifications, technical assistance, or real-time comments

Although the actual output from the design session is an indicator of the usefulness of EDDEaid to the users, the testing is essentially for users to evaluate EDDEaid for its intended purposes rather than for assessing users' instructional design capability or their technical performance in using EDDEaid. As such, the last part of the evaluation process is a structured post-test interview. Users are asked to provide feedback on the ease of use of EDDEaid, both technically and logically, its usefulness for the intended design, and the effectiveness of different features in the program. Participants provide concrete evaluations on specific EDDEaid recommendations, such as whether a certain EDDEaid suggestion resonates or conflicts with their existing knowledge of instructional design or how EDDEaid helps them address the challenges encountered in such a task.

5.2.1 Test Cases and Analysis

This section reports on results of evaluation with faculty members. Specifically, the evaluation of EDDEaid will provide insight into the following aspects: implications for pedagogy, technology selection and interface design, added value for instruction, and improvements for the tool itself. Analysis of results is presented as a set of questions addressing each of these aspects.

The total of participants for these evaluations was 9, of which 8 were assistant professors and 1 professor, either in construction engineering and management or building construction programs. Participants' teaching experience in college ranged from 0-17 years. As a whole, this group of faculty represents the target audience of EDDEaid: instructors with typical—limited—background in instructional and interface design who are interested in exploring ways to incorporate technology in their teaching. Interview summaries and tool designs for each participant can be found in Nguyen (2010).

TABLE 17: Concrete recommendations from EDDEaid best rated by participants

Participant #1 - Design 1: 4D Building Information Models

(Goal: Procedures. Strategy: Skill building simulations)
- **Add sound/audio feedback in form of "virtual coach"**
- **Provide intrinsic and educational feedback**
- **Breaking content into modules, specific assignments to target specific goals**
- **Emphasize learning, not acting.**

Participant #1 – Design 2: BIM Case Studies

(Goal: Facts. Strategy: Interactive case studies)
- **Reward student achievement**
- **Virtual field trip as a demo/expectation setting tool.**
- **Use classic/historic events to motivate and trigger thinking**
- Provide interactive feedback and discussions

Participant #3: Estimating

(Goal: Calculations/mathematical analyses. Strategy: Math-based simulations)
- **Use short quizzes as educational feedback and learning guidance**
- **Emphasize simplicity for the interface**
- Ways to gain attention

Participant #4: Earthwork

(Goal: Reasoning/decision making. Strategy: Role-playing)
- **Dramatize on the method of creating challenges for roles (a press conference, an alert, a newspaper headline, etc.)**
- **Use a current event or an interesting demo video to gain attention and trigger thoughts**

Pay attention to student diversity and match roles to skills

Participant #5: Safety

(Goal: Judgment. Strategy: Role-playing)

- **Present the situation as a conflict, a crisis, a controversy, a dilemma, a comedy.**
- Align each major stimulus with a learning objective
- Students are visual: avoid using too much text, using graphics to summarize content (especially with construction students).
- Students are more comfortable with structured content rather than open-ended.
- Give in-depth feedback of actions and consequences. Provide opportunities to take corrective actions.
- EDDEaid helps address challenge: emphasize learning, not playing in games.

Participant #7: Request for Information cycle

(Goal: Procedures. Strategy: Skill building simulations)

- Gagne's model helps design lesson plan better, especially how to incorporate assessment in instruction.
- Have a somewhat linear structure to deliver content gradually.
- EDDEaid's recommendation for instructional strategy confirmed own choice
- Emphasize retention and transfer to job: relate to real world practice, detailed performance report to students.
- Bloom's taxonomy helps address challenge in terms of what level of depth to teach

Participant #8: Decision and risk analysis

(Goal: Reasoning/decision making. Strategy: Interactive case studies)

- **Gagne's model: interesting and useful**
- Help rethink student background and skills: how to make learning effective for a diverse student audience

Participant #9: Risk management

(Goal: Theories. Strategy: Interactive case studies)

- **Enabling feedback affordable only through technology**
- EDDEaid suggests several ways to communicate with students and makes instructors may more attention to how people learn
- EDDEaid opens up options when you start designing courses
- Learn more about the design task as the moment right now is confined with what data are available now.

***Bold**: aspects that had never before been considered by each participant

Given the participants' limited background in instructional design, it was expected that most of the knowledge in instructional model and design procedure was new to them. This was reflected in the feedback. They all agreed that the instructional model of Gagne's Nine Events ensures that the instructional tool is pedagogically sound. Comments indicated that the structured process aids in systematical reflection on the instructional design problem in construction courses. An important aspect of this reflection is awareness for students' perspective, which enhances communication to account for different students' backgrounds and learning preferences. One of the participants expressed that "EDDEaid helps you formalize and verbalize your thinking in planning and creating instruction, starting with learning objectives then content building then syllabus development, instead of the other way round (which most of us faculty tend to do.)"

Table 17 provides a list of concrete feedback from the test participants on how specifically EDDEaid helped them create better designs by pointing out at certain recommendations (taken from their EDDEaid design output), and explaining how the recommendations triggered their thinking, resonated with their own understanding of the design task, made them reflect on what they were doing, and challenged them to innovate. Table 17 presents those ideas that were considered top priorities for implementation, as well as other ideas from EDDEaid that were considered valuable.

It can be seen that many of the recommendations participants found valuable emphasized the importance of a good pedagogical design. The participants' feedback confirmed the importance of addressing student background and skills in designing instruction. In addition, a few participants mentioned the challenges of using technology to teach domain knowledge. According to these participants, EDDEaid could help address some of these challenges. Participants #1 and #5 observed that the consistent implementation of Gagne's model ensured the focus of technology-supported instruction was on learning, not acting or playing, especially when a game was employed as the learning strategy.

As shown in Table 18, most evaluators—despite their different backgrounds—agree or mostly agree on the value of EDDEaid as a tool to make systematic, solid and efficient designs of instructional tools. Similarly, important insight is provided into instructional design concepts that users were not previously aware of. There is some disagreement about specific aspects, such as the capacity of user interface design principles to show how interaction features can support learning. This is important to note, as participants who were neutral about this statement—participants 6, 7 and 8—have the most teaching experience in construction education. These participants also happen to have the least experience with developing their own instructional tools, as compared to other participants—such as 1, 4 and 5—who have developed games to aid their instruction. The overall usefulness and efficiency of the framework was acknowledged.

TABLE 18: Specific assessments of EDDEaid

	Statement/Quality	P1	P2	P3	P4	P5	P6	P7	P8	P9	Avr
1	The classification of instructional goals is valuable and helps you define better learning goals.	5	5	4	4	4	5	3	4	5	**4.3**
2	The classification of instructional strategies (game/simulation types) is useful and helps you make better decisions.	5	4	5	4	4	4	4	4	4	**4.2**
3	The notes/comments about the potential impact of student background on the choice of instructional goals, instructional strategies and instructional events are useful.	4	5	3	3	5	5	4	5	4	**4.2**
4	The user interface design principles provide a good overall picture of how interaction features can be used to support learning.	5	5	4	4	4	3	3	3	3	**3.8**
5	The use of Gagne's Nine Events of Instruction model ensures that the conceptual design created is pedagogically sound.	4	4	5	4	4	4	4	5	4	**4.2**
6	The way information is spread out and presented to users only when needed (through mouse-overs, information icons, pop-up windows, notes boxes) reduces the memory load and helps me process information better.	5	5	4	4	5	3	3	4	4	**4.1**
7	I get important insights about instructional design and interface design with EDDEaid that I have not been aware of before.	4	5	5	5	4	5	4	5	4	**4.6**
8	Compared to the unguided design experience, EDDEaid helped you create a better and more solid learning module.	5	5	4	4	4	4	4	5	4	**4.3**
9	EDDEaid provides a framework that consolidates the literature in instructional design and user interface design to make the design process of technology-supported learning tools systematic, solid and efficient.	5	5	4	5	5	5	4	5	3	**4.6**
	Average	**4.7**	**4.8**	**4.2**	**4.1**	**4.2**	**4.3**	**3.8**	**4.7**	**3.9**	**4.2**

1 – Strongly disagree 2 – Disagree 3 – Neutral 4 – Agree 5 – Strongly agree

In addition to open-ended questions that allowed participants to provide feedback on various aspects of EDDEaid, the post-test interview also included a list of positive statements about the qualities of EDDEaid. This section of the interview is summarized in Table 18. The response is a 5-point Likert-scale rating that indicates the level to which they agreed with the statement being made, with "1" being "strongly disagree" and "5" being "strongly agree". Average ratings per dimension and per participant are also shown in the table.

TABLE 19: The value of EDDEaid to target audience

Value added	Confirmation from user feedback
Help formalize instructional design process	<u>Enforce structure and process, help prevent design errors</u> • Help formalize and verbalize thinking and instruction planning and creation • Help design better lesson plans and assessment • Provide complete and structured view of instructional strategies in form of simulation/game-based applications • Inform users of potential problems/traps/issues that might lie ahead • Provide guidelines for user interface design <u>Facilitate thinking</u> • Thought provoking and systematic: makes you think about the whole process at different levels from broad to specific • Provide an efficient checklist of important and useful ideas, things you might not think of otherwise <u>Trigger reflections and critical assessment of instruction</u> • Help understand learning from student's perspective • Make aware of difference between instructor and student perspective • Help review and enhance existing design by comparing EDDEaid insights with my own observations and student feedback.
EDDEaid: A good practical tool	<u>Informative and educational</u> • Rich information, lots of ideas on how to teach better • Information buttons • Most content new (and important) to most users <u>Comprehensive and diverse</u> • Covers a wide range of instructional goals and strategies • Multiple paths to explore <u>Flexible</u> • Allows users to add own ideas • Allows users to explore different paths before deciding • Can be used at different points in the iterative design process <u>Versatile/generic:</u> • Applicable to different domains • Wide range of instructional goals, not just limited to calculations and technical areas

According to the test participants, the user interface design guidelines introduced in EDDEaid to a large extent were considered valuable in terms of providing a good overall picture of how interaction features can be used to support learning, earning a 3.8 score for the overall assessment from Table 18, a slightly lower level of confirmation from the participants compared to the pedagogical value EDDEaid offers. The tool, however, proved to be providing useful recommendations in specific instances. Participant #3 found that "simplicity" was a very good guideline for designing a math-based simulation so that the most important analysis task could be at the center throughout the exercise and students would not forget what they were doing analysis, not calculations. Another value of these guidelines is that they make users aware of the importance of doing it right, both in terms of preventing problems and making the best out of the technology being used for teaching; as participant #4 described it: "[EDDEaid] informs users of potential problems, traps or issues that might lie ahead." Many of these might not be obvious to a person of limited background in interface design. Because of this, EDDEaid also serves as "an efficient checklist of things I might not have thought of, but when I see them, I know I need them" (participant #4). It is evident from the positive feedback that the test participants enjoyed exploring instructional strategies and were comfortable with taking EDDEaid's suggestions for user interface design as the starting point for the design of their technology-supported learning tools.

The in-depth interview sessions with test participants yielded insightful feedback on what value EDDEaid had for each of the test cases involved. While each participant might have had different specific observations and assessments of the tool, there were some themes that could be recognized from the feedback. Table 19 provides a concise summary of the test participants' evaluation of the value EDDEaid contributes to their own knowledge in instructional design. The biggest consensus was to consider EDDEaid an effective tool that helped formalize the complex process of instructional design. This was made possible first of all by the way EDDEaid enforces a structure to the process that helps prevent design errors. The framework was also able to trigger thinking and visualizing the big picture of instructional design from the broad starting point to the specific instructional creation. EDDEaid was proved to facilitate critical thinking and reflections through which instructors became more aware of their role and perspective in the learning process of students.

TABLE 20: Overall assessment of EDDEaid

	Ease of use	Amount of info/knowledge	User's effort	Flexibility
P1	Very easy	Comprehensive & reasonable	Reasonable	Reasonable
P2	Easy	Comprehensive, a bit overwhelming	Reasonable	Reasonable
P3	Average	Comprehensive & reasonable	Reasonable	Reasonable
P4	Very easy	Comprehensive & reasonable	Reasonable	A little structured
P5	Very easy	Comprehensive & reasonable	Reasonable	Reasonable
P6	Average	Comprehensive, a bit overwhelming	Reasonable	Reasonable
P7	Easy	Comprehensive & reasonable	Reasonable	Reasonable
P8	Easy	Comprehensive & reasonable	Reasonable	A little structured
P9	Very easy	Comprehensive & reasonable	Reasonable	Reasonable

Another important consensus resulting from the evaluation was the recognition of EDDEaid as an effective and practical tool that is both flexible and educational. All of the participants found the tool comprehensive and generally easy to use (Table 20). Four out of six thought the amount of knowledge in EDDEaid was reasonable, and the other two found it a little bit overwhelming. Most of the knowledge was new to the users, especially in the instructional design area. As a design support tool, EDDEaid was flexible in the way it allows users to explore multiple options before proceeding and add their own thoughts to customize the design. Despite the fact that the examples provided in EDDEaid are mostly construction-related and the participants are all in the construction domain themselves, they realized the generic scope of the tool and commented on the applicability of EDDEaid in other domains.

In terms of content and logic, some of the comments were about additional automatic functions of EDDEaid to calculate the input for students' background information. Some other suggestions can be simply addressed by providing supplemental material without making significant changes to the interface. Other comments were more of a referential nature, as they were concerned with the basis for including selected content in the tool. For example, participant 6 stated that "I need to see verifications or confirmations of the value of EDDEaid: add case studies, success stories. As of now I do not trust that 100% information in EDDEaid is valid". This comment is quite relevant for future research; the value of specific content in EDDEaid has to be further documented, despite the fact that the framework is considered useful in general.

Regarding the interface, one participant suggested having a button for the reference materials on all screens so that users do not have to go back and forth when they need to refer to some literature or instructions, or providing users a local access to those materials in one document. To address this comment, a complete user's manual document was created, which is to be packaged with the EDDEaid software itself as a finished product. The same user questioned the validity of the information in EDDEaid because of the lack of direct references for every recommendation/feature given. For clarity, all references were taken out of the interactive screens of EDDEaid. With the existence of a more elaborate user's manual, these references can now be reintroduced back into the EDDEaid package for completeness. A "Help" or "Q&A" button was also be added to all screens to answer most common questions that users might have. Overall, usability problems do not pose a threat to practicality in utilizing the tool.

6. CONCLUSIONS

This paper presents a novel framework and useful tool that reflects a synthesis of knowledge in user interface design and instructional design to enhance technology supported instruction. The importance of this contribution lies in making resources available for educators that would otherwise be disaggregated and disconnected.

The research demonstrates that distributed research findings in separate studies in instructional design and interface design can be systematically incorporated in a design framework that supports the creation of technology-improved teaching/learning tools. The research offers a method for creating this framework by first identifying the critical design components from the literature in instructional and interface design. By synthesis, it also creates links between these domains and hence develops the missing connections necessary for making the framework actionable.

The value of the framework developed in this research has been demonstrated through applications in the construction education domain. The evaluation results suggest that EDDE is useful to improve the consistency in learning outcomes when the recommendations generated are implemented. Also, the tool EDDEaid was accepted and perceived by professors in construction management and building construction as a useful and effective aid to create technology-supported instruction for their own topics and students. It should be noted that the reduced sample sizes of learners and instructors point at further testing and validation. However, this initial acceptance by the target audience supports the vision of EDDE as an effectively integrated design process that guides the development of technology-assisted instruction.

The users were also positive about EDDEaid's ability to help make better choices of simulation-based instructional strategies and shapes good initial user interfaces for the learning tool. Users' evaluation of EDDEaid recognized its significance as a new framework that formalizes and structures an otherwise complex and ad hoc process. In addition, users of EDDEaid found it helpful in both guiding the design of new learning tools as well as facilitating critical assessment of existing tools. The test participants provided several suggestions for short-term refinement of EDDEaid as well as its long-term development. Some suggestions have already been addressed in the current version of EDDEaid, while some others are considered for future research.

With respect to future work, there are several aspects to address. There is a need to refine the framework and consider the recommendations made by the users. Also, continuation on the synthesis from the literature could focus on more explicit relationships between games and their support for the learning conditions in Gagne's Nine Events of Instruction model. And the tool can also continue to evolve; the more EDDEaid gets used, the more valuable user feedback can be fed back into the tool to refine, enrich and expand the content of the framework.

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