Mobile Learning Applications using Handheld Devices: Ubiquitous training of visual-spatial skills

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Abstract *This research seeks the development of **mobile learning** applications that provide ubiquitous training in **visual-spatial skills** using wireless **handheld mobile devices** (i.e. PDA, cell phones). The paper reports about the findings of a first stage in which the application targeted the handling of spatial representations and the qualitative understanding of 3D spaces. Evidence was collected regarding effectiveness of the instructional strategy related to specific aspects of the students' visual-spatial competency and obtained qualitative feedback regarding the students' level of satisfaction about the learning experience using the initial prototype. The paper provides recommendations for future implementations of an m-learning beta version.*

Introduction

Visual-spatial competence is a multidisciplinary, crosscutting skill that underlies both mathematical talent and creativity (McGee 1979), and it is essential in most creative endeavors, including architectural. Yet, a substantial amount of anecdotal evidence suggests that college students, especially those in introductory design studios, have serious limitations in applying visual-spatial skills in design activities. The problem posed by poor visual-spatial ability is particularly pressing because at the same time that there is a lack of competence among the students, new manufacturing and fabrication technologies can allow the building industry to handle growing levels of geometrical complexity in the solid and spatial morphology of buildings (Schodeck et al. 2004; Mitchell 2005). As a consequence, architecture graduates who do not exhibit good levels of visual-spatial competence will not be able to take advantage of these opportunities and meet the challenges of the future.

The objective of this research project is to undertake innovative methods for addressing these fundamental limitations in the training of visual-spatial skills by means of extra-curricular teaching/learning formats. The project will explore the use of mobile computing technology by developing a set of mobile learning (m-learning) (Trifonova and Ronchetti 2004) instructional modules and testing the degree to which the students' visual-spatial competence is enhanced. The instructional modules will make use of media-rich representations (graphics and animations) for conveying the nature of 3-D spaces. These modules will be designed, produced, and deployed making use of the most accessible mobile devices (cellular phone and/or PDA) among college-level undergraduate design students.

Related work

The impact of environmental conditions, formal training, and multimedia software on visual-spatial skills has been studied in a number of engineering disciplines (Sorby and Gorska 1996) but it has been substantially neglected in design disciplines such as architecture.

In 2001, the PI collaborated with a number of faculty from the College of Architecture in the development of a conceptual framework called "The Third Eye Method." The Third Eye Method has demonstrated, along with numerous studies (Lowery and Knirck 1982), that visual-spatial performance can be improved by practice. This method makes use of 3-D modeling software and digital visualization techniques for training the student in the execution of very fast cycles of visualization and representation. It directly targets the ability to imagine and to represent what is being imagined, bridging over analytical drawing conventions. In the context of this method, the computer application offers information in the visualization framework and provides immediate feedback on the improvement of students' visual-spatial skills. This method has been formulated and updated based on current cognitive and developmental research on visual-spatial thinking processes, and literature on the measurement of skill development (Shah and Miyake 2005). Until now, all the implementations of the Third Eye Method have been based on stationary computing and some implementations have been successfully used in graduate design studios. By extending the number of resources aligned with "The Third Eye Method" from stationary to mobile computing, the PI expects to reach a younger and more tech-savvy generation of students.

The vast majority of teens in the US own some type of mobile media device and they are leading the transition to a fully wired and mobile nation (Lenhart et al. 2005). However, because applications for wireless internet mobile devices in higher education are relatively new, research on their actual use is fairly scarce (Roschelle 2003). Worldwide, some academic institutions are committed to providing access to a number of resources for understanding the use of mobile technologies in support of teaching and learning (Educause 2007; JISC 2007). However, there is no precedent in the use of mobile devices to provide direct training in the enhancement of visual-spatial competence. This will be the first monitored implementation of its kind.

Implementation On the development of the proposed m-learning application, three general stages have been identified. This paper explains the findings resulting from the implementation of the first stage, the authoring and publishing of a prototype for testing learning strategies; to be deployed on stationary computers

The First Stage In general terms the m-learning applications will target the student's handling of spatial representations (Tversky 2005), and specifically, the qualitative understanding of a wide array of 3D spaces. Through the prototype of the first stage the students were trained to develop egocentric perspective mental transformations (Zacks et al. 2000). The egocentric perspective transformations are imagined rotations or translations of one's point of view relative to a reference frame. These transformations allow us to anticipate how an environment will look from different points of view. The prototype included three instructional modules: (1) description of topics; (2) training exercises using quizzes; and (3) game-like challenges using the same exercises. When using the quizzes and challenges, the design students were asked to recognize different views of a given geometrical configuration (e.g. building) from any given location, only using conventional axonometric and orthographic views as elements of reference. The prototype was developed using the software StudyMate by Respondus Inc. The file format of quizzes and challenges was Macromedia Flash. The files were embedded in html pages, and made available to the students through the WebCT VISTA site of the class. The VISTA system provided tracking and reports of students' activities when using these pages. The quizzes and challenges used only graphic content to depict questions, multiple-choice options, and correct and failed answers. The feedback for quizzes was provided by means of animations that depicted the progressive construction of any given geometrical configuration and the translation of the user's point of view until the correct perspective was viewed.

The Experiment To assess the effectiveness of the prototype an experiment was conducted under the following hypotheses:

• Students who practice using the prototype will improve their 3-D visual-spatial skills; specifically they will develop egocentric perspective mental transformations, as measured by standardized tests on specific visual-spatial skills.

• The training methods showcased in the prototype's quizzes and challenges will be satisfactory to the students in terms of perceived learning experience and usability of the prototype. This information will be gathered from the survey about the perceived learning benefits and usability of the prototype.

There were 21 participants in the experiment, all of them freshman (male = 12, female = 9) who learn to apply digital visualization techniques to perform diverse design tasks such as drawing, painting, modeling, rendering, and animating with computer techniques. Before the experiment, all the students were fairly familiarized (intermediate users) with the use of 2-D graphic design but had no prior knowledge or experience in 3D modeling or rendering concepts and software.

Data Analysis The target group was asked to undertake the PURDUE standardized visualization tests battery (PSVT) (Guay 1977) on visual-spatial abilities before and after using the prototype quizzes and challenges. The PURDUE battery includes three sections that target different visual-spatial abilities: testing of object development (folding/unfolding), mental rotation, and views of objects. The pre-test helped to identify two sub-groups: low-spatial ability and high-spatial ability subjects. The bench mark to recognize the level of spatial-ability was set to 75% of correct answers in all three parts of the pre-test. See *Table 1* for the pre-test scores using mean and standard deviation factors.

Table 1 Low/High visual-spatial ability subjects.

Level	Mean	Standard Deviation
Low Ability	58.75	7.1261
High Ability	86.7188	7.526

Since the quizzes and challenges were available online, the students were asked to use them anytime, anywhere, using any stationary conventional computing (PCs or laptops) for about two weeks as an extra-curricular activity. The tracking system of WebCT VISTA reported concentrated use of the application at the beginning and at the end of the two weeks. The students practiced for about 37 minutes on average, giving more emphasis to the complex type of quizzes and challenges.

The analytical method for assessing the visual-spatial skill improvement was achieved by comparing the means and standard deviation of the sections of the pre- and post-test scores among the low/high visual-spatial ability subjects *(Table 2).*

Additionally, the target group filled out a survey about the prototype quizzes and challenges. The survey questions targeted comprehensibility, interestingness, enjoyment, and motivation (Kim et al. 2007) in the use of tool and the learning experience *(Table 3)*.

Table 3 Mean Scores about usability and satisfaction

Question Types	Mean	Standard Deviation
Perceived comprehensibility	77.29	14.22
Interestingness	74.52	14.36
Enjoyment	73.56	15.9
Motivation	82.48	14.86

Table 2 Skill differential according to test sections

Sections	Development			Rotation			Views		
Ability	High	Low	Total	High	Low	Total	High	Low	Total
PRE -TEST Means	95.614	58.333	92.063	86.274	54.166	80.158	86.363	32.5	60.7143
S Deviation	7.5402	11.785	13.559	14.714	41.666	24.405	13.055	16.873	31.1964
POST-TEST Means	85	33.33	82.539	78.82	35	70.476	93.75	35	79.7619
S Deviation	11.969	0	16.224	14.95	10	22.466	11.180	13.693	28.0836

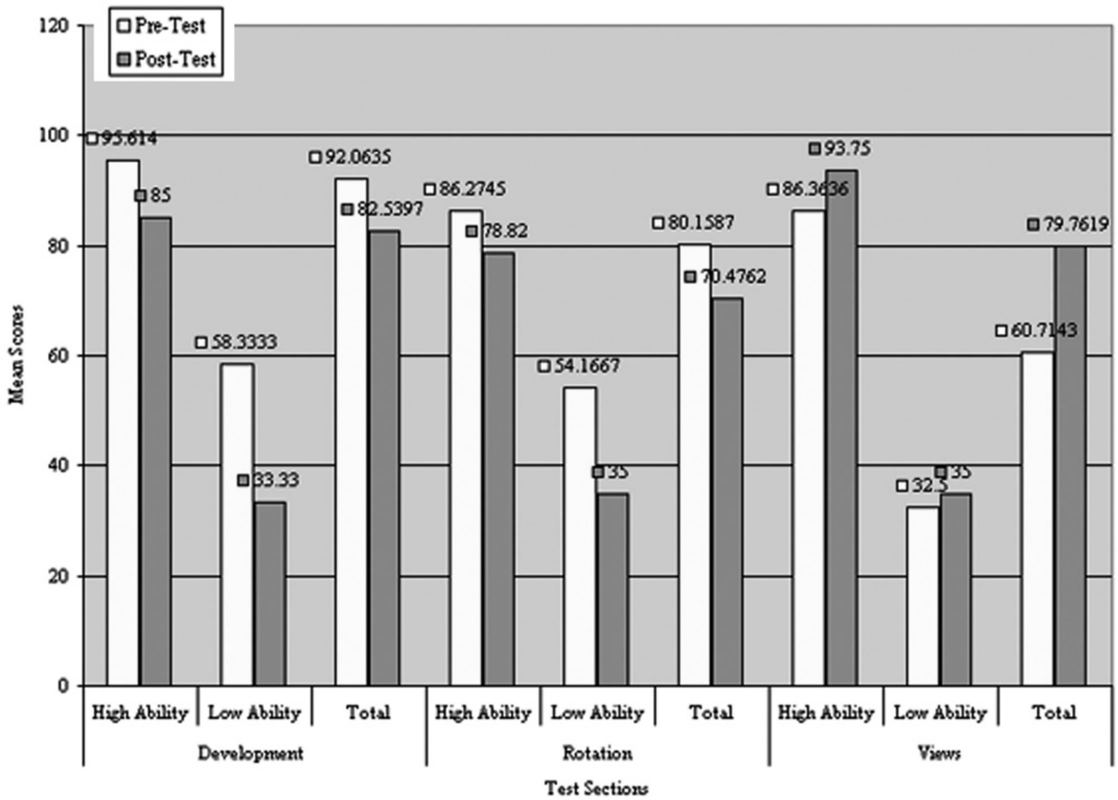

Figure 1 Pre- and post-test mean results.

Results From the analysis of the collected data, there is evidence that suggests that the students who practiced using the prototype improved their ability to develop egocentric perspective mental transformations. Scores for the "views" section of the test have increased not only for the total number of participants or the high visual-spatial ability students, but also for the students with initially low visual-spatial ability *(Figure 1)*.

This experiment also provides evidence supporting situated cognition (Brown et al 1989), which states that instructional developers should focus on creating applications that are similar to the actual context in which the spatial skills will eventually be used (Okagaki and Frensch 1994). The prototype did not target the improvement of object development (folding/unfolding) or mental rotation skills, where some declining scores have been reported. The analysis of the survey indicates that extra-curricular activities without grading can be very difficult to introduce among college students unless there is a very strong motivation. The students obtained a good mean score on motivation (82.48). They seem knowledgeable and comfortable using the media-rich prototype (77.29), they showed interest in the tool and the learning experience (74.52), and they enjoyed using the quizzes and challenges as a learning tool (73.56). These scores clearly suggest that the experiment has been satisfactory. However, more elaboration is needed to boost scores of interestingness and enjoyment via improving motivation among students, comprehensibility of the tool, and the entertainment value of the experience.

Future Work The next development stage of this m-learning application, at beta version, will be based on the results of the tested prototype. The "beta version" project will study the methods and instrumental issues of transforming content previously delivered by means of static computing into mobile computing. It will also study of the constraints affecting the learning engagement; among them it can be mentioned the device characteristics (i.e. device's ergonomics, screen size, etc) and the informal learning context (anytime, anywhere). Furthermore, the project will also take into account conditions that enrich the learning context including, mobility, increased motivation and engagement, privacy, self-evaluation, and reflection.

Among the different mobile devices available in the market today, PDAs and cellular phones seem the most suitable for the implementation of this m-learning application. So in general terms, the idea is to realize a platform independent application that can be used in different operating systems, with limited processing power, viewed in a variety of screen resolutions, using different input possibilities, and accessing data in a flexible mode (use-pause-use again).

The testing of the proposed beta version implementation will contribute to the building of new knowledge in the subject of m-learning and it will lead to recommendations on criteria needed for the design, production, and deployment of instructional resources in mobile devices. In this stage, the research will test the effectiveness of the educational quiz for usability and interface effectiveness. Data will be collected by means of satisfaction/usability surveys, and these will be analyzed using methods that provide mean factors and deviations on different aspects that measure the user's expectations regarding the communication of the content and the human-computer interface.

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