

Ubiquitous Training of Visual-Spatial Skills

ON THE DEVELOPMENT OF MOBILE LEARNING APPLICATIONS
USING HANDHELD DEVICES

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This research project seeks to develop m-learning applications that provide training in visual-spatial skills using wireless handheld mobile devices (e.g. PDAs and cellular phones). The paper acknowledges the role of visual-spatial competence as fundamental in science and most creative endeavors, including its critical role in architectural design. It also recognizes that there is a substantial amount of anecdotal evidence suggesting that undergraduate students in architecture have serious limitations in applying visual-spatial skills for design activities. A potential solution to this problem is envisioned through the introduction of extra-curricular learning activities that are ubiquitous and learner-centered. The suggested m-learning applications will include a set of instructional modules making use of media-rich representations (graphics and animations) for conveying the nature of 3-D spaces. As a first step toward reaching this development, a prototype was created and used for testing learning strategies. This experiment provided evidence regarding improvements to specific aspects of the students' visual-spatial competency, and it also collected qualitative feedback regarding the students' level of satisfaction about the learning experience. The paper provides recommendations for a future implementation of the beta version, including the learning strategy, content authoring, publishing, deployment, and criteria for the selection of the most accessible mobile device.

1. INTRODUCTION

Visual-spatial competence is a multidisciplinary, cross-cutting skill that underlies both mathematical talent and creativity (McGee 1979; Felder and Silvermann 2002), and it is essential in most creative endeavors, including architectural design (Halpern 1986). 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.

Even though visual-spatial skills are of fundamental importance in generating spatial inferences, the curricula of most architecture programs in the United States have shown diminishing interest in supporting this kind of learning. For instance, the disappearance of the descriptive geometry course from the architecture curricula (Liapi 2002) has resulted in the neglect of content that was directed not only toward the production of representations but also toward the development of visual-spatial skills (Kvan et al. 2004). Furthermore, the content of this course has not been included in traditional and/or digital media courses (Cheng 2006). Several trends have undermined the ability to address this situation, namely, (1) reduction in the number of curricular credit hours; (2) content compression in most courses of the curricula; and (3) the pervasive availability of computer aided drawing (CAD) techniques in support of production (drawing and rendering) tasks while masking the students' inadequacy of visual-spatial competence.

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.

2. 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; Gerson et al. 2001) but it has been substantially neglected in design disciplines such as architecture.

Visual-spatial skills have been addressed as people's "third eye." In architecture, designers draw what they imagine and they should do so without having to go through the process of translating 3-D imagery into 2-D orthographic drawings relying on laborious analytical methods. 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 (Gagnon 1985; Lowery and Knirck 1982), that visual-spatial performance can be improved by practice. This method makes use of three-dimensional 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 (Career Change 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).



FIGURE 1 (above left) Simple Configuration Example

FIGURE 2 (above right) Complex Configuration Example

FIGURE 3 (left) Simple and Complex Challenge Examples

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.

3. 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):

- Authoring and publishing of a prototype for testing learning strategies; to be deployed on stationary computers.
- Development of a beta version for deployment on selected mobile devices and testing of interface design and usability.
- Development of a *first version of the m-learning application*, and testing of the students' visual-spatial competency and level of satisfaction with the learning experience when deployed in a selected mobile device.

3.1 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 understand-

ing 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. This is critical for interacting with and navigating in environments, as well as in describing them to others. The ability to predict the consequences of object motion and perspective change is important for everyday reasoning, and for the understanding and design of 3-D spaces.

The prototype included three instructional modules: (1) description of topics; (2) training exercises using quizzes; and (3) game-like challenges using the same exercises. The description of the topics was given during class. 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. StudyMate helped to create the quizzes and game-like challenges of the prototype. The prototype included two versions of the

quiz and challenge: simple and complex, which correspondingly depicted simple and complex geometrical configurations. Each quiz and challenge consisted of 20 exercises (See Figures 1, 2, and 3).

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 (See Figure 4).

3.2. 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

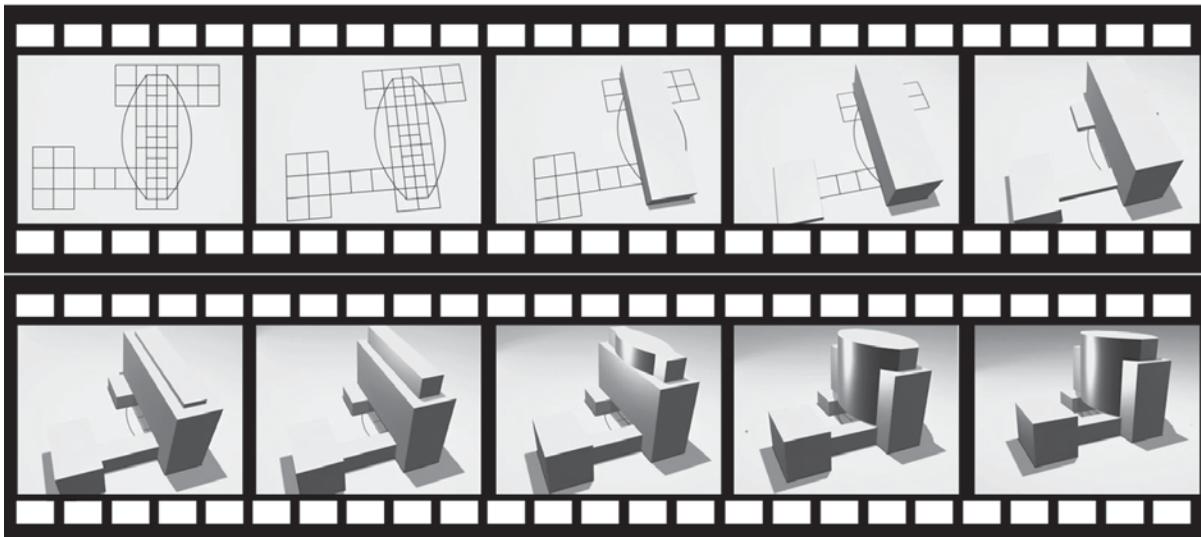


FIGURE 4 Feedback through animation for simple and complex configurations

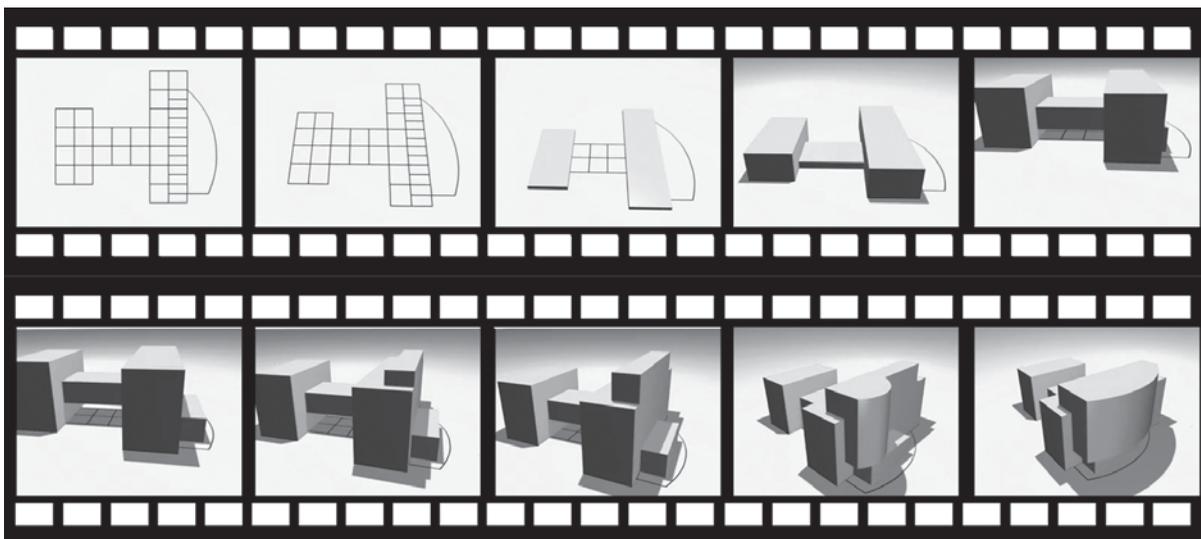


FIGURE 5 The animation provides visual clues and associations between orthographic plans and 3-D views of the geometrical configuration. It also generates the viewer's illusion of rotating and translating until reaching the desired point of view.

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 learning Computer Techniques for Design Visualization (ENDS170). In general terms, the students of this class are 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 3-D modeling or rendering concepts and software.

3.1. 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 of questions 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

3.2. 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 6). 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 (Figure 6).

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)—the highest score among the different types of questions of the survey. They seem knowledgeable and comfortable using the

Table 2: Visual-spatial skill differential according to test sections

Sections	Development			Rotation			Views		
	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

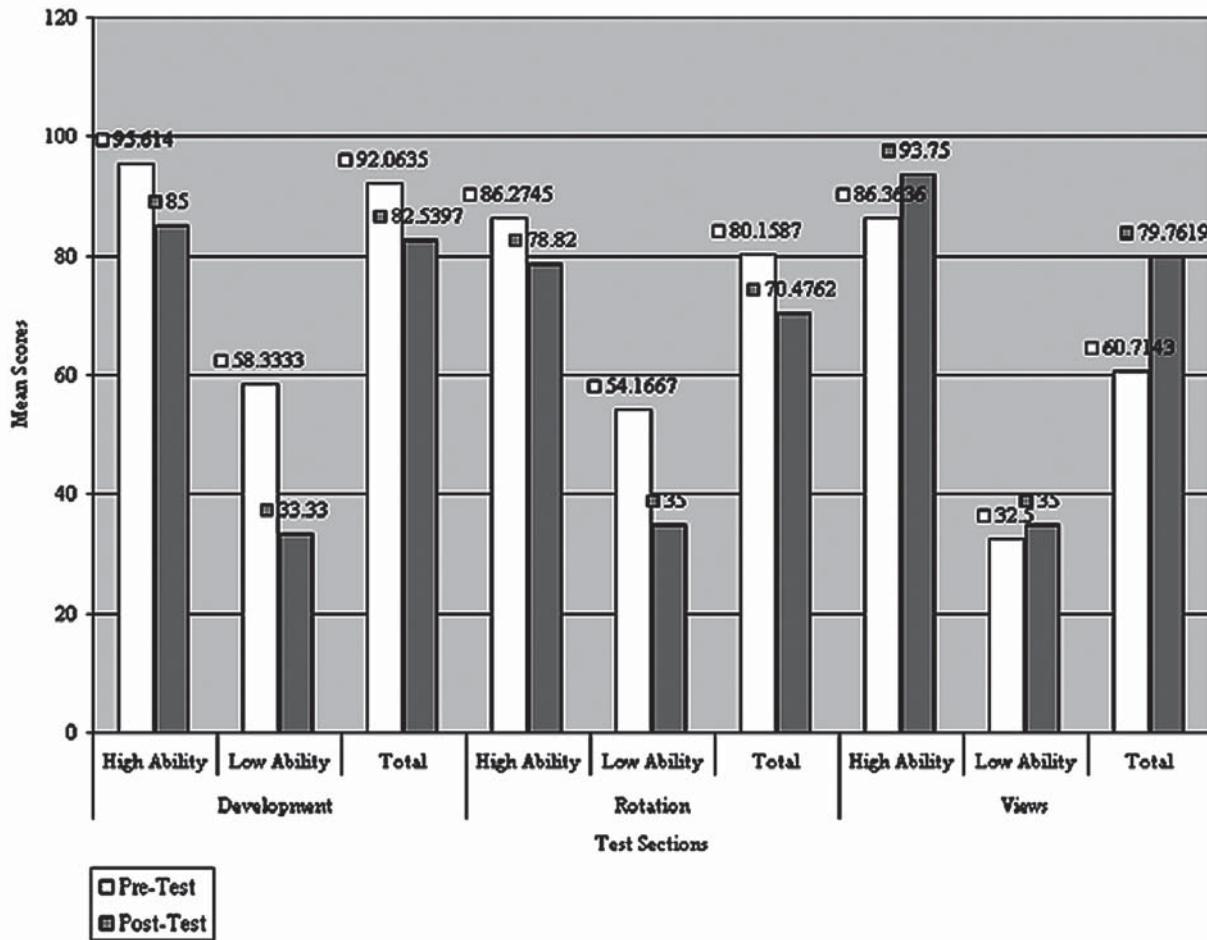


FIGURE 6 Chart depicting the learning outcomes through the comparison between pre- and post-test mean results

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 but more elaboration is needed for improving motivation among students, comprehensibility of the tool, and the entertainment value of the experience to boost scores of interestingness and enjoyment.

4. TOWARD THE DEVELOPMENT OF THE M-LEARNING APPLICATION

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 will continue to support student-centered learning with a behaviorist approach (Skinner 1968). The use of mobile devices to present learning materials, obtain responses from learners, and provide faster appropriate feedback, fits well within the behaviorist approach. This learning approach has lost none of his momentum in transferring to the

use of mobile devices instead of desktop PCs; there is currently a great deal of interest in the use of mobile devices as a means to deliver such content (Naismith et al. 2006). Some advantages of the m-learning application’s drill and feedback exercises will include: (1) content and feedback can be tailored to suit particular areas of deficiency in visual-spatial skills; (2) valuable data can be gathered about the progress of individual students; (3) the capacity to offer each student the ability to select the appropriate difficulty level, which will provide increased motivation.

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 moti-

vation 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. PDAs are affordable, mobile, accessible, and readily available. They are popular in the business market, but at the same time they are more associated with m-learning than cell phones. Their use has been integrated into various disciplines within high schools, universities, and medical schools (Carlson 2002). PDAs offer numerous uses, including internet, wireless access, and file-sharing. Data is also easily backed up on PCs. Wireless technology for a PDA is available through applications such as Bluetooth software. Access to the internet will allow the students to browse the corresponding m-learning websites. The majority of PDAs run the Windows Mobile/Pocket PC OS.

The main advantage of the cellular phone is its generalized availability. This may encourage learning wherever and whenever, especially during idle periods, which could be used for learning. However, due to restrictions (1) on the limited processing power and resources; and (2) on the variety of sizes and general low resolution of the display, not all the cellular phones are suitable for m-learning. Smart Phones are a combination of mobile phone and personal assistant that can be described as a pocket computer; these more powerful devices are more suitable for the m-learning application. Moreover, the current trends in mobile computing are towards devices that are more embedded, ubiquitous and networked than those available today. The capabilities of mobile phones, PDAs, game consoles, and cameras will merge (Naismith et al. 2006).

The constraints common to these specific mobile devices include (Legget et al. 2006):

- *The speed of CPU and amount of RAM* (300 Mhz for cellular phones, faster for PDAs)
- *Screen resolution* (ranging from 160x160 to 640x480 for cellular phones and from 320x240 to 1000x1000). The size of a typical PDA's screen (320 x 240 px) allows adequate delivery of content for static, animated graphics and text.
- *Input devices* (Cellular phones will use mainly keypads, some phones also offer a joystick. PDAs will use fully featured keypads and stylus/pen device or touch screen)
- *Connectivity and network speeds* (Network speeds are generally slow: 3G)
- *Idle use* of the m-learning applications imposes special requirements for flexible accessibility of information.

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 user interface (UI) issues, depending exclusively on the selected mobile device, that will affect the authoring and production of the m-learning application's content include, the fonts, color palette, soft keys for important functions, soft notifications, navigation, help features, visual and audio feedback.

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.

REFERENCES

- Educause. 2007. http://www.educause.edu/content.asp?page_id=5527&bhcp=1
- Brown, J.S., A. Collins, and P. Duguid. 1989. Situated cognition and the culture of learning. *Educational Researcher*, 33:33-42.
- Cheng, R. 2006. Suggestions for an integrative education. In *AIA Report on Integrated Practice, ed. D. Friedman*. http://www.aia.org/SiteObjects/files/5_Cheng.pdf.
- Felder, R. and L. K. Silvermann. 2002. Learning and teaching styles in engineering education. *Engineering education*, 78(7):674-681.
- Gagnon, D. 1985. Videogames and spatial skills: an exploratory study. *Educational Communication and Technology Journal* 33: 263-275.
- Gerson, H., S. Sorby, A. Wysocki and B. Baartmans. 2001. The development and assessment of multimedia software for improving 3-D spatial visualization skills. *Computer Applications in Engineering Education* 9:105-113.

- Guay, R.N. 1977. *Purdue Visualization Tests*. Purdue Research Foundation: West Lafayette, Inc.
- Joint Information Systems Committee (JISC) 2007. http://www.jisc.ac.uk/whatwedo/programmes/elearning_innovation/eli_practice.asp
- Kvan, T., E. Mark, R. Oxman, and B. Martens. 2004. Ditching the Dinosaur: Redefining the Role of Digital Media in Education. *The International Journal of Design Computing* 7. <http://faculty.arch.usyd.edu.au/kcdc/journal/vol7/papers/kvan/>
- Kim, S, M. Yoon, M. Whang, B. Tversky, and J. Morrison 2007. The effect of animation on comprehension and interest. *Journal of Computer Assisted Learning* 3(3):260-270 (11).
- Lenhart, A., M. Madden, and P. Hitlin 2005. Teens and technology. *PEW Internet and American Life Project*. http://www.pewinternet.org/pdfs/PIP_Teens_Tech_July2005web.pdf.
- Legget, R., W. de Boer, and S. Janousek. 2006. *Foundation Flash Applications for Mobile Devices*.US: Apres Inc..
- Liapi, K. 2002. Geometry in Architectural Engineering Education Revisited. In *Journal of Architectural Engineering* 8(3):80-88.
- Lowery, B. and Knirck F.C.1982. Microcomputer videogames and spatial visualization acquisition. In *Educational Technology Systems*, 11(2):155-166.
- McGee, M.G. 1979. Human spatial abilities: Psychometric studies and environmental, genetic, hormonal, and neurological influences. *Psychological Bulletin* 86, 889-918.
- Mitchell, W. 2005. Constructing complexity. In *Proceedings of CAAD Futures 2005*, ed. Bob Maartens and Andre Brown, 41-50. Vienna, Austria: Vienna University of Technology Press.
- Naismeth, L., P. Lonsdale, G. Vavuola, and M. Sharples. 2004. Literature Review in Mobile Technologies and Learning. *FutureLab Series Report 11*. http://www.futurelab.org.uk/research/lit_reviews.htm.
- Okagaki, L. and Frensch P.A. 1994. Effects of video game playing on measures of spatial performance: Gender effects late adolescence. *Journal of Applied Developmental Psychology*, 15: 33-58.
- Roschelle, J. 2003. Keynote paper: Unlocking the learning value of wireless mobile devices. *Journal of Computer Assisted Learning*, 19:260-272.
- Schodeck, D., M. Bechthold, K. Kriggs, K.M. Kao, and M. Steinberg. 2004. *Digital design and manufacturing*. New Jersey:Wiley and Sons.
- Shah, P. and A. Miyake. 2005. *The Cambridge Handbook of Visuospatial Thinking*. New York: Cambridge University Press.
- Skinner, B.F. 1968. *The Technology of Teaching*. NY: Apple-Century-Crofts. Reprinted 2003: BF Skinner Foundation.
- Sorby, S. and R. Gorska. 1998. The effect of various courses and teaching methods on the improvement of spatial ability. In *Proceedings of the 8th International Conference on Engineering Design Graphics and Descriptive Geometry, Austin, TX, 252-256*. Tokyo, Int. Soc. Geometry and Graphics (ISGG).
- Trifonova, A. and M. Ronchetti. 2004. A general architecture to support mobility in learning. In *Proceedings of ICALT 2004*, ed. Eisuke Yoshida and Hirotsugu Kakugawa, 26-30. Los Alamitos, CA: IEEE Computer Society Press.
- Tversky, B. 2005. Functional significance of visuospatial representations. In *The Cambridge Handbook of Visuospatial Thinking*, ed. P. Shah and A. Miyake,1-34. Cambridge, MA: Cambridge University Press.
- Zacks, J., J. Mires, B. Tversky, and E. Hazeltine. 2000. Mental Transformations of objects and perspective. *Spatial Cognition and Computation Journal*, 2(4):315-332.