Virtual Reality-based Spatial Skills Assessment and Its Role in Computer Graphics Education

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Abstract

One element of using contemporary computer graphics tools is the creation of accurate 3D geometry for a variety of purposes. As part of developing effective instructional experiences for students engaged in such activities, computer graphics educators must take into account a person's spatial abilities and skills. Literature has shown these abilities are widely considered to be a significant predictor of the probability of a person's success in computer graphics-related professions. Typical spatial skills assessments examine such abilities as mental rotations, spatial visualization, and spatial perception all of which are involved in the creation of 3D computer graphics. However, most of these assessment instruments are paper-based, and the nature of the human ability being measured is such that the paper-and-pencil format currently used has no mapping to the target construct domain – namely 3D computer graphics in the real world.

This lack of authenticity puts into serious question not only the perceived validity (face validity) of the test, but also the purposes for which test scores from the assessment instruments are put to use (construct validity). One such instrument is The Mental Cutting Test (MCT) which is commonly used to measure spatial visualization skills relative to a cutting plane passing through an object, which are critical in the use of many contemporary computer graphics tools. In an effort to minimize validity issues, the cognitive psychology and computer graphics communities have begun developing virtual reality-based versions of mental rotations instruments to examine various constructs. But a mental rotations assessment does not provide a complete coverage of a person's spatial abilities. This paper outlines the relationship to spatial abilities and computer graphics education and a methodology for pilot testing a working prototype of a virtual reality-based version of a spatial abilities assessment instrument which uses the MCT as a model.

1 Psychological Background for Spatial Ability

Spatial ability as a component of human intelligence has been considered by cognitive psychologists for many years. Work by such development pioneers as Piaget, Thorndike, Lowenfeld, and others is routinely cited by researchers as they attempt to situate their studies within established theoretical boundaries [MAGIN AND CHURCHES 1994; SORBY 1999; MILLER 1992]. However, often more challenging than establishing the foundational framework for such empirical work is the task of actually defining what is meant by the phrase 'spatial ability.' Strong and Smith [2001] made the claim that there are many definitions often applied to this term, and that spatial ability is often interchangeably used with descriptors such as visualization and spatial visualization. Others synonymously used spatial skills [GORSKA, SORBY, AND LEOPOLD 1998], spatial intelligence [KAUFMANN 2003 February], and spatial visualization ability [DENO 1995]. Velez, Silver, and Tremaine [2005] related spatial ability to those "skills involving the retrieval, retention and transformation of visual information" (p. 512).

Researchers that study spatial issues also disagree on the key components or sub-factors that constitute spatial ability. There has been a history in cognitive psychology that there are three primary factors involved in quantifying spatial ability, as well as several sub-factors. According to Eliot and Smith [1983], a multitude of paper-based tests were developed during early periods of spatial research, which examined many different influences on spatial ability, including gender, age, learning style, and environment. From these early tests, it became apparent that gender and environment do have some effect on the development of spatial ability GEARY AND GILGER [1989]; GILGER AND HO [1989]; GEARY [1998]. In addition, early work by Thurstone lead to the discovery of three constructs that characterized spatial ability: an ability to discern an object when viewed from alternate angular orientations (S1); the ability to discern elements of an object which are moving or do not remain in their original position (S2); and using one's own body orientation to address inaccuracies in determining spatial orientation (S3) [Thurstone 1950].

The ability of visualizing three-dimensionally in the mind's eye has been cited by many authors as a key indicator of educational and career success in many fields. Due to the nature of the topical content, engineering and technology professions are frequently highlighted as professional areas requiring spatial ability [DENO 1995; FIELD, 1999; MAGIN AND CHURCHES 1994; STRONG AND SMITH 2001; VELEZ, SILVER AND TREMAINE 2005]. However, researchers have pointed out several other careers that require spatial ability and comprehension, such as architecture, design, piloting, air traffic control, science, mathematics, medicine, and computers [ADANEZ AND VELASCO 2002; DENO 1995; DUFF 1979; SMITH ET. AL. 2005]. Sorby [1999] summarized from many others that more than 80 careers are impacted by spatial skills, including such diverse fields as structural chemistry and art. Furthermore, Smith et al. [2005] noted that the ability to spatially visualize is a clear indicator of educational performance in many design and technical graphics courses. Quaiser-Pohl [2003] also pointed out the long history of spatial ability as a major aspect of many intelligence models, tests, and theories. Kaufmann [2003 February] stated that "spatial abilities present an important component of human intelligence" (p. 2).

There is some debate among researchers as to the innate nature of spatial ability, and whether and how such skills can be developed (e.g., Geary [1998]). Although some cognitive scientists feel that spatial visualization cannot be improved, many practitioners in education and industry claim that this ability can be increased. Sorby [1999] differentiated between spatial ability (innate in a person prior to training) and spatial skill (learned or achieved through training). Saito, Suzuki, and Jingu [1998] proposed that courses in descriptive geometry and computer graphics seemed to improve spatial skills. Field [1999] also supported the use of freehand drawing (sketching) in courses to enhance spatial visualization skills, while Kaufmann [2003 February] felt that the main purpose of geometry instruction is to improve students' abilities in spatial comprehension. Smith, et al. [2005] stated that "visualization is a skill that can be learned, developed, and improved with proper instruction and methods" (p. 16). Strong and Smith [2001] felt that while it has not been validated that spatial ability can be taught in a classroom, there is support for such skills being enhanced by experiences in work environments.

There is a significant amount of variance in the general population regarding spatial ability. For example, Velez et al. [2005], Tsutsumi, Ichikawa, and Kadowaki [2001], Sorby [1999], and Makino, Saito, Shiina, Suzuki, and Jingu [1992] noted the difference in spatial abilities of males and females. Sorby [1999] commented that there are many theories as to why spatial abilities of women seem to lag behind men, including genetic differences and development experiences. Strong and Smith [2001] noted spatial ability differences by gender, but additionally claimed that spatial skills can vary by age, individual differences, and life experiences. It is also fairly well accepted that such skills can be developed through a variety of approaches and methods, and that there are considerable differences in spatial ability among the general population. Some of these differences can be noted by categorical distinctions such as gender, age, life experiences, and other individual differences. It would seem then, that spatial ability is a key indicator of performance and success in various sectors of cognitive research, education, and a broad range of professional careers. In this current study, the main focus will be on the aspects of mental rotation (orienting an object in 3D space, or S1) and mental cutting (mental transformation of an object affected by a defined cutting plane, or S2).

2 Spatial Ability, Mental Object Dissection, and the Use of Contemporary Computer Graphics Tools

Contemporary computer graphics systems, especially those used to model 3D geometry, lend themselves to a certain geometry creation process and strategy formation on the part of the user [WIEBE 1999; WIEBE 2003]. Sketcher-based 3D modeling procedures depend on a user's ability to recognize the forms that make up an object and to mentally dissect the features of that object into their constituent elemental cross-sections [HARTMAN 2005; HARTMAN AND BRANOFF 2005; WIEBE 1999]. They typically allow a user to sketch a representative cross-section corresponding to a feature of the object being modeled, and then apply a 3D form to that sketch, such as extrude or revolve. Complex, multi-rail sweep operations also fall into this procedure. This process is repeated in an iterative fashion until all of the object's geometry is created.

In order to successfully integrate these tools into engineering, design, or computer graphics curricula, and to design effective instructional strategies and assessment methods, the use of proper techniques and instruments must be used. Mental rotations are important to the use of sketcher-based computer graphics tools, but their importance is limited due to their lack of range. When using most forms of contemporary 3D modeling systems, a user generally has the option to select a plane on which to sketch their desired profile. The constructs being assessed during a mental rotations test are used here – the ability to recognize an object from a different viewing orientation. Since these tools often re-orient the user into a 2D view of the chosen sketching plane immediately prior to sketching [WIEBE 1999], a user must be able to ascertain their relative orientation to the object in order to avoid sketching the profile in the wrong orientation or position. The requisite next step of the modeling process, sketching the profile, is where the rotations-based tests fall short.

How does a person know what to sketch? They must be able to mentally conjure the corresponding trace of an imaginary sketching (cutting) plane passing through the portion of the object they are currently creating [HARTMAN AND BRANOFF 2005; WIEBE 1999]. In order to create that visual image, the user must be able to mentally reposition the 2D profile from its true position on the 3D object to its "new" location on the selected sketching plane. This process corresponds to the spatial visualization (S_2) process described previously. While spatial visualization used in this fashion can be difficult for some students when given existing objects to model, this process can become increasingly difficult when modeling an object that does not exist yet [WILEY 1990]. When asking students to model an object, instructors typically have multiple goals for this activity: visualization, experience with using a computer graphics tool, and understanding of geometry to name a few. However, it is also important for students to develop a strategy for modeling an object. Students should be able to plan the types of features that they are going to use as a way to study geometry. They need to mentally dissect an object into its elemental features to effectively use a computer graphics modeling tool. Students must practice open-ended modeling projects to understand the inner-workings and the potential options available to them while using the tools and techniques of their profession [HARTMAN AND BRANOFF 2005].

Sketcher-based computer graphics tools have enjoyed wide-spread existence in most educational settings for roughly fifteen years; however, the assessment of spatial abilities has dealt primarily with rotations-based tests. Another instrument exists that could give a better view of a person's ability to operate sketcher-based computer graphics tools and to create constraint-based geometry. The Mental Cutting Test (MCT) shown in Figure 1 is an assessment instrument created to examine a person's spatial visualization abilities. It requires a person to view a 3D object with a cutting plane passing through it, make a decision regarding the resulting trace of that cutting plane, and then to select the correct corresponding trace of the plane from a list of possible choices. Such a process corresponds to the process of creating geometry within a sketcher-based computer graphics system. Sorby [SORBY 1999; SORBY 2000] suggested the use of such a test, as well as others, when examining the spatial abilities of engineering students in an EDG course. However, the apparent focus of the assessment was to examine the student's ability to grasp course concepts related to traditional EDG content. It is these authors' contention however that we can extend the use of a battery of visualization tests to examine a person's ability to effectively use contemporary constraint-based computer graphics tools, as well as their understanding of geometry.

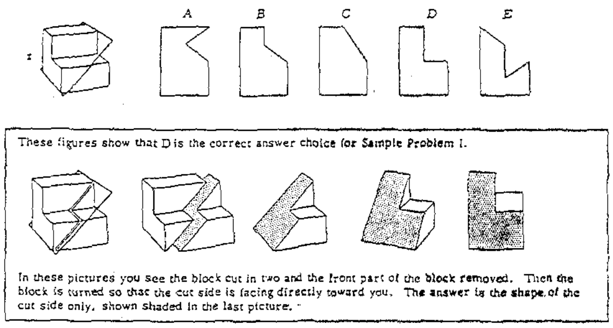

Figure 1: Mental Cutting Test [CEEB, 1939]

The suggested battery of tests to assess visual abilities would account not only for mental rotations but also for mental object dissection, both of which are critical to the use of sketcher-based contemporary computer graphics tools [HARTMAN AND BRANOFF 2005]. Creating sketch-based geometry is a process that includes the common steps of selecting a sketching plane, which establishes the final 3D orientation of the feature, and the sketching the profile on that plane, which requires the user to visualize the requisite 2D profile by mentally dissecting the feature [WIEBE 1999; HARTMAN 2005; HARTMAN AND BRANOFF 2005]. A user will use the visualization abilities inherent to mental rotations when selecting the sketching plane for a feature since this step requires them to visualize the part in the proper 2D orientation for the feature they wish to create. When sketching the feature's profile, the user utilizes abilities inherent to spatial visualization as it requires them to mentally dissect an object [WILEY 1989; HARTMAN AND BRANOFF 2005].

3 Immersive Environments in Support of Learning

Virtual reality (VR) technologies give users the ability to interact with objects and environments that they may not otherwise be able to interact with. Virtual reality also allows for the examination of phenomena that are otherwise unavailable in a physical testing environment. It allows researchers the ability to create experimental scenarios that may be too costly or too dangerous in physical reality. They also provide endless scenarios for training and education where traditional assessments and educational materials fail. Levels of immersion and fidelity in VR environments, and the corresponding abilities to improve learning and knowledge retention, are the critical factors involved in determining if VR technologies will reach their potential educational settings. It is suggested that "the fusion of computers and telecommunications would lead to the development of highly realistic virtual environments that would be collaborative and interactive" [OSBERG 1992].

Virtual reality technologies typically have the most potential in educational settings when dealing with scenarios that are difficult or impossible to create or re-create otherwise, such as examining internal human physiology, psycho-perceptual phenomena, and non-sensical environments meant to examine specific cognitive processes. This can be described as "a sense of immersion and inclusion in a virtual environment which allows the learner an opportunity to interpret and encode his or her perceptions in a broader, deeper set of experiences than those existing in current standard educational environments" [OSBERG 1992].

This generally includes scenarios where the size, shape, proportion or orientation of an object changes, and those changes in perceptual cues are necessary for learning. In addition, scenarios where multiple senses can be stimulated at the same time with a sense of fidelity to the physical world are also suited for the use of VR technologies. Many learning domains including Sciences, Mathematics, Engineering, Statistics, Economic and Financial Sciences, and Art have such learning areas. Recent uses of VR in education include it use as an exploratory tool for simulation and training of dangerous phenomena, the creation of virtual laboratories and performing virtual experiments, and to teach difficult concepts.

Studies have shown that the positive effects of using VR technologies in an educational environment include: i.) the similarity between the psychological processes in virtual and real environments; ii.) the fact that VR gives students the opportunity to manipulate and interact with learning objects; and iii.) the increased activity and motivation towards learning that the VR environment induces [MASEDA ET. AL. 2000; FÄLLMAN 2000; OSBERG 1992; CAPANEMA ET. AL. 2001]. Relative to the current study, the authors hope to take advantage of these items (particularly i and ii) to examine subjects spatial skills and abilities. Current literature emphasizes the use of VR technologies in those areas where text-based or other traditional methods are inappropriate or inadequate, which is why the authors of this study hope to use VR technologies to show that traditional, two-dimensional spatial assessment instruments do not adequately assess three-dimensional spatial skills.

4 Spatial Ability Testing and Virtual Reality

Virtual reality is a broad and encompassing term that includes many aspects of computer-generated environments and subsumes various levels of immersion, such as desktop VR, semi-immersive or augmented VR, and fully immersive VR [Fallman 2000]. Bryson [BRYSON 1996] described VR as an "interface paradigm that uses computers and human-computer interfaces to create the effect of a three-dimensional world in which the user interacts directly with virtual objects" (p. 62). Some researchers [EDWARDS ET.AL. 2004; MEEHAN ET.AL. 2001; SMITH AND LEE 2004] considered VR from a fully immersive, completely artificially created, multi-sensory paradigm, while others [KAUFMANN 2003 FEBRUARY; SZALAVARI AND GERVAUTZ 1997] examined the virtual experience from an augmented perspective – a combination of artificial and existing environments. Feedback to the user can vary in both of these scenarios. Some augmented or immersive contexts are visual-feedback only, while some may include audio or haptic response [EDWARDS ET. AL. 2004]. The anticipated context for this study will be a fully immersive, completely artificial environment, with visual-only sensory feedback to the user.

The uses for virtual reality are also many and varied. Smith and Lee [SMITH AND LEE 2004] reported many applications in the design and manufacturing industries for virtual mockups and product design verification. VR has proven to be effective for industrial, military, and other training applications [STANNEY ET. AL. 2002]. Meehan et al [MEEHAN ET. AL. 2001] reported VR activity in psychological treatment such as post-traumatic stress cases and phobia intervention, and Rizzo et al. [RIZZO ET. AL. 1998] indicated potentially major impacts of VR in neuropsychological assessment and cognitive rehabilitation. Velez et al. [VELEZ ET. AL. 2005] stated that VR technology is being adopted in such diverse fields as scientific visualization, medical applications, industrial applications, information display, and airport security.

To this point in time, virtual reality applications in education are scattered and minimal, but promising. Topic areas such as geometry, mathematics, science, and engineering have all been reported successful in VR educational settings, as have spatial ability and visualization skill development [KAUFMANN AND SCHMALSTIEG 2002; SMITH AND LEE 2004; SMITH ET. AL. 2005]. Besides practical topic instruction assistance, VR promises to benefit learners in more intangible ways. Student motivation, social interaction, and collaboration (especially in distance education scenarios) can be impacted by this technology [KAUFMANN 2003 FEBRUARY; SMITH ET. AL. 2005]. Fällman [FALLMAN 2000] also noted that VR may benefit educators by allowing for physical impossibilities to be modeled and displayed. These might include changes to users' size relative to objects, artificial sensory cues to indicate information or situational changes, and representation of objects with no form in the physical world in order to make abstract knowledge tangible. Hindrances to VR applications in the classroom include technological and economic challenges, training, hardware and software roadblocks, lack of sufficient empirical data to support VR inclusion, and user/VR interaction issues such as cyber sickness and other immersive impacts [BRYSON 1996; KAUFMANN 2003 FEBRUARY; SMITH ET. AL. 2005; STANNEY ET. AL. 2002]. The overall outlook for VR impact in education is positive and will no doubt increase rapidly. Passig and Sharbat [PASSIG AND SHARBAT 2001] reported:

> According to . . . experts, the use of VR in education can be aimed to provide more attractive, motivating, and much more interesting learning experiences to future students. [Experts] would like to see the novelty, the immersion, the stimulation of the senses, and the feeling of exploration encouraging the student to move from passive learning to active learning. Most of all, they would like to see VR technology supporting the cooperative learning environment we all strive for. (p. 11)

While some virtual reality testing of spatial abilities has been accomplished, such research generally has centered on rotational tasks and instruments. Preliminary research has shown that not only might VR remove some inherent biases in paper-based tests (male/female differences among high and low visualizers, 2D assessment of a 3D ability, and the ambiguity of isometric illustrations in 2D instruments), but also that VR instruments may be more effective in truly measuring spatial ability [KAUFMANN AND SCHAMALSTIEG 2002; STRONG AND SMITH 2001; TSUTSUMI ET. AL. 1999; TSUTSUMI ET. AL. 2001]. The MCT has specifically been identified as a promising VR development area [TSUTSUMI ET. AL. 2001]. The potential for 3D spatial ability testing in actual (artificial) 3D environments is a natural outgrowth of technological and information advances in both the fields of spatial ability assessment and virtual reality. In order to further empirical research in virtual reality and its impact on spatial ability development, an immersive VR version of the Mental Cutting Test (MCT) will be developed and tested. It is proposed that such an instrument would overcome many of the limitations that hamper current paper-based MCT assessments.

5 Virtual Reality-based Mental Cutting Test

In order to compensate for the ambiguities and imperfections inherent to traditional spatial visualization assessment methods, a new battery of instruments is necessary – one that more accurately examines the mental faculties called upon in the use of contemporary computer graphics tools. It is our contention that this can be done by developing a virtual reality-based battery of assessments that include the constructs of spatial visualization and dissection of geometry. This would correspond to the operational mechanisms inherent to many contemporary computer graphics tools. To accomplish this goal, a prototype of a virtual reality-based assessment (VRBA) instrument will be developed. It will utilize a similar research design as that employed by Rizzo et. al. [RIZZO ET. AL. 1998] and Alpaslan et al. [ALPASLAN ET. AL. 2005], except the comparison will be between the paper-based version of the test and the virtual reality version of the same or similar test.

It is noteworthy that the planned VRBA tests will provide a wealth of unique data and cognitive/performance measurements not available through more standard spatial assessments. For example, we hope to design a VRBA instrument that will capture these performance indices: a.) overall correctness of response; b.) response times for overall response as well as per each move and completion of component steps; c.) the degree of movement of pieces in 3D space as the individual approaches the problem, correctly or incorrectly; and, d.) a graphic depiction of the process of problem solving over time. Each of these parameters can be analyzed towards a complete picture of the individual's errors and correct steps.

This research project asks can a virtual reality-based assessment instrument be developed that is *at least* as effective in measuring visualization and 3Dimensional comprehension as traditional spatial visualization assessment methods? In addition, how do engineering and non-engineering students perform on the paper-and virtual reality-based versions of the Mental Cutting Test (MCT)?

Design: This study will involve virtual reality technology in an attempt to compare paper-based and virtual reality-based versions of a spatial ability instrument. To that end, an immersive virtual environment and VR testing instrument will be created. The pilot study and initial survey results will provide corrective information for the VR instrument and procedures, as well as assisting in determination of the needed number of participants for a larger follow-up study. Table 1 outlines the basic design for this study. This study is a 2 (Student Major) by 2 (MCT Format) factorial design [GALL, GALL, AND BORG 2003].

Participants: The participants for this study will be 60 Purdue University freshmen and sophomores from the Colleges of Education and Engineering. The undergraduate population at the university is representative of Midwestern universities in general, and care will be taken to fully describe the participants' demographic characteristics. Thirty students from each of the two majors will be ascertained voluntarily through advertisements on campus. All 60 participants will receive the paper-based and the virtual reality-based version of the MCT prototype. Data from interviews and questionnaires, as well as GPAs will also be collected. These data will be used to identify areas of needed refinement of the VRBA, as well as serve as some post-hoc and statistical covariates in our analyses. Subjects will be paid for their participation.

The Instruments: Three types of instruments will be used in this study. The first is the existing paper-based version of the Mental Cutting Test (MCT) (See Appendix A for complete instrument). The MCT contains 25 problems requiring the participant to select from five options the correct cross section resulting from a planar cut through the representation of a 3D object. In order to determine the correct response, participants must mentally manipulate the object to visualize the resultant cross section. A sample problem from the MCT was shown in Figure 1.

As mentioned previously, the MCT is appropriate for measuring the spatial ability factors of mental imaging and spatial visualization [Makino et. al. 1992; Sugai and Suzuki 1999]. Further work [Adanez and Velasco 2002; Saito et al. 1998; and Sugai and Suzuki 1999] has addressed the construct validity of the MCT using Item Response Theory, error analysis, and exploratory factor analysis, respectively. The reliability of the paper-based MCT has been examined in depth [Magin and Churches 1994], and reported to have Kuder-Richardson formula 20 values (proportion of participants passing and failing each item) for MCT posttest scores for students in five different classes ranging from .86 to .89. KR21 values (using mean scores and variances) for pretest and posttest scores for the same five classes ranged from .82 to .88.

The purpose of this study is to assess the effectiveness of a virtual reality-based version of the MCT. This second instrument, the VRBA currently under development, will be utilized to measure the spatial ability of students in an immersive ‘CAVE’ environment. Figures 2 and 3 shown below depict the layout and selection options for the VRBA. At this stage of the research, the participant will simply have stereoscopic vision in a passive environment. No interaction with the object will be allowed in an attempt to establish a baseline measure of the effects of stereoscopic vision on a person’s MCT score. The participant will be outfitted with active stereoscopic glasses and a control wand for locating the position of the hand. A view of each MCT problem will be shown to the participant, and five possible answers will be given. They will be asked to select the correct answer from the choices given. Each problem of the VRBA matches the corresponding problem on the paper-based MCT in terms of the object shown, the orientation of the view, and the position of the cutting plane. The participant will not be allowed to rotate, pan, or zoom in and out on the model, as is the case on the paper-based MCT. By directing the locating vector to the appropriate response (A, B, C, D, or E) and depressing a button on the control wand, a participant is able to select their desired answer.

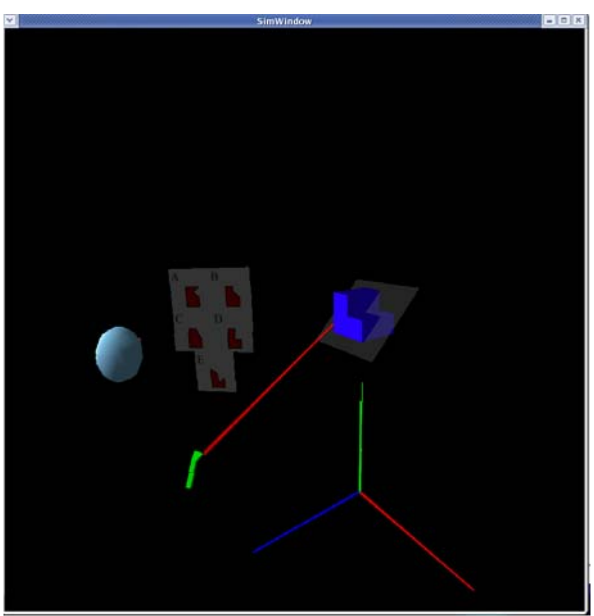

Figure 2: Layout of a Sample VR MCT Test Problem

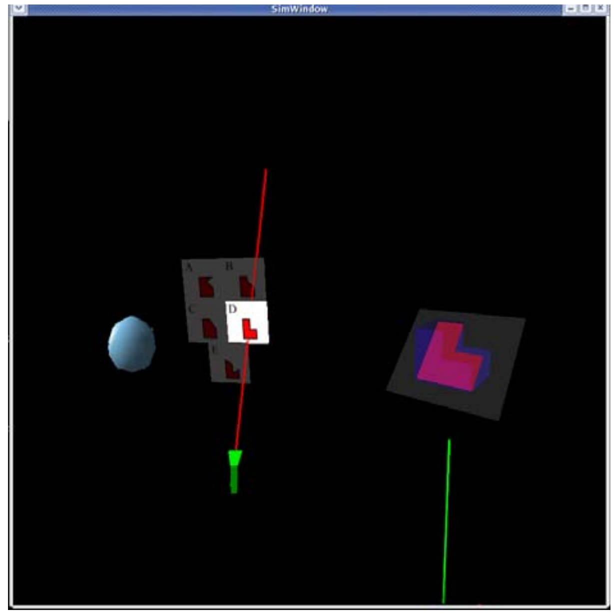

Figure 3: Answer Selection within the VR MCT Environment

A third set of instruments will be used to collect demographic information about the participants regarding age, academic class, academic major, GPA, SAT score, computing experience, life experiences, and other pertinent information.

Procedures: Initially, an immersive virtual environment will be developed utilizing the technological capabilities of the Envision Center at Purdue University. This environment will be established in the 3D CAVE domain, providing projections to three walls and floor of the test area and creating an immersive effect for the participants. Additionally, a virtual reality version of the Mental Cutting Test (MCT) will be created to act as the testing instrument. These two steps (currently in process for the environment creation) will occupy significant lead time in programming and pretesting operations.

All subjects will become familiar with the testing procedures and tasks. Half of each student major group will take the paper-based MCT version first, followed by the immersive VR version. The other half of each major group will take the VR version first followed by the paper-based version. For each test, data will be collected as to the number of items answered correctly, and which items were missed for each participant. Time to complete the tasks will also be recorded. Upon completion of the spatial tasks, participants will be asked to complete a survey that will gather information on perceived benefits and shortcomings of the environment, instruments, and potential side effects such as cyber sickness [Edwards et. al. 2004; Stannjey et. al. 2002].

Demographics questions asked of subjects will include both Likert scale quantitative measures and open-ended response questions. All paper-based testing will occur under standardized methods and under researcher observation. Participants will have 20 minutes to complete the 25-question MCT. Virtual reality-based testing will have automatic score recording via computer response instruments under participant control. Data from all tests will be entered into a storage database for analysis and safekeeping. Survey results will be tabulated, coded (where necessary), and cross-checked for accuracy.

Data Analysis: Because this is a pilot study and instrument development project, statistical issues like power are not critical at this time. Moreover, for the VRBA instrument it is difficult at this juncture to identify power properties such as expected effect size and reliability. However, prior work in the area of spatial ability testing has found effects and been successfully published with sample sizes of this size and fewer [GEARY 1998]. Prior to any inferential analyses, the distributional properties of the data will be examined and outliers will be removed and/or normalization processes will be applied if needed. Our general primary analysis is a 2x2 Mixed Analysis of Variance (ANOVA) of the test error rates and correct response rates. There is one between Ss factor, major type, and one within subjects factor, test type. This analysis will yield main effects for test type, subjects major type, and a test type by subjects major type interaction. Secondary analyses of test performance will later include the response time data, and other dependent variables available. The survey or interview data and GPA data will be used to inform the researchers as they VBRA instrument is further developed. Some of these data will also be used as covariates in some of the analyses planned (e.g., GPA or age).

6 Anticipated Outcomes and Educational Impacts

While there are many questions regarding how VR technologies may impact educational strategies, it is hoped that the results of this study will highlight significant areas of focus that can be leveraged to improve education approaches, curricular issues, and at-risk student methodologies. Another potential contribution may involve testing approaches utilizing current and emerging technology. Lastly, it is hoped that the results of this study will lead to other studies in many related and similar areas to further the impact of this technology in educational practices.

The anticipated outcomes of this project fall into two categories: the development of the virtual assessment environment and the actual examination to participants. It is anticipated that a satisfactory virtual environment can be developed with the existing facilities at the Envision Center for Data Perceptualization at Purdue University. The virtual environment will pass through a development and refinement phase relative to the experimental population chosen [RIZZO ET. AL. 1998; ALPASLAN ET. AL 2005]. In fact, it is the goal of the authors to present pilot data for this assessment prototype during the SIGGRAPH 2006 conference.

For the initial pilot stage of the VRBA development, it is anticipated that there will be no significant differences between participants' scores on the VRBA and the paper-based MCT. As described in the Instrument section above, this could be attributed to the close parallel between the VRBA and the paper-based MCT. If so, it may be possible to state that the VRBA is at least as effective as the paper-based MCT at measuring spatial visualization ability. Further study will involve manipulation of the VRBA to allow for greater levels of immersion and interactivity within the VR assessment environment. It is anticipated that differences between the VRBA and the paper format will be seen at that time. However, if significant differences are witnessed between a person's scores on the paper MCT and the VRBA, it could possibly be concluded that the simpole condition of an immersive, stereoscopic environment gives subjects the ability to visualize complex mental cutting operations.

With respect to the future testing environment and the pilot test itself, it is anticipated that there will be significant differences in scores on paper-based assessments versus immersive nad interactive virtual reality-based assessments. The hope is that these differences can be attributed to the ability of the virtual environment to track the orientations and translations that the participant goes through to determine the proper cross-section of a given object (and a series of mental rotations/orientations as time permits). The hope of the authors is that they will be able to determine the mental progression that the participant goes through to determine when they have achieved the correct cross-section for the given object when passing a virtual cutting plane through the given virtual object.

It is anticipated that the results will show significant differences between the results for paper-based tests between the engineering and non-engineering students. This would be consistent with previous research done in this field. It is assumed that there will also be differences between the virtual reality-based results for engineering and non-engineering students. This will help validate the virtual reality-based assessment instrument. This could indicate a preference for either the VR-based instrument or paper-based instrument, and/or indicate the relative effectiveness of one version of the instrument over another and lead to further studies related to these questions.

The authors have suggested that the methods by which visualization is assessed, and the comparisons of those results to one's aptitude for using contemporary CAD tools, must change to reflect the inherent processes in those tools. In addition to assessment strategies, instructional activities must change also. Traditional instructional techniques for creating 3D model geometry, such as the conversion of multiviews sketches to pictorial figures and vice versa, only address a portion of the visualization abilities of students – mental rotations constructs while not adequately addressing spatial visualization and the ability to mentally dissect an object. Other strategies, such as model dissection [HARTMAN AND BRANOFF 2005] or the construction of cross-sectional views, are able to address spatial visualization as well as mental rotations.

While instructional strategies are important to improve student visualization abilities, the aforementioned strategies are based on traditional assessment instruments and their associated results. In order to account for the ambiguities and imperfections inherent to traditional spatial visualization assessment methods, a new battery of instruments are necessary, one that more accurately examines the mental faculties called upon in the use of contemporary CAD tools as well as computer graphics technology in general. It is suggested that future assessment instruments include virtual and haptic media and devices.

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