

# Enhancing Creativity in Synthetic Biology with Interactive Virtual Environments

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**Abstract** - The objective of the work reported in this paper is to test 4 main hypotheses: (1) Interactive Virtual Environments (IVE) support and enhance students' creativity in synthetic biology; (2) The level of immersion of an IVE affects students' creativity in synthetic biology and a higher degree of immersion promotes higher creativity in synthetic biology; (3) Students creativity in synthetic biology can be measured; and (4) Immersive IVE are *measurably* more effective than current teaching methods for increasing creativity in synthetic biology. In the paper we describe the development of two virtual environments (which show two different degrees of immersion--2.5D and 3D) and we outline the evaluation and assessment plans that will be used to test the hypotheses. Although still under development, the project described in the paper provides a methodology using emerging technologies in computer graphics to teach creativity and domain-specific knowledge by integrating scientific inquiry with engineering design within IVE.

*Index Terms* - Interactive Virtual Environments, Creativity, STEM education, Synthetic Biology

## INTRODUCTION

Science and technology are changing rapidly resulting in a society that needs graduates who can identify problems and creatively design working solutions. This problem is magnified as disciplines merge and problems become interdisciplinary and ill-defined. In order for science and technology to continue to drive the economy, students must be creative and educated to innovate, an activity that has become even more important now with a global economy.

An enmeshing of disciplines within the biological sciences and engineering is creating an interdisciplinary environment in the workplace and academia, which has created a need for interdisciplinary educational environments that enhance creative thinking and innovative problem solving. A recent report from the National Academy of Engineering, entitled *The Engineer of 2020*, stated "*Creativity (invention, innovation, thinking outside the box, art) is an indispensable quality for engineering, and given the growing scope of the challenges ahead and the complexity and diversity of the technologies of the 21st century, creativity will grow in importance[1].*" Science educators should also integrate creativity into their curriculum[2]. But how do you teach students creativity and

innovation? How do you teach students to work effectively and solve interdisciplinary, ill-defined problems? The acquisition of such knowledge is critical and so there is a need for methods to teach and assess student creativity and provide a model for innovation and creativity in other Science, Technology, Engineering and Mathematics (STEM) disciplines.

The *long-term research goal* of this work is to use emerging computer graphics technologies to develop and validate innovative learning environments that support human creativity and lead to innovative educational approaches in other STEM disciplines beyond biological sciences and engineering. The emergence of creativity is dependent in part on domain-specific knowledge and skills [3,4]. However the method in which the knowledge is acquired affects the development of creativity. Visualization is a major component of creative discovery and visualization research holds tremendous promise for education.

The objective of the proposed work is to test the following hypotheses:

**Hypothesis 1:** Interactive Virtual Environments (IVE) support and enhance students' creativity in synthetic biology.

**Hypothesis 2:** The level of immersion of an IVE affects students' creativity in synthetic biology and a higher degree of immersion promotes higher creativity in synthetic biology.

**Hypothesis 3:** Students creativity in synthetic biology can be measured using the *Geneplore model of creativity* proposed by Finke, Ward, & Smith[5]

**Hypothesis 4:** Interactive Immersive Virtual Environments are *measurably* more effective than current teaching methods for increasing creativity in synthetic biology.

The *rationale* for our research objectives is that successful completion of the proposed research will provide a methodology to use emerging technologies in computer graphics to teach creativity within Interactive Virtual Environments (IVE).

## BACKGROUND

*Students' Creativity in Synthetic Biology: Current Limitations*

The synergy of biological science with engineering has led to the emergence of a new field, dubbed synthetic

biology. “*Synthetic biologists engineer complex artificial biological systems to investigate natural biological phenomena and for a variety of applications*[6]” Recently, it has been noted that “the rate-limiting factor for the future development of synthetic biology may actually be human creativity[7].” Sufficient knowledge, sometimes innovation comes from the fringes, which often lack entrenched thinking. This new field of synthetic biology can be viewed as a creative response to the more established fields in biological science and traditional engineering disciplines.

#### *Interactive Virtual Environments and Learning*

The pedagogical benefits of interactive virtual learning environments have been examined (and are currently being examined) by researchers in the areas of computer graphics, cognitive psychology, visual cognition, and educational psychology. In general, research findings show that virtual learning environments are often more effective than traditional teaching tools[8,9,10]. Research also shows that Virtual Reality (VR) technology is particularly suitable to mathematics and science education. VR technology presents concepts in concrete terms and offers a valuable alternative to the conventional study of mathematics and science, which is based primarily on textual descriptions and 2D representations[11].

Recent reviews have concluded that technology has a great potential to enhance student achievement[12,13,14]. Technologies, such as VR, can be used to create interactive learning environments where learners can visualize abstract concepts easily and receive feedback to build new knowledge and understanding[15,16,17]. VR also supports learning in a nonlinear fashion which has been shown to be effective in teaching students how to be critical and creative thinkers[18]. Although some authors have documented that VR experiences provide advantages over more traditional instructional methods[19], studies of VR projects are still relatively rare and a need exists for investigations of VR in the undergraduate biology classroom[18].

Visualization is important for research scientists and for learning in science courses[20,21,22]. In addition, many key discoveries in science reportedly involved creative visual thinking[20,23]. It has been suggested that 3D visualizations can help students build appropriate connections between 2D representations and 3D objects which could lessen the students cognitive load as it is no longer necessary to mentally build the 3D objects [24]. There are three types of visualizations: external (such as graphs, diagrams and simulations[25]), internal (such as mental images used in problem solving[26]) and spatial [27]. The process of learning involves the interplay of all three types of visualizations[28] and creativity is proposed to occur by reinterpretation of the existing image’s meaning or by changing the image’s set frame of reference[23,29]. The relationship of visualization and thinking has been classified into different categories, one of which is creativity[23,30].

#### *Development of Two Interactive Virtual Environments (IVE) with Two Different Degrees of Immersion*

An Interactive Virtual Learning Environment (IVE) is defined as a designed information space in which the information is explicitly represented, educational interactions occur, and students are not only active, but actors, i.e., they co-construct the information space[31]. VR researchers generally distinguish between 3 types of IVEs, which correspond to 3 different degrees of immersion. The degree of immersion of an IVE can be defined by the *dimensionality* of the experience: 2D, 2.5D and 3D.

“...The first (and lowest) degree of immersion is referred to as ‘2D’. Here, users work with data displayed on a typical computer screen in ways with which anyone who has used a computer is familiar. The user may move the data up and down and left to right... The second degree of immersion is referred to as 2.5D. It confines the user to a 2 dimensional computer screen however, the data are displayed in such a way that the user can appear to move around the screen in three dimensions. That is, the user may move ‘into the screen’ along the ‘z’ axis. This creates an illusion of three-dimensions on a two-dimensional display. The term ‘two-and-a half D -- 2.5D’ reflects this compromise. Most arcade-like computer games and VRML ‘flythroughs’ fall into this category. The third degree of immersion allows the user to ‘enter’ a fully three-dimensional VE....Using head and hand tracking technology the user is surrounded by stereo images representing data. This condition is referred to as ‘3D’...[31].”

Our project compares 2 IVEs corresponding to 2 different levels of immersion: 2.5 D and 3D. The first version is a **2.5D Desktop VR application** with non-immersive 3D graphics deliverable on standard PCs/Macs/web. The second version is a **3D immersive IVE** with head/hand tracking and stereo vision. deliverable in multiple-screen immersive devices (i.e the Fakespace FLEX)

#### *Implementation of the 2.5D Environment*

Several production tools were used to develop assets for the application. Adobe Photoshop was used to generate 2D assets, such as glyphs, icons, and interface elements. Autodesk Maya was used for generation of 3D content.

Datasets retrieved from the Protein Databank and the National Center for Biotechnology Information were converted into formats that are compatible with the production tools. The resulting data was then optimized for implementation in a real-time environment.

Several open source and commercial packages are available that could have been used to develop the application. Many of the open source solutions have limited development tools when compared to commercial solutions. The cost of commercial software can be a problem, but

Unity, a commercial solution has a license available for \$200. This includes a fully integrated development environment that directly interfaces with the production tools that was used to develop content, requiring minimal effort for conversion. Unity graphics engine was used to build the 2.5D application as shown in Figure 1.

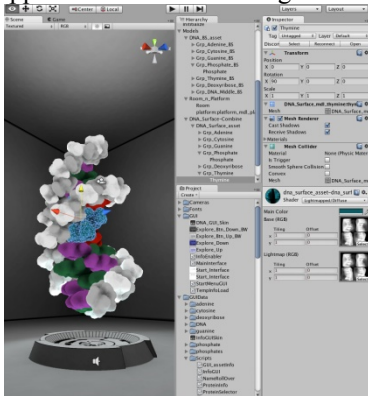


FIGURE 1

THE FIGURE SHOWS THE INTEGRATED DEVELOPMENT ENVIRONMENT WITHIN UNITY. 3D VIEWPORT FOR MANIPULATION OF MODELS (LEFT), FUNCTIONALITY COMPONENTS (MIDDLE). THE RIGHT SECTION ALLOWS FOR EASY MANIPULATION OF VARIABLES WITHIN THE COMPONENTS.

Javascript was written to incorporate the functionality of the application. All components of interaction required code for implementation. Separated into multiple sections, the core section of the application is an environment with DNA that allows the user to toggle between surface and ball & stick models while navigating in XYZ space (see Figure 2, right).

The second section enables the user to perform a simplified transcription of DNA (see Figure 3). The content that we are developing for the IVE will be designed based upon the components necessary for genomics visual literacy. Some of the basic conceptual steps that comprise genomics visual literacy include: gene structure, gene orientation and organization, gene relationships, and genome relationships[32]. In addition, students will learn about molecular function, biological process and cellular components based upon how researchers classify genes[33] and the IVE will allow students to see the dynamic relationships among these components. The interactivity of the visualization follows the principles for designing effective 3D representations and will allow students to manipulate virtual molecules[34]. Interactivity helps students engage in productive scientific thinking and the construction of mental models[35,36,37].

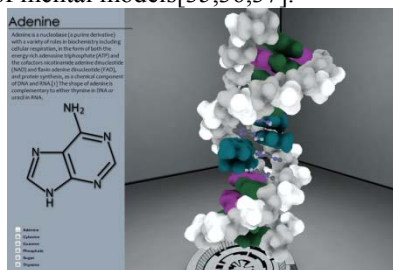


FIGURE 2

SCREENSHOT OF THE APPLICATION. MODEL OF DNA BASE (LEFT), 3D MODEL OF DNA (RIGHT).

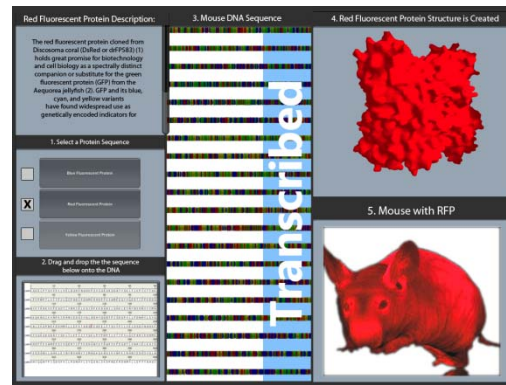


FIGURE 3

A SCREENSHOT FROM THE TRANSCRIPTION MODULE OF THE APPLICATION. PROTEIN DESCRIPTION AND NUCLEOTIDE SEQUENCE (LEFT), DNA SEQUENCE TRANSCRIBED (MIDDLE), RED FLUORESCENT PROTEIN AND ENGINEERED MOUSE (RIGHT).

Application use is tracked through Google Analytics. The following information will be tracked:

- User login
- Time on task
- Time spent manipulating images
- Time moving around environment
- Relationship between movement and modules of the application

Providing flexible delivery, Unity supports one-click deployment outputting to Mac, Windows, and web browser. The initial application is being distributed via the web for tracking purposes.

*Implementation of the 3D Environment:*

For use in a multiple-screen immersive device (i.e. the CAVE) Unity3D will require newly developed code, extending it to the multiple displays used for this virtual environment. A separate instance of the central code of the application will be run on each individual computer controlling the separate screens.

Unity3D comes with networking code built-in. A method known as State Synchronization will be used that will send specific sets of data across the network to the multiple instances of the application[38]. In this way the screens can be synchronized based on user input through multiple devices, such as the head tracker and controller.

Calibration between the system and application will be very important and an interface must be available that will enable quick changes to key variables. Variables such as screen offset, image separation, etc. need to be considered

Stereoscopic 3D implementation has been implemented with Unity3D as well. Several games have been developed. Cruiser Paradise is an example of a game that uses anaglyph 3D[39]. A method for implementation of stereoscopic using dual projectors is detailed and will serve as a base for implementation[40].

The application’s graphical user interface will need to be redesigned for the virtual environment. The 2.5D has a disconnected interface that could reduce the immersive effect. The interface will be integrated into the environment

and provide a more natural feel and presentation of information.

#### PLAN FOR EVALUATION AND ASSESSMENT

##### *Theoretical Framework: Evaluation Methods of Creativity*

In cognitive science research, *creativity* is often defined as the ability to produce work that is (1) novel (i.e., original, unexpected) and (2) useful (i.e., appropriate, meeting task constraints; see [41,42,43]). Despite its critical importance to real world problem solving, creativity represents a small area of research within psychology and cognitive science. Our program of research is founded in a cognitive theory of creativity known as the *Genevieve model of creativity* proposed by Finke, Ward, & Smith[5,44,45]. This framework proposes that creativity is rooted in normal cognitive processes, and the model seeks to identify and specify those component processes. The Genevieve model proposes that there are two core phases to creativity: (1) a *generation* phase in which students generate candidate ideas, and (2) an *evaluation* phase in which students examine relations among ideas and synthesize them into creative products. our project will leverage the Genevieve model to make predictions about what factors will enhance creativity and how our VR intervention can enhance processes that support student creativity. For example, in order to generate candidate ideas in the initial generation phase, students need to have a coherent and detailed conceptual structure about the domain. Aside from rare instances where creative contributions appear to arise “spontaneously,” the cognitive approach to creativity holds that prior learning and knowledge in a domain is necessary for normal creative processes to occur. Thus, enhancing the depth and detail of students’ knowledge structures will enhance generation and, in turn, enhance creative output. Further, during the evaluation phase, students must have a basis on which they can evaluate the novelty and usefulness of their ideas (or combinations of ideas). This evaluation process must occur in reference to an established knowledge structure about the domain. Again, the prediction derived from the Genevieve model is that enhancing the quality of students’ conceptual knowledge structures will enhance the evaluation processes necessary for creative learning. Our overall prediction is that Interactive Virtual Environments (IVE) will enhance creativity and this enhancement will be mediated by several cognitive factors. First, IVE will provide students with the more detailed conceptual structure than students would obtain with traditional teaching approaches, such as lecture, pre-lab activities including non-interactive 2D virtual environments hands-on laboratory experiments. Second, IVE will help students develop higher spatial skills, which has been linked to improved performance in STEM disciplines and to high levels of creativity. This will in turn enhance students’ ability to (1) generate novel candidate ideas, (2) form novel relations among the candidate ideas, and (3) evaluate the novelty and usefulness of their own creative products.

In addition, to address our hypotheses and to see if the innovative IVEs affect the creativity of the students, the project plans to pre- and post-test students using the longstanding and well-known Torrance Tests of Creative Thinking (TTCT)[46]. The TTCT has solid psychometric evidence of yielding valid, reliable, and predictive data. The TTCT measures fluency, flexibility, originality, and elaboration—creative abilities involved with divergent production, a concept that combines divergent thinking, problem solving, and intelligence[47]. We will also administer the Abbreviated Torrance Test for Adults (ATTA)[48], which yields results for: Fluency, Flexibility, Originality, and Elaboration and criterion-referenced creativity indicators. Because scoring can be subjective for each of these measures we will use trained scorers from the instrument company. By administering both the TTCT and the ATTA, we will be able to investigate how well the ATTA works for this content area by comparing its scores to the more time-trusted and evidence-based TTCT scores.

*Comparative evaluation of learning outcomes in 3 different conditions: (traditional lecture + lab + 2D (traditional condition); 2.5 D IVE condition; and 3D IVE condition)*

In this project, we propose to empirically examine the influence of 2.5D and 3D IVE on students’ creativity, learning, and engagement. Although still small in scale, this project will utilize control and experimental conditions to analyze the relationship between using the *Interactive Virtual Environments* and gains in bioscience knowledge and creativity. Our research design is summarized in Figure 4.

We will use a between subjects research design comparing students who receive traditional lab/lecture +2D in a comparable class with students who receive this AND 2.5D and 3.0 D. We will use two classes each semester to provide sufficient power for comparative, inferential analyses of quantitative measures. Specifically, all students will be pretested on the dependent variables of creative thinking, biological sciences knowledge, and spatial ability.

Treatment students will be tested again after use of 2.5D and 3 D materials and finally, one semester later to examine lasting effects of treatment. One of the dependent variables, creative thinking will be measured after using 2.5D and all dependent variables will be measured after 2D and again after 3D (students’ bioscience knowledge, creativity, and spatial ability). We will measure all the dependent variables at three times, first as a pretest and then as two post tests – one after traditional teaching method and one after both IVE experiences. This will allow us to examine changes in students’ knowledge, creativity, and spatial ability between the traditional condition and two IVE conditions. We will also administer a creative thinking test to examine the influence of 2.5 D IVE condition versus 3D IVE condition.

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## REFERENCES

- [1] National Academies of Engineering of the National Academies.(2005) Educating the Engineer of 2020: Adapting Engineering Education to the New Century. Washington D.C.: National Academy Press.
- [2] Yager, R.. (2000) A vision for what science education should be like for the first twenty five years of a new millennium, *School Science and Mathematics*, 100, 327-341.
- [3] Alexander, P. A. (1992). Domain knowledge: Evolving themes and emerging concerns. *Educational Psychology*, 27, 33-51.
- [4] Amabile, T. M. (1996). *Creativity in context*. Boulder, CO: Westview Press.
- [5] Finke, R. A., Ward, T. B., & Smith, S. M. (1992). *Creative Cognition: Theory, Research, and Applications*. Cambridge, MA: MIT Press.
- [6] Andrianantoandro, E., Basu, S., Karig, D. K., and Weiss, R. (2006). Synthetic biology: new engineering rules for an emerging discipline. *Molecular Systems Biology* 2: 1-14.
- [7] Forster, A.C. and Church, G.M. (2007). Synthetic biology projects in vitro. *Genome Research* 17: 1-6.
- [8] Dalgarno, B., & Harper, B. (2004). User control and task authenticity for spatial learning in 3D environments. *Australasian Journal of Educational Technology*, 20(1), 1-17.
- [9] Shin, Y. S. (2003). Virtual experiment environments design for science education. *Proceedings of IEEE International Conference on Cyberworlds (CW03)*.
- [10] Winn, W. (2002). Current trends in educational technology research: The study of learning environments. *Educational Psychology Review*, 14(3), 331-351.
- [11] Johnson, A., Moher, T., Choo, Y., Lin, Y. J., & Kim, J. (2002). Augmenting elementary school education with VR. *IEEE Computer Graphics and Applications*, March/April, 6-9. Retrieved March 2007 from <http://www.nsta.org/positionstatement&psid=13>
- [12] Cognition and Technology Group at Vanderbilt. (1996). Looking at technology in context: A framework for understanding technology and education research. In D. C. Berliner and R. C. Calfee, (Eds.) *The Handbook of Educational Psychology*, New York: Macmillan. (pp.807-840).
- [13] Dede, C. (Ed.). (1998). Introduction. *Association for Supervision and Curriculum Development (ASCD) Yearbook: Learning with Technology*. Alexandria, VA: Association for Supervision and Curriculum Development. pp. v-x.
- [14] President's Committee on Advisors on Science and Technology. 1997. Report to the President on the use of technology to strengthen K-12 education in the United States. Washington, DC: U.S. Government Printing Office.
- [15] Barron, B. J., Schwartz, D. L., Vye, N. J., Moore, A., Petrosino, A., Zech, L., Bransford, J.D. et al. (1998). Doing with understanding: Lessons from research on problem and project-based learning. *Journal of Learning Sciences* 7(3,4), 271-312.
- [16] Kafai, Y. B. (1995). *Minds in play: Computer game design as a context for children's learning*. Hillsdale, NJ: Erlbaum.

FIGURE 4

## EXPERIMENTAL RESEARCH DESIGN

Control students from the comparison group will receive pre and post-test only in content knowledge and creative thinking. Further, to help discern the effects of 3D compared to 2.5D, treatment students in each class will be randomly assigned to one of two conditions, involving development of the final product discussed earlier, either after their 2.5 D or 3.0 D experience. A pre-test of spatial ability will ensure that the random assignment does not result in one group of students with a stronger initial spatial ability.

The final project will allow students to build on the various units in the course completed via traditional and IVE conditions and perform more abstract visualization and problem solving. These final products will be assessed for content accuracy, creativity, novelty, and potential usefulness using a scale developed with experts during the course of this project. We will use instruments to measure student learning, satisfaction, creativity, and adaptive expertise. The instruments include a multiple choice biology concept inventory[49], Student Perceptions of Classroom Quality[50], Torrance test of creative thinking (TTCT).

## CONCLUSION

In conclusion, our main research question is to determine whether Interactive Immersive Virtual Environments are *measurably* more effective than current teaching methods for increasing undergraduate students' creativity in synthetic biology. We have described the development of two virtual environments (which show two different degrees of immersion--2.5D and 3D) and outlined the evaluation and assessment plans that will be used to test our 4 main hypotheses in the future. Our project provides a methodology using emerging technologies in computer graphics to teach creativity and domain-specific knowledge by integrating scientific inquiry with engineering design within IVE.

- [17] Bransford, J. D., Brown, A. L. & Cocking, R. R. 1999. *How People Learn: Brain, Mind, Experience, and School*. Washington DC: National Academies Press. Available at <http://books.nap.edu/catalog/6160.html>
- [18] Strangman, N., & Hall, T. (2003). *Virtual reality/simulations*. Wakefield, MA: National Center on Accessing the General Curriculum. Retrieved March 2007 from [http://www.cast.org/publications/ncac/ncac\\_vr.html](http://www.cast.org/publications/ncac/ncac_vr.html)
- [19] Ainge, D. J. (1996). Upper primary students constructing and exploring three dimensional shapes: A comparison of virtual reality with card nets. *Journal of Educational Computing Research*, 14(4), 345-369.
- [20] Shepard, R. (1988). The imagination of the scientist. In K. Egan and D. Nadaner (Eds.), *Imagination and education* (pp. 153-185). New York: Teachers' College Press.
- [21] Lord, T. (1985). Enhancing the visuo-spatial aptitude of students. *Journal of Research in Science Teaching* 22(5), 395-405.
- [22] Reynolds, S.J., Johnson, J.K., Piburn, M.D., Leedy, D.E., Coyan, J.A., and Busch, M.M. (2005). Visualization in Undergraduate Geology Courses. In J. K. Gilbert (Ed.), *Visualization in Science Education* (pp.253-266). Netherlands: Springer.
- [23] Gilbert, J.K. (2005). Visualization: A Metacognitive Skill in Science and Science Education. In J. K. Gilbert (Ed.), *Visualization in Science Education* (pp.9-27). Netherlands: Springer.
- [24] Reynolds, S.J., Johnson, J.K., Piburn, M.D., Leedy, D.E., Coyan, J.A., and Busch, M.M. (2005). Visualization in Undergraduate Geology Courses. In J. K. Gilbert (Ed.), *Visualization in Science Education* (pp.253-266). Netherlands: Springer.
- [25] Frederiksen, C., and Breuleux, A. (1988). Monitoring cognitive processing in semantically complex domains. In N. Frederiksen, R. Glaser, Lesgold, and M. Shafto (Eds.), *Diagnostic monitoring of skill and knowledge acquisition*, Hillsdale, NJ: Lawrence Erlbaum.
- [26] Johnson-Laird, P.N. (1985). Mental models. In A. Aitken, and J. Slack (Eds.), *Issues in cognitive modeling*. London: LEA Publishers
- [27] Ekstrom, R.B., French, J.W., Harman, H.H., and Dermen, D. (1976). *Manual for Factor Referenced Cognitive Tests*. Princeton, NJ: Educational Testing Service.
- [28] Gobert, J.D. (2005). Leveraging Technology and Cognitive Theory on Visualization to Promote Students' Science. In J. K. Gilbert (Ed.), *Visualization in Science Education* (pp.73-90). Netherlands: Springer.
- [29] Reisberg, D. (1997). *Cognition*. New York: Norton.
- [30] Peterson, M.P. (1994). Cognitive issues in cartographic visualization. In A.M. Maceachren and D.F. Taylor (Eds.), *Visualization in Modern Cartography* (pp.27-43). Oxford: Pergamon.
- [31] Dillenburg, P. (2000). *Virtual Learning Environments*. Proceedings of EUN Conference 2000 - Workshop on Virtual Learning Environments
- [32] Takayama, K. (2005). Visualizing the science of genomics. In J. K. Gilbert (Ed.), *Visualization in Science Education* (pp.217-252). Netherlands: Springer.
- [33] Consortium, T.G.O. (2000). Gene Ontology: tool for the unification of biology. *Nature Genetics*. 25, 25-29.
- [34] Stieff, M., Bateman, Jr, R.C., Uttal, D.H. (2005). Teaching and Learning with Three Dimensional Representations. In J. K. Gilbert (Ed.), *Visualization in Science Education* (pp.93-118). Netherlands: Springer
- [35] Rapp, D.N. (2005). Mental Models: Theoretical Issues for Visualizations in Science Education. In J. K. Gilbert (Ed.), *Visualization in Science Education* (pp.43-60). Netherlands: Springer.
- [36] Scaife, M., and Rogers, Y. (1996). External cognition: How do graphical representations work? *International Journal of Human Computer Studies*, 45, 185-213.
- [37] Rapp, D.N., Taylor, H.A., and Crane, G.R. (2003). The impact of digital libraries on cognitive processes: Psychological issues of hypermedia. *Computers in Human Behavior*, 19, 609-628.
- [38] UNDERdog. (2009) [www.underdog.be](http://www.underdog.be) - Online 3D Games. [Online]. <http://www.underdog.be/games/cruiserVR/>
- [39] Unity3D. (2009) [Unity3D.com](http://unity3d.com). [Online]. <http://unity3d.com/support/documentation/Components/net-StateSynchronization.html>
- [40] Paul Bourke. (2008, December) Paul Bourke - Personal Pages. [Online]. <http://local.wasp.uwa.edu.au/~pbourke/miscellaneous/Unitystereo/>
- [41] Runco, M. A. (2004). Creativity. *Annual Review of Psychology*, 55, 657-687.
- [42] Sternberg, R. J., & Lubart, T. I. (1996). Investing in creativity. *American Psychologist*, 51, 677-688.
- [43] Sternberg, R. J., Lubart, T. I., Kaufman, J. C., & Pretz, J. E. (2005). Creativity. In K. J. Holyoak & R. G. Morrison (Eds.), *The Cambridge Handbook of Thinking and Reasoning* (pp. 351-369). Cambridge: Cambridge University Press.
- [44] Smith, S. M., Ward, T. B., & Finke, R. A. (1995). *The Creative Cognition Approach*. Cambridge, MA: MIT Press.
- [45] Ward, T. B., Smith, S. M., & Finke, R. A. (1999). Creative cognition. In R. J. Sternberg (Ed.), *Handbook of Creativity* (pp. 189-212). New York: Cambridge University Press.
- [46] Torrance, E.P. (1992) *Torrance Tests of Creative Thinking: Streamlined Scoring Guide. Figural A and B*, Bensenville, IL, Scholastic Testing Service, Inc., 43p.
- [47] Guilford, J. P. (1956). Structure of intellect. *Psychological Review*, 53, 267-293.
- [48] Goff, K. & Torrance, E.P. (2002). *The Abbreviated Torrance Test for Adults manual*. Bensenville, IL: Scholastic Testing Service
- [49] Klymkowsky, M.W. and Garvin-Doxas, K. (2008) Recognizing student misconceptions through Ed's tool and the biology concept inventory. *PLoS Biology*, 6 (e3), 1-4.
- [50] Gentry, M., & Owen, S.V. (2004). Student perceptions of classroom quality: Differences between honors, AP, and advanced students and students in general classes. *Journal of Secondary Gifted Education*, 16(1), 20-29.