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E-mail of author: gustavt@nada.kth.se

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CID, Centre for User Oriented IT Design
NADA, Deptartment of Numerical Analysis and Computer Science
KTH (Royal Institute of Technology)
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Teaching Computer Graphics Constructively

Gustav Taxén*
Center for User-Oriented IT Design

Abstract

This paper is concerned with the teaching of interactive computer graphics. It provides a short overview of two influential constructivist epistemologies and describes a preliminary attempt to apply them in practical graphics education.

CR Categories: K.3.1 [Computers and Education]: Computer Uses in Education -- Collaborative learning; K.3.2 [Computers and Education]: Computer and Information Science Education -- Computer science education

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1 Introduction

During the last few decades, many educational practitioners have increasingly turned their attention to *constructivist* models of learning. These models are substantially different from traditional modernist views of learning in that instead of conceptualizing knowledge as something that is transmitted from the teacher to the learner, they emphasize learners' active construction of their own subjective comprehension. Constructivist pedagogies have been successfully used in learning situations where the acquiring of a deep understanding of a subject is required, although they seem less suitable for memorization or training [Twomey Fosnot 1996; von Glasersfeld 2001].

The philosophy of constructivism can be said to have evolved as a post-modernist reaction against the traditional modernist view of knowledge as something in the mind that reflects or represents a fixed external reality. Instead, constructivists typically claim that at least some – or all – aspects of the world that from a traditional realist perspective are seen as ontological facts, stem from (or consists of) human constructions and social relations. Many philosophical variations of constructivism can be identified, ranging from those that see both the world and our knowledge of it as purely constructed to the more common view that there is a world independent of human beings but that our knowledge of it is restricted to our own constructions [Kukla 2000]. This latter perspective (which is probably most common among educational practitioners) can be further divided into two main groups:

- *Cognitive oriented constructivism*, which emphasizes the cognitive mechanisms of individual persons, and
- *Socio-culturally oriented constructivism*, which emphasizes the internalization of socio-cultural activities.

Although the two groups stem from different theoretical foundations, it is possible to view them as complementary. In this case, learning can summarized as a *process of active individual construction that occurs when the learner is engaged in a social practice, frequently while interacting with others* [Cobb 1996].

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*e-mail: gustavt@nada.kth.se

2 Constructivist Epistemologies

Cognitive constructivists typically see *organizations of experience* as a fundamental unit of epistemology. According to their view, cognitive structures develop in response to experiences of the world, so that if the current set of structures does not accommodate a specific experience they may, under certain circumstances, be updated to again support a conceptual equilibrium.

Figure 1. The author assisting a group of learners in constructing knowledge of the graphics hardware pipeline.

One of the main proponents of cognitive constructivism is Ernst von Glasersfeld, whose model of learning is based on Jean Piaget's notions of *assimilation*, *accommodation* and *action schemes* [von Glasersfeld 1995]. An action scheme is a cognitive structure that associates an action with a remembered experience and an expected result. The carrying out of an action scheme proceeds similar to the following:

1. A current experience is assimilated, i.e. it is compared to remembered experiences to see whether it is an instance of one of them. This process is highly selective: it is prone to disregard items in the perceptual field that does not fit into current cognitive structures.
2. The associated action is carried out. It can be directed either at sensi-motor level activities or at mental constructs.
3. The experience of the result of the action is again assimilated.

If the result of the action is unexpected, it leads to a *perturbation* to which one can react with disappointment or surprise. If the initial situation associated with step 1 can still be perceived it can be reviewed, and a new scheme that fit the outcome better can be constructed. This process – accommodation – is equivalent to learning. Thus, in the cognitive constructivist model the only way to acquire new knowledge is through perturbations. It should be noted that because of the selective character of assimilation, perturbations are difficult to achieve: we are (unconsciously) reluctant to break our epistemological equilibrium.

Socio-culturally oriented constructivists typically base their work on the writings of Lev Vygotsky and the later work of Ludwig Wittgenstein and often see the *activity of communication* as a fundamental unit of epistemology [Ernest 1998; Rogoff 1990].

Wittgenstein rejected the modernist view of units of language (sentences, phrases or words) as the carriers of unique meaning. Instead, he introduced the concept of *language games* – patterns of linguistic behavior embodied in types of social activity – and proposed that meaning is equivalent to the role of utterances in such games. That is, to understand the meaning of an utterance is equivalent to acting or responding to it in a way consistent with the implicit rules of the particular language game in which one takes part. Such rules are defined by the social context in which the game is played and vary with the communities, situations and participants involved. Moreover, the rules may change over time, allowing the game to grow, change and lead in unanticipated directions [Wittgenstein 1958]. If the rules are not followed, communication breaks down and the participants have to negotiate another way of continuing the exchange.

The Soviet psychologist Lev Vygotsky developed a psychological model around the concept of *internalization*, i.e., every function of a child's cultural development – including voluntary attention, logical memory, and the formation of concepts – is transformed from being a social, public action to an internal, psychological activity. Since every higher mental function is acquired through such social interaction with others, Vygotsky argued that the way people think and reason is uniquely shaped by their previous relationships with others [Vygotsky 1978]. Through participating in social activities, children – and adults – successively learn to participate in a growing range of different social contexts and language games. Vygotsky also noted that children that encounter a problem too difficult for them to solve on their own, often manage to solve it if they receive assistance from a more knowledgeable person. He used the term *zone of proximal development* to indicate the difference in "developmental level" between these two persons.

3 Constructivist Pedagogies

There are a number of descriptions of how constructivist epistemologies can be applied in classroom teaching practice. In [von Glasersfeld 2001], for example, the following guidelines are suggested:

- The teacher should aim to maneuver the learners into situations where their network of explanatory concepts turns out to be unsatisfactory, while remaining as neutral as possible. The learners' current knowledge is not "wrong", nor is the teacher's view "correct"; the learners are simply interpreting the world according to their current epistemological equilibrium.
- In addition to being familiar with the subject in question, the teacher needs a repertoire of didactic situations in which the corresponding concepts can be applied, situations that ideally evoke the learners' spontaneous interest.
- When learners solve problems, their work and effort should be acknowledged, regardless of whether the solutions are viable or not. Otherwise, their interest in future work may disappear.
- In order to be able to appropriately challenge the learners' current mental concepts, the teacher must have some model of those concepts, i.e., the teacher must know something about the learners' current knowledge.
- The easiest way to encourage reflection is by having the learners talk about what they are thinking. Thus, problem solving should ideally also initiate conversations.

In [Twomey Fosnot 1996], the following additional guidelines are presented:

- Learning is equivalent to the development of individual learners' understanding. Therefore, they must be allowed to raise questions, generate hypotheses and test them for viability.
- The learners must be given time to reflect so that they can mentally organize and generalize what they have learned. Examples of techniques to support this process include journal writing and the creation of representations in multiple forms of media.
- The learners should be responsible for defending, proving, justifying and communicating their ideas to the rest of the classroom community. An idea is only accepted as viable when the community has reached consensus.

Socio-culturally oriented constructivists often place a large emphasis on *scaffolding*, i.e., methods where the teacher guides the learner towards a solution to a problem, or where the learner solves a problem in collaboration with peers. In [Stoll Dalton and Tharp 2002], the following principles are emphasized:

- Joint productive activity: teacher and learners produce together.
- Developing language and literacy across the entire curriculum.
- Connecting school activities to the learners' lives.
- Teaching through instructional conversation.

For some socio-culturally oriented constructivists, however, the concept of classroom practice is problematic, because it implies that knowledge can (at least in part) be socially *decontextualized*, i.e., that knowledge acquired in one context can be reapplied in a different context. In practice, however, such decontextualization may not always be the possible, especially not for advanced topics. Thus, these educationalists focus on the relationships between the school and the communities of practice where the knowledge is to be applied, and how the learners come in contact with those communities [Lave and Wenger 1991].

The constructivist pedagogical focus on dialogue and learner participation puts a number of traditional didactic methodologies in question [Ben-Ari 2001]. In lecturing, for example, the lecture necessarily follows the speaker's line of thought (since he or she created the lecture) – but this does not necessarily mean that the narrative matches the listeners' conceptual explanatory framework. Furthermore, the physical circumstances of lecturing may discourage questions and dialogue. Often, the number of participants is large, which can make a listeners feel that their questions are "stupid". Also, the speaker usually has a tight time schedule, which necessitates short answers to questions that arise. Thus, one cannot assume that listeners "learn" what the speaker is presenting. However, this does not at all imply that lectures have no place in modern education. On the contrary, lectures can be quite suitable for raising an interest, presenting demonstrations, and for providing overarching frameworks to which learners can relate when they are engaged in other learning activities.

4 Technology-Based Learning Tools

A multitude of computer-based tools designed to explicitly support different constructivist pedagogies have been available since the early 1980s, and a number of researchers have presented guidelines for the development of such tools (e.g., [Osberg 1997; Jonassen and Rohrer-Murphy 1999]). Examples include multimedia CD-ROM products like Mulle Meck, (http://www.barnlandet.se/mulle/), children's programming languages like LOGO [Papert 1980], re-usable components like E-Slate (http://e-slate.cti.gr/), and systems that allow learners to gain access to the concepts, problem solutions, and jargon used by experts [Karlgren 2001]. More recently, a number of collaborative environments based on virtual reality and augmented reality technologies have been introduced (e.g., [Dede et al. 1996; Spalter et al. 2000; Taxén and Naeve 2002; Kaufmann and Schmalstieg 2002]).

The number of educational tools designed explicitly for constructivist-oriented teaching of modern interactive computer graphics is much fewer. A common didactical approach is to use books and on-line or off-line educational components [Hunkins and Levine 2001] or higher-level systems like Alice [Conway et al. 2000] to give students a theoretical foundation, and a low-level programming library like OpenGL or Direct3D for practical exercises, projects and assignments.

At the Center for User-Oriented IT Design, we are developing a system called Wasa that it is mainly used for prototyping of moderately complex graphics applications. Wasa allows the graphics hardware pipeline to be configured interactively through XML shader files in a way similar to RenderMonkey (http://www.ati.com/developer/). This allows the functionality of the graphics hardware to be *exposed incrementally* without the need for explicit programming, so that its fundamental parameters can be manipulated first, and additional detail can be revealed later as the need arises. I believe features similar to this could be used in constructivist-oriented teaching to provide the learners with a useful problem manipulation space (cf. [Jonassen and Rohrer-Murphy 1999]).

5 Constructivist Teaching of Computer Graphics

As an initial attempt to make use of a constructivist-oriented epistemology in computer graphics education, I organized a workshop called *3D Graphics for Dummies* in December 2002. The educational goal of the workshop was to help the participants acquire an understanding of the graphics hardware pipeline and the fundamental concepts of hierarchical transformations and animation. Because Wasa allows easy modification of graphics hardware configurations without the need for programming, I decided to attempt to use it as a learning environment for the workshop. Thus, the only explicit prerequisite was that the participants had some previous experience with computers.

The workshop had about 20 participants. It was approximately three hours long and was divided into two parts. The goal of the first part was to guide the participants in constructing a theoretical understanding of the graphics pipeline, while the second part allowed the participants to apply their knowledge in practice. From a traditional educational perspective, it might have been appropriate to initiate the first part of the workshop with a lecture describing the pipeline. As we have seen, however, constructivist epistemology suggests that for the purpose of supporting learners in their construction of conceptual understanding, this may be an inefficient way of proceeding. Thus, I instead chose an approach where my role was to guide the participants in constructing a conceptual image of *what components the graphics pipeline is likely to have, given that it has certain capabilities*.

I began by running a Wasa program that draws an image of two triangles, one in wireframe and one filled with a solid color (I used a projector to allow the participants to see the output of the program). I then asked what the computer must be able to do in order generate such an image. After some discussion, the notion of a rasterizer was suggested: a component that takes vertices as input and generates sets of pixels as output. At this point, I drew a text box containing the word *rasterizer* on a whiteboard. The next step was to show the participants a rotating wireframe model and ask how such a thing as rotation could be accomplished. This led to the notion of transformation of vertices. Thus, I drew a corresponding text box containing the word *transformation* on the whiteboard and connected it to the rasterizer. Concepts like image plane projections, z-buffering, lighting, texturing, alpha blending, stenciling and environment mapping were developed analogously. The end product was an image on the whiteboard illustrating the main components of the modern graphics hardware pipeline (figure 1). The whole process took about one hour. Sometimes, the participants would "get stuck". In such cases, I asked them to attack the problem in groups of two. At other times, I would do "live" rewriting of my example programs in order to clarify a line of reasoning or in response to questions.

Having thus acquired a conceptual knowledge of the pipeline, it was then time for the learners to apply their knowledge in practice. They were divided into groups of two and each group was presented with a computer running Wasa. In addition, each group was given a compendium containing a Wasa overview and twelve exercises. The aim of the exercises was to encourage the learners to solve a number of relevant problems related to the manipulation of the graphics pipeline. The problems included:

- Move the camera and light sources to different positions and change their properties.
- Make a model rotate twice as fast.
- Add a texture to a model.

During this phase of the workshop, I would answer questions from the groups and guide them towards the solution of the problems if necessary. After two hours, most of the participants had successfully completed a majority of the exercises.

6 Discussion and Future Work

Although there was not enough time to do any detailed evaluation of the educational outcomes of the workshop (we were not allowed to continue beyond three hours), I have some anecdotal evidence that it was successful. All participants thought that the theory part was rewarding, although a few were concerned with the variations in tempo: the "flow" of my presentations of problems were interrupted by the comparatively long "awkward silences" when people were thinking. Furthermore, most participants expressed an understanding of the graphics pipeline and seemed to enjoy the exercises, although some thought the formulation of a few of the problems were a bit unclear.

Because I could not interview any of the workshop participants, it is impossible to draw any strong conclusions about the nature of the understanding they acquired. In addition, due to the time constraints, the participants were not given the opportunity to discuss their understandings with the entire group, nor were there time to talk about the participants' individual backgrounds and personal interests. However, I think the outcome of the workshop indicates that rich opportunities exist for designing a constructivist-oriented computer graphics course. At least for smaller groups, the methodology of "constructing the graphics pipeline" seems very promising. Thus, I am currently introducing a number of constructivist-oriented exercises at the introductory computer graphics course at the Royal Institute of Technology in Stockholm.

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References

BEN-ARI, M. 2001. Constructivism in Computer Science Education, *Journal of Computers in Mathematics and Science Teaching 20*, 1, 45–73.

COBB, P. 1996. Where Is the Mind? A Coordination of Sociocultural and Cognitive Constructivist Perspectives. In Twomey Fosnot, C. Ed. *Constructivism. Theory, Perspectives, and Practice*. Teachers College Press.

CONWAY, M., AUDIA, S., BURNETTE, T., COSGROVE D., CHRISTIANSEN, K., DELINE, R., DURBIN, J., GOSSWEILER, R., KOGA, S., LONG, C., MALLORY, B., MIALE, S., MONKAITIS, K., PATTEN, J., PIERCE, J., SHOCHET, J., STAAK, D., STEARNS, B., STOAKLEY, R., STURGILL, C., VIEGA, J., WHITE, J., WILLIAMS, G., AND PAUSCH, R. 2000. Alice: Lessons Learned from Building a 3D System for Novices. In *Proceedings of CHI 2000*, ACM Press / ACM SIGCHI, 486–493.

DEDE, C., SALZMAN, M. C., AND LOFTIN, B. 1996. Constructivism in Computer Science Education, *Journal of Computers in Mathematics and Science Teaching 20*, 1, 45–73.

ERNEST, P. 1998. *Social Constructivism as a Philosophy of Mathematics*. State University of New York Press.

VON GLASERSFELD, E. 1995. *Radical Constructivism. A Way of Knowing and Learning*. RoutledgeFalmer.

VON GLASERSFELD, E. 2001. *Radical Constructivism and Teaching*. http://www.umass.edu/srri/vonGlasersfeld/onlinePapers/html/geneva/.

HUNKINS, D. R., AND LEVINE, D. B. 2001. Rich Resources for Computer Graphics Educators. In *Proceedings of SIGGRAPH 2001 Conference Abstracts and Applications*, ACM Press / ACM SIGGRAPH, 45–48.

JONASSEN, D. H., AND ROHRER-MURPHY, L. 1999. Activity Theory as a Framework for Designing Constructivist Learning Environments, *Edcuational Technology Research and Development* 47, 1, 61–79.

KARLGREN, K. 2001. Talk Tracks – Learning from Practitioners Deliberating on their Problems. In *Proceedings of Euro-CSCL 2001*, Maastricht McLuhan Institute, 340–347.

KAUFMANN, H., AND SCHMALSTIEG, D. 2002. Mathematics And Geometry Education With Collaborative Augmented Reality. In *Proceedings of SIGGRAPH 2002 Conference Abstracts and Applications*, ACM Press / ACM SIGGRAPH, 37–41.

KUKLA, A. 2000. *Social Constructivism and the Philosophy of Science*. Routledge.

LAVE, J., AND WENGER, E. 1991. *Situated learning. Legitimate peripheral participation*. Cambridge University Press.

OSBERG, K. M. 1997. *Constructivism in practice: the case for meaning-making in the virtual world*. PhD thesis, University of Washington.

PAPERT, S. 1980. *Mindstorms: Children, computers and powerful ideas*. Basic Books.

ROGOFF, B. 1990. *Apprenticeship in Thinking*. Oxford University Press.

SPALTER, A. M., STONE, P. A., MEIER, B. J., MILLER, T. S., AND SIMPSON, R. M. 2000. Interaction in an IVR Museum of Color. In *Proceedings of SIGGRAPH 2000 Conference Abstracts and Applications*, ACM Press / ACM SIGGRAPH, 41–44.

STOLL DALTON, S., AND THARP, R. G. 2002. Standards for Pedagogy: Research, Theory and Practice. In Wells, G., and Claxton, G. Eds. *Learning for life in the 21st century: sociocultural perspectives on the future of education*. Blackwell.

TAXÉN, G., AND NAEVE, A. 2002. *A system for exploring open issues in VR-based education*, Computers and Graphics 26, 593–598.

TWOMEY FOSNOT, C. ED. 1996. *Constructivism. Theory, Perspectives, and Practice*. Teachers College Press.

VYGOTSKY, L. S. 1978. *Mind in Society*. Harvard University Press.

WITTGENSTEIN, L. 1958. *Philosophical Investigations*. Blackwell.