Engineering Design Graphics Instruction Through a Lens of Cultural-Historical Learning Theory

Dr. Theodore J. Branoff, Illinois State University

Dr. Branoff is a professor and chair of the Department of Technology at Illinois State University. He taught engineering graphics, computer-aided design, descriptive geometry, and instructional design courses in the College of Education at North Carolina State University from 1986-2014. He also worked for Siemens-Switchgear Division and for Measurement Group, Inc. Dr. Branoff’s research interests include constraint-based solid modeling strategies and spatial visualization abilities in undergraduate students. He has conducted CAD and Geometric Dimensioning and Tolerancing workshops for both industry and education professionals. Dr. Branoff served as President of the International Society for Geometry and Graphics from 2009-2012. In 2013 he was elected into the Academy of Fellows of the American Society for Engineering Education, and in 2014 he received the Distinguished Service Award from the Engineering Design Graphics Division of ASEE.

Dr. Kevin L Devine, Illinois State University

Kevin is the Program Coordinator for the Engineering Technology major at Illinois State University. His primary teaching assignments are in engineering graphics, industrial robotics, and CNC programming/machining.
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Abstract

Expert engineering design graphics educators have mastered a complex network of symbols and cognitive tools. Their expertise has been developed by gaining rich experience working with communities of educators, industry professionals, and students. Examining specific learning examples through a lens of cultural-historical learning theory provides a method of understanding the “ways of knowing” within this field. The specific signs and symbols of engineering design graphics are considered psychological tools which are used in daily activities to direct the mind and change the process of thinking. Experienced educators know the appropriate times to introduce these signs and symbols when students would not spontaneously discover them on their own. They help students learn the languages of graphics by recognizing emerging abilities and using questioning strategies and other techniques to move a student from their actual development to their potential development. This scaffolding technique is recommended within collaborative, culturally meaningful, problem-solving environments. This paper will outline the signs and tools prevalent in engineering design graphics, explain engineering design graphics instruction within the context of cultural-historical learning theory, and describe specific learning examples within this theory.

Introduction / Review of Literature

The process engineering graphics educators use to design instruction, select course materials, and execute an educational plan is influenced by many factors. Some educators instruct primarily using methods that they experienced as students. They use instructional strategies that have successfully produced results over time. Others are reflective practitioners and ponder the theory that motivates their classroom instruction. The learning theory they embrace informs the types of instructional strategies they use in the classroom¹.

During the early 1900s, the study of learning theory became prevalent after formal schooling had been developed. Popular theories include operant conditioning – Skinner; information processing theories – Anderson, Paivio, etc.; metacognition; cognitive-development theory – Piaget; cultural-historical theory – Vygotsky; and social-cognitive theory – Bandura⁵. This paper will focus on how Vygotsky’s cultural-historical learning theory can be used to explain the ways of knowing within engineering graphics education.

Vygotsky was mainly concerned with how human development was influenced by political and social systems¹. He believed that an individual’s behavior is the result of two different processes of mental development: the biological evolution of the human species and the process of the development of humans as the result of the use of signs and symbols to change their mental functions⁵. For him, studying the way cultures use language (signs and symbols) was a primary source for understanding human development within a culture¹.
Signs and Tools

According to Vygotsky, the signs and symbols of language are considered to be psychological tools. These tools are used in daily activities to direct the mind and change the process of thinking. Educators are responsible for introducing students to the signs and symbols within a subject where students would not discover these psychological tools on their own. Experts, within the context of this theory, have mastered the signs and symbols of their culture. For engineering and technical graphics, experts may have mastered several languages (e.g., orthographic projection, the semantics of a computer-aided design program, geometric dimensioning and tolerancing, etc. – Figure 1). Educators are responsible for helping students learn the languages of graphics within a collaborative environment where the students can see how this language fits within the larger context of an industry or enterprise.

Figure 1. Signs and Tools within Engineering Graphics.

Cultural-Historical Theory and Engineering Graphics

Engeström developed an activity theory based on Vygotsky’s cultural-historical theory to explain how learning takes place within a system (Figure 2). This model illustrates how individuals derive sense and meaning within a system that is influenced by language (tools and signs), the rules of the system, the community, the division of labor, the objective or subject, and even by the individual. Although operant conditioning refers to behaviors based only on a stimulus-response system, Vygotsky embraced a more complex system where an individual’s response to a stimulus is influenced by many other factors.

Figure 2. Engeström’s Model for Cultural-Historical Theory.
Figure 3 shows a modification of Engeström’s model specifically for engineering graphics. The signs and tools within this system are the mediating artifacts or visuals we use in the classroom (orthographic projection, dimensioning, etc.). Rules are the standards and conventional practices that are part of the engineering graphics culture. These rules are influenced by the many individuals who are part of the culture and are formed by multiple viewpoints, traditions, and interests. The community is made up of other students, faculty, and industry professionals. The division of labor or effort is typically created as the result of the activity. These are the roles that individuals assume during the activity.

Over time this system may change. We see that with the modifications that occur with standards (e.g., ASME, BSI, DIN, etc.), conventional practices, importance of content by professional societies (e.g., EDGD, ATMAE, etc.), and methods for designing and producing products (e.g., constraint-based CAD, designs without drawings, etc.). The community of professionals modifies the system based on their needs and industry practices. On a smaller scale, educators are responsible for selecting the content that is critical in the classroom. They preserve the most important content and eliminate topics which are not essential. Vygotsky called this orientation, where students are kept focused on the key elements of the instructional experience.

**Key Instructional Ideas**

There are a few key ideas within cultural-historical theory that are critical for instruction. The first is that instruction should occur where the student collaborates with an expert or more knowledgeable other within the cultural context of the content. For engineering graphics this could be a design or engineering environment using problem-based learning. The teacher is the expert in formal learning settings and is responsible for modeling the desired behavior, explaining important ideas, and probing the student for explanations. The teacher’s role is to help the student develop the ability to monitor their own self-questioning strategies. This is done by monitoring the student’s actions but also by predicting what is going on within the student’s thinking.
Another key idea within cultural-historical theory involves human development. Human development within this theory has two levels – *actual development* and *potential development*. Actual development is the work a student can complete on his or her own. Potential development is the work a student can complete with the help of an expert or more knowledgeable other. The difference between what the student can accomplish individually and with assistance is called the *zone of proximal development* (ZPD). Within the ZPD the expert instructor recognizes emerging abilities and uses questioning strategies and other techniques to move a student from one level to the next. This instructional technique is known as scaffolding and is recommended within collaborative, culturally meaningful, problem-solving environments\(^5\). Figure 4 illustrates the instructor, or more knowledgeable other, providing scaffolding within the ZPD to help students from the level of actual development to the level of potential development.

![Figure 4. The Zone of Proximal Development.](image)

A third key idea for instruction within cultural-historical theory is that the signs and symbols used to communicate are also the mechanisms for developing thinking. Children develop verbal thinking by using word meaning and speech\(^5\). As one learns more words and verbalizes them, their verbal thinking changes. This is also true for other symbol systems such as mathematics, or in the case of this paper, engineering graphics symbol systems. Complex mental functions develop when these symbol systems are internalized and are made part of the thinking system. If the goal of instruction is just to impart or transmit knowledge, these complex mental functions will not develop and students will not be able to think and speak the language\(^8\).

**Learning Examples within Engineering Graphics**

How does engineering graphics instruction look within cultural-historical theory? What follows are three examples that describe a range of instruction in engineering graphics. The first example describes how one might approach a constraint-based solid modeling exercise in an introductory engineering graphics course. The second describes a real scenario where the instructor walked students through a visualization sketching exercise. The third learning example describes how one might approach a larger unit on dimensional tolerancing using the scaffolding technique. Each example addresses how one might explain learning within the context of cultural-historical theory.
Learning Example 1
In this example students enrolled in an introductory engineering graphics course are taught basic solid modeling skills. The students in the course have no prior experience with solid modeling, and the expectation is that they will be able to create solid models of relatively simple parts by the end of the course. To help students improve their modeling skills, the instructor uses a variety of scaffolding techniques designed to help them progress through the ZPD.

Instruction and demonstrations early in the semester include explicit step-by-step instructions to introduce the students to the basic software tools and modeling techniques commonly used to model parts. Modeling strategies for specific parts are provided to students at this point (Figure 5), and probing questions are asked to help students develop their metacognitive skills. Gradually the learning scaffolds are removed throughout the course. For example, after an initial modeling exercise has been completed, the instructor may facilitate a group discussion regarding possible strategies to model a part. Explicit clicks-and-picks are not provided at this stage of instruction and the instructor helps the class evaluate the various modeling strategies that may be appropriate to model assigned parts. At the end of the course, all scaffolds are removed, and students are given projects to complete without any (or minimal) instructor assistance.

Figure 5. Sample Part with Instructional Scaffold.
**Learning Example 2**

In this example students were given top and front views of an object and asked to create the side view and pictorial (Figure 6). An instructor who embraces cultural-historical learning theory would fully orient students to the problem by explaining that the given views are not the best views to describe the object and that this particular problem has multiple solutions. The instructor had a clear understanding of the students’ spatial abilities and their abilities in engineering graphics (actual development). As the students sketched on the white board, the instructor observed their sketching and their conversations. The instructor used questioning strategies to probe students on their thinking and anticipated what they might produce next. With the instructor’s help, students were able to complete the problem (potential development).

![Figure 6. Visualization Exercise.](image)

**Learning Example 3**

In this example the students already have a general understanding of solid modeling and manufacturing processes and are being introduced to dimensional tolerance concepts, terminology, industry conventions and applications. Much of the work in this 4-day unit of instruction is completed in small groups with the instructor making use of explicit scaffolds early in the unit, which are gradually withdrawn as the unit progresses. The goal of this exercise is to provide students with the skills required to interpret basic tolerance notations found on simple part prints (Figure 7).
Much of the instruction in this unit involves group discussions and students working with partners. The unit begins with a guided note taking activity where students are given a topical outline that contains fill-in-the-blank sections. This activity is designed to introduce overarching dimensional tolerance concepts, terminology and symbols. Students are then introduced to assembly fits concepts and conventions and common tolerance notations on sample part prints. On two occasions students work in small groups to measure physical parts in order to relate the tolerance specifications supplied on a simple part print to a physical work piece. Figure 8 provides an overview of this unit and illustrates the notion that the instructor uses scaffolding and probing questioning strategies to guide the students through the ZPD.

**Conclusion**

The way in which students master the signs and symbols of their chosen field is a complex process. Examining this process through the lens of cultural-historical learning theory provides a method of understanding the *ways of knowing* within engineering graphics.
So what does this mean for developing instruction for engineering graphics? First, instructors need to assess students to determine their current level of understanding. Once the ability is assessed and the instructor knows the activities that the student can partially complete, instructional activities should be carefully planned to move students from their actual development to their potential development using the scaffolding process. In the case of complex mental functions, activities should be created where students are using the signs and symbols of the engineering graphics language to think and speak. Designing rich instructional environments where students can practice and apply this language can change the way students think of school. Instead of classroom exercises being thought of as academic busy work, well thought out activities immersed within the appropriate engineering context can increase students’ abilities to use the signs and symbols of engineering graphics to communicate with industry experts.

Bibliography