Learning Theories: Applications for Instruction in Constraint-Based Solid Modeling and Other Engineering Graphics Topics

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Abstract

Constraint-based modeling tools, as well as computer graphics tools in general, offer the user many choices in commands and techniques for creating graphics, which forces the user to have a strategy or plan as they proceed. The formulation of this plan is often dependent on the integration of existing knowledge and current factors, such as customer specifications and the time element assigned to the particular project. In addition, the user must have a thorough understanding of the software functionality and the ability to gather information related to implementing a particular modeling strategy. This process of strategy development and implementation coincides with components of learning theory. As engineering graphics educators, it is helpful to reflect on how students learn in our classrooms and laboratories as well as reflect on how we develop instruction. This paper outlines three theories of learning that are applicable to graphics education, discusses the assumptions about the learner and the learning environment, presents the components of learning for each theory, discusses major issues related to complex learning and designing instruction, and summarizes some of the criticisms and contributions to education of each theory. Indeed, a process is presented for applying elements of these learning theories to constraint-based modeling.

Introduction

Throughout the development of human civilization, people have learned about specific topics and how to do certain things, often without thinking about the process through which they have accomplished such things. Teaching was often done by parents or "masters" with little consideration given to a framework for this instructional experience. Whether or not they recognized their own particular allegiance to a learning theory, teachers were likely teaching as they had been taught themselves. These educational experiences often focused on practical issues relevant to daily life, but when educational settings became more structured in the form of schools, students were often not able to see the relevance of the topic they were learning. Since that time, teachers have been aware that these formalized educational settings often lack efficiency and effectiveness, some of which can be attributed to the lack of a sound theoretical basis for learning and instruction (Bigge & Shermis, 1999).

Any particular learning theory has with it an implied set of classroom practices for the design of instruction and the assessment of learning. The manner in which educators select learning materials and design classroom experiences for their students is dependent in large part on how they define "learning" (Bigge & Shermis, 1999). However, it should be noted that there are differences between several terms which are central to this discussion, namely philosophy, learning theory, and instructional strategy, and that the focus of this paper deals predominantly with learning theories and their applications to engineering design graphics instructional strategies.

While learning theories and philosophies involve making assumptions and hypotheses about the way things are, learning theories attempt to explain *how* people learn, whereas a specific philosophy is concerned with a value system of a particular group. A major tenet of engineering design graphics philosophy is the communication of information within a given environment, which can be difficult to assess due to the subjective and specific nature of most environments in which this occurs. A learning theory is intended to be empirically tested through scientific investigation, but it is different from an instructional strategy, because an instructional strategy is often the combination of the framework imposed by a philosophy and the stages of the learning process described by the theory. An instructional strategy describes what actually takes place during classroom delivery, although it is influenced by the learning theory to which the instructor subscribes. Examples might include cooperative learning, direct instruction or lecturing, advanced organizers, or project-based learning. In addition, instructional strategies may not be applicable to all learning environments. They are dependent on subject area, grade level, age, and classroom setting, while learning theories are independent of these variables (Gredler, 2001). A learning theory is "a systematic integrated outlook in regard to the nature of the process whereby people relate to their environments in such a way as to enhance their ability to use both themselves and their environments in a most effective way" (Bigge & Shermis, 1999, p. 3).

Several authors have expounded on the necessity of curriculum reform (Branoff, Hartman & Wiebe, 2002), assessment and evaluation (Baxter, 2002; Wiebe, Branoff & Hartman, 2002), and the similarities of contemporary engineering graphics tools (Wiebe, 1999), but the focus here is the relationship between the aforementioned learning theories and engineering graphics instruction, particularly the emphasis on engineering design graphics as a communication medium, the study and use of visualization techniques, and techniques for developing modeling strategies using constraint-based CAD tools. While there are many learning theories from which to choose, such as operant conditioning, cognitive-developmental, Gestalt psychology, Gagne's conditions of learning, and attribution theory, Table 1 includes three other common learning theories and their general elements, which will be described in further detail.

Cultural-Historical Theory

Most key ideas within cultural-historical learning theory have been attributed to Lev Vygotsky. His writings are evidence that he was deeply concerned about the relationship between the social experiences of children and how they learn (Gredler, 2001). Cultural-historical theory is concerned about how one's individual developmental history interacts with political and social relations. These interactions with social environments influence both how we think as well as the development of our language. As one develops more complex cognitive structures, one is able to express thoughts as cognitive wholes. As one moves toward mastery, higher order structures are created and replace previous structures. These higher order structures allow individuals to see the bigger picture within an area of expertise (Bigge & Shermis, 1999).

Cultural-historical theory makes several assumptions. First, human behavior is different from animal behavior. Humans progress beyond their biological heritage. They are able to shape their environment rather than just react to it. Second, work is seen as a social activity rather than a natural activity. "Work provides the means through which humans perceive the world as independent objects and acting subjects." "…human labor transforms both nature and human experience. The discovery of fire, the invention of simple agricultural tools, and the discovery of electricity are examples" (Gredler, 2001, pp. 278-279). A final assumption has to do with the relationship between psychological tools and technical tools. Psychological tools are the signs and symbols we use in our daily activities. Technical tools change external situations, "but psychological tools direct the mind and change the process of thinking" (Gredler, 2001, p. 279).

There are several components of learning within cultural-historical theory. The first has to do with cognitive development. According to this theory, *learning is cognitive development*. Cognitive development involves creating complex mental structures that make use of external stimuli and stimuli that is created internally by the individual. Another component of learning involves the mastery of signs and symbols. Individuals who are considered experts have learned to master the signs and symbols in their particular culture or area of expertise, and they have been able to use these signs and symbols to gain mastery over their own behavior. Once they have gained mastery in an area, several outcomes related to complex

Learning Theory	Key ideas about learning, motivation, etc. Components of Learning	Designing instruction for complex learning	Contributions to Classroom Practice
Cultural-Historical Theory of Psychological Development	Learning is cognitive development-the development of complex mental functions that make use of both given stimuli and created stimuli. Internalization actions that first appear on an interpsychological plane; the mastery of signs and symbols of one's own culture and learning to use them to master one's own behavior. Outcomes of learning include complex mental functions such as self-regulated attention, categorical perception, conceptual thinking, and logical memory.	Designing instruction for complex learning involves the development of conscious awareness of and mastery of one's thinking through teaching concepts, and the use of writing for thinking.	Recognition of the psychological contribution of created stimuli in cognitive development; the importance of social interaction and the social nature of learning.
Social-Cognitive Learning Theory	Learning occurs when verbal and visual codes are established. They may or may not be performed later. Modeled behaviors, consequences to the model, and the learner's cognitive processes.	In addition to component skills, develop the learner's sense of self-efficacy and self-regulation.	Description of a variety of attitudes and behaviors acquired from the mass media; provides a detailed description of the mechanisms of reinforcement and punishment in group settings; identifies the importance of self-efficacy in learning.
Information-Processing Theories	Learning is the process by which information is gathered from the environment and transformed into cognitive structures. Learning outcomes are the formation of some type of cognitive structure such as semantic networks. The components of learning involve the processes of perception, encoding, and storage in long-term memory.	Metacognition: defining a task, setting goals and planning, enacting tactics and strategies, adapting. Differences between experts and novices. Problem-solving: Representing the problem, planning, overcoming obstacles, executing plans.	Important contribution has been designing instruction for the cognitive processes in learning; learning "how-to-learn" skills. Differences between younger and older learners and experts and novices.

Table 1

mental functions are typically evident. These outcomes might include self-regulated attention, categorical perception, conceptual thinking, and/or logical memory (Gredler, 2001).

There are several ideas relative to designing instruction for complex learning that can be applied to engineering graphics education. The first has to do with the role of subject-matter concepts. According to Vygotsky, learning a definition does not allow a student to complete a complex task. Students must learn a concept within a particular context. When the student has mastered the concept, "he or she can define it easily, implement it in various logical operations, and identify relationships between it and other concepts" (Gredler, 2001, p. 302). Another key idea in cultural-historical learning theory is collaboration in the classroom. Collaboration is used quite often in educational settings, and it takes on many meanings. Within this theory of learning, collaboration refers to the interaction between the teacher and an individual student. This interaction includes teacher activities such as modeling, explaining, and probing the student for explanations. The teacher's role is to help develop the student's ability to monitor their own self-questioning strategies when they study and review materials. Probably one of the most recognized ideas within cultural-historical theory is that of the *zone of proximal development*. Vygotsky described human development by two levels; actual or completed development and potential development. A student's actual development is the work that he or she can complete independently. Potential development refers to work that can be completed with help. At this level abilities are just beginning to emerge, and a skilled instructor can recognize these emerging abilities (Gredler, 2001). The zone of proximal development is the difference between what the student can accomplish individually and with assistance. Using questioning strategies and other techniques, the instructor can take a student from one level to the next. Also known as scaffolding, this movement from one level to the next is recommended within culturally meaningful, problem-solving oriented, collaborative environments.

How can this learning be applied in an engineering graphics setting? Since those who embrace cultural-historical learning theory believe that the mastery of signs and symbols (language) within a culture or area of expertise is a critical component of learning, engineering graphics educators should create environments that foster that type of learning. Students should be put in a setting that is as close to a working environment as possible. This may involve some type of internship or it may consist of a classroom environment that is set up like an enterprise. It is important for students to master the language of graphics within this type of context so that they will be able to develop higher order cognitive structures. In context, these structures help students see how the graphics they create fit into the bigger picture of an enterprise (e.g., the downstream use of their graphics). Also critical within cultural-historical theory is the role of the instructor. The instructor must collaborate with each student and know their individual strengths and weaknesses. This is important because within cultural-historical theory the instructor must recognize what each student can accomplish on their own and what each can accomplish with some help. Through questioning strategies, the instructor can move a student from one level of cognitive development to another.

Social-Cognitive Theory

Albert Bandura's social-cognitive learning theory borrows ideas from both cognitive and behavioral learning theories (Theory Into Practice). The main premise of the theory is that learning complex skills and abilities takes place when an individual observes the modeled behaviors of relevant peers and the behavioral consequences of their actions (Gredler, 2001). Social-cognitive theory seeks to explain learning and human behavior by examining the interaction between a person's cognitive processes, behavior, and environment (Theory Into Practice).

Many of the assumptions in social-cognitive theory focus on the weaknesses in previous types of theories. Bandura's research focused on children's imitative behaviors and how earlier theories emphasis on the relationship between the young child and adults were inefficient. Also lacking in previous theories is the role of personal decision making on the part of the learner, especially when looking at prosocial and antisocial behaviors. Many behaviorist theories cannot explain complex learning by the simple interaction between the environment and the individual. Finally, Bandura assumed that performance was not necessary to indicate that learning had occurred. "Individuals acquire internal codes of behavior that may or may not be performed later" (Gredler, 2001, p. 317). He believes that learning and performance are separate events where learning involves acquiring symbolic representations that serve as guidelines for future behavior (Gredler, 2001).

The main components of learning in social-cognitive behavior are "(1) the behavioral model, (2) the consequences of the modeled behaviors, (3) the learner's internal processes, and (4) perceived self-efficacy" (Gredler, 2001, p. 318). The behavioral model serves three purposes: to pass key information on to the observer or learner; to increase or decrease the likelihood of particular behaviors; and to demonstrate new patterns of behavior. The consequences of modeled behaviors include vicarious consequences (related to the observed behaviors of others) and self-imposed consequences (self-reinforcement such as self-prescribed standards of behavior or reinforcing events under the control of the individual). Playing a key role in social-cognitive theory are the cognitive processes of the learner. These processes include attentional processes (attention to and accurate perception of behaviors), retentional processes (symbolic coding of perceived behaviors and their storage), motor reproduction processes (selection and organization of responses), and motivational processes. The final component of learning in social-cognitive theory is the role that self-efficacy plays in motivating the learner. Self-efficacy has to do with "personal beliefs about one's capabilities to be successful in tasks with novel or ambiguous elements" (Gredler, 2001, p. 315). Self-efficacy is developed and matures through "mastery experiences, vicarious experiences, social persuasion, and physiological and emotional states" (Gredler, 2001, p. 327).

When designing instruction for complex learning, instructors are encouraged to focus on the learner's self-regulatory system. Learners who are able to perform complex tasks in a subject area not only exhibit strategy knowledge and metacognitive knowledge, they also are able to set goals for themselves, accurately monitor their learning, and select appropriate strategies for learning. The learner's self-efficacy is critical since it determines how realistic their goals are for learning. The instructor's role in social-cognitive theory is to identify appropriate models for students in the classroom, establish the functional value of behavior, and guide the learner's internal processes. In most classrooms settings the instructor tends to serve as the model for the behavior, however, graduate students or upper level undergraduate students might also serve as relevant models. Instructors can take advantage of students' expertise by designing classroom environments where students may model the desired behaviors. When establishing the functional value of behavior, instructors should focus on positive outcomes. Students should be shown the usefulness of new learning as well as the usefulness and timeliness of learning strategies. Like cultural-historical theory, engineering graphics instructors should emphasize how new learning fits within the bigger context of an engineering enterprise. Guiding the learner's internal processes includes designing instruction where students have the opportunity "(1) to code the observed behavior into visual images or word symbols and (2) to mentally rehearse the modeled behaviors" (Gredler, 2001, p. 338). When modeled behavior is coded into words, labels, or images, retention is likely to be better than simply observing the modeled behavior. Engineering graphics educators who embrace social-cognitive theory would likely encourage students to keep some type of sketchbook where notes as well as sketches would be kept. Students would be encouraged to represent new material in as many ways as possible (e.g., notes, sketches, computer models, etc.). Finally, learners are also more likely to adopt particular modeled behaviors if the person modeling the behavior has admired status, the behavior has functional value, and it results in outcomes they value (Theory Into Practice). For engineering graphics students, this might involve showing freshmen and sophomores the type of graphics upper level undergraduates, graduate students, and local companies are producing.

Information Processing Theory

Information processing theory is the backbone of the cognitive perspective of learning, and it is essentially concerned with the way individuals obtain, code and remember information (Gredler, 2001). Developed as a result of the study of computing systems and artificial intelligence systems

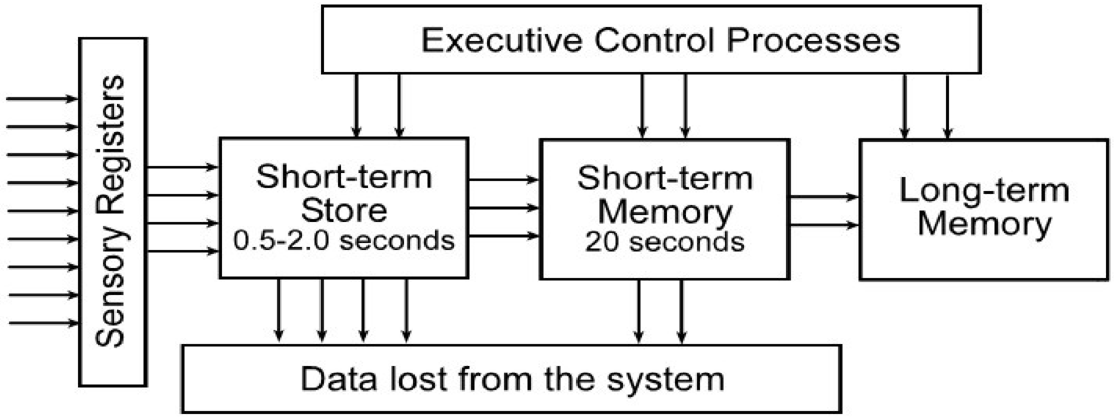

Figure 1. Information Processing Model

in the 1960s and 1970s (Anderson, 1990), information processing theory addresses the sequence of mental operations and the information obtained while performing a cognitive task. Information processing theory makes two basic assumptions: the human memory system actively organizes and processes information, and prior knowledge is instrumental in the learning process (Gredler, 2001). In addition, certain assumptions are made regarding the representation and organization of knowledge in long term memory.

Human memory actively selects the stimuli that it will process and retain, and the predominant approach for characterizing the function of the human memory system is the multistage approach (Broadbent, 1958; Craik & Lockhart, 1972) (see Figure 1). It considers memory to be a series of stages through which stimuli pass. The sensory registers receive incoming stimuli, and pass it to the short-term store to begin the encoding process. Working memory further transforms the information by encoding it into a particular format, and long-term memory stores the information as assimilated knowledge to be recalled as necessary in the future. The executive control function manages and directs this entire process. While the mechanisms of human memory are important for the understanding of how information is processed, it is the storage format and subsequent organization of that information in memory that is critical in the performance of daily activities.

Representation of knowledge in long-term memory typically takes some type of symbolic form. The stored form of the information is not identical to the stimulus because signals received by the senses are not perfect representations of the physical world. The information is transformed so that it is remembered, either in a dual code approach or in a verbal-only format (Paavio, 1986). Once information has been represented as knowledge, it is then organized in a useful way for the individual (Newel & Simon, 1972). Schemata and mental models are examples of knowledge organizations based on past experiences, levels of knowledge within an area, and future expectations (Neath, 1998; Driscoll, 2000). They provide a framework to accommodate new information, serve as a guide for future activity, and help explain the process of acquiring information and organizing it according to events or knowledge from the past to be used for future problem solving scenarios. In addition, the scope and depth of a person's mental model or schema is in large part affected by their experiences within a particular knowledge domain. While there are many views as to the organization of information in the human mind, all of them have as a central tenet the idea of a "representation". By comparing new information to knowledge that is previously stored, an individual is able to make sense of a given situation.

The processing of information to create knowledge does not take place in a vacuum. Past experiences, previous knowledge, and the current learning context all affect the manner in which a person perceives, encodes, and stores information. Learning is a result of the interaction between the learning context and the person's actions during the learning process (Gredler, 2001). Since humans have a limited capacity to perceive and process incoming stimuli and information and convert that to knowledge (Wickens & Hollands, 2000), previous experience and knowledge act as a filter for coding information into a usable form. The extent of a person's existing domain knowledge will also have an effect on the manner in which incoming information is organized and processed. Effective teaching and learning strategies should focus on the efficient encoding of information by capturing and maintaining a learner's attention and an encoding process that emphasizes establishing links between existing knowledge and new information. When designing instruction to support the information processing approach to learning, activities which require the student to differentiate between relevant and irrelevant information in order to organize the topic to be learned, and to develop strategies for learning in a particular context and for monitoring learning progress, are desirable. Learning activities which require the application of previously learned knowledge or skills also follow an information processing approach (Gredler, 2001).

Engineering Design Graphics Framework

A theoretical function of engineering design graphics is to communicate product design information within the engineering environment (Bertoline & Wiebe, 2002). Engineering design graphics includes many concepts, standards, techniques, and skills that are taught as an accepted body of knowledge (Duff, 1990; Hartman, 2003), including the use of relevant traditional and electronic tools. Its intent is to define the geometry and specifications of a given object and document that information to aid in the creation of that object. In doing so, a great deal of tacit knowledge and domain knowledge concerning engineering fundamentals and the design and manufacture of products are embedded in these documents (Bertoline & Wiebe, 2002; Branoff, Wiebe & Hartman, 2003), regardless of whether they take an electronic or paper form. Other engineers and designers that interact with these documents are able to interpret them based on their past experiences and knowledge within an engineering design environment. To practice these various concepts, standards, skills, and techniques, engineering graphics students are often asked to create 3D models or technical drawings of objects within a classroom environment. While this possibly gives a view of the overall process of documenting the design and production of an object, it does not necessarily emphasize the strategic approach to the use of certain tools, particularly three-dimensional modeling tools in general and constraint-based CAD tools specifically.

Another theoretical tenet of engineering design graphics is the enhancement of spatial visualization ability (Miller & Bertoline, 1991). A person's ability to spatially manipulate an object and its inherent orientation is beneficial when creating engineering documentation, especially 3D solid models. To develop this ability in students, educators require students to sketch objects from different vantage points, create multiview sketches of a given pictorial representation, create a pictorial sketch of a given multiview representation, and create 3D models of various objects (Branoff, Wiebe & Hartman, 2003). While these approaches have been used traditionally, they often lack the context necessary for complete definition and documentation of an object's geometric form. They are also often difficult for students to understand, especially for those students who do not have well-developed visualization abilities to begin with. Finally, they do not readily lend themselves to a strategic problem-solving approach necessary for the creation of a 3D model with a constraint-based CAD tool (Branoff, Wiebe & Hartman, 2003). The following section describes the details of a model dissection process to be used as an instructional strategy, and how it relates to the previously discussed learning theories. To address the aforementioned issues, a new instructional strategy is being suggested for the creation of 3D models with a constraint-based CAD tool which encompasses the communicative and documentary nature of the engineering graphics process as well as the visualization skills necessary to construct features as required by most constraint-based CAD tools on the market today (Wiebe, 1999; Branoff, Wiebe & Hartman, 2003).

The Modeling Procedure and Its Relationship to Learning Theory

When asking our students to model an object, we typically have multiple goals for this activity: visualization, experience with using a CAD tool, and understanding of geometry to name a few. However, it is also important for students to develop a strategy for modeling an object. Strategy development is an important component

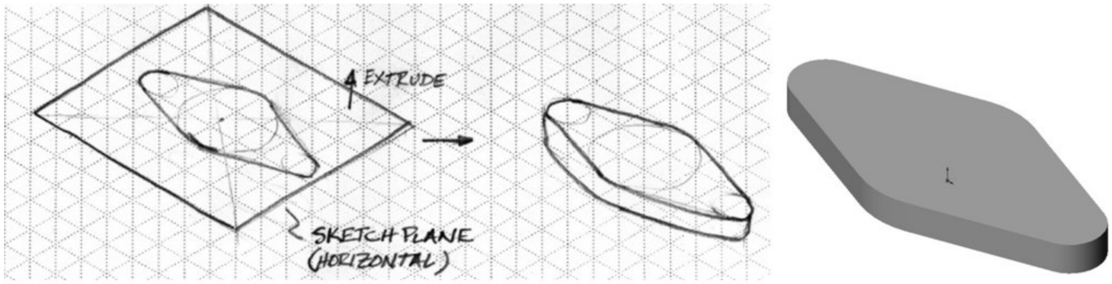

Figure 2. Step 1 of Modeling Procedure and Accompanying Solid Geometry

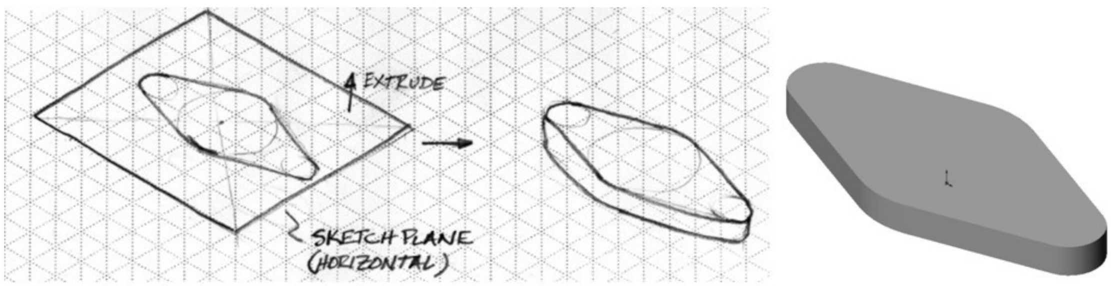

Figure 3. Step 2 of Modeling Procedure and Accompanying Solid Geometry

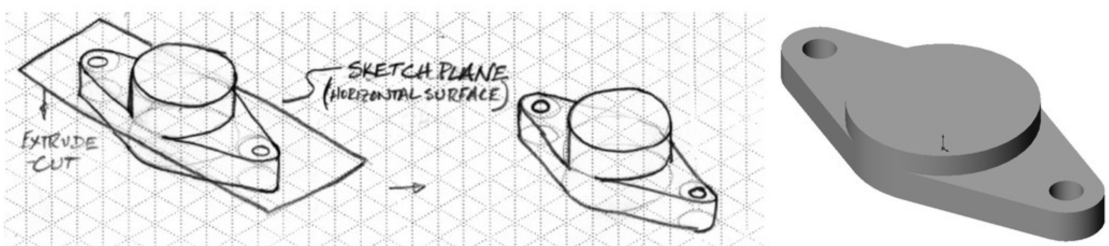

Figure 4. Step 3 of Modeling Procedure and Accompanying Solid Geometry

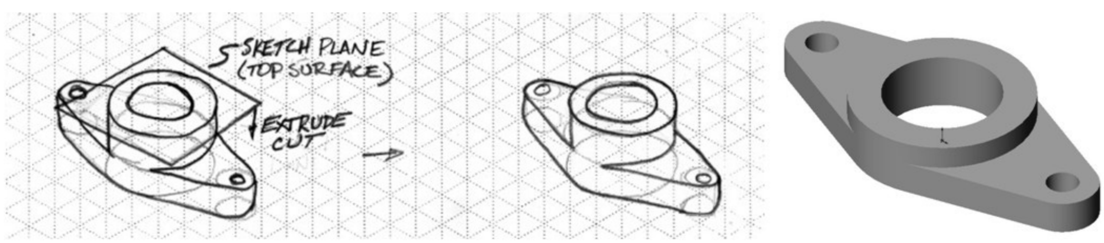

Figure 5. Step 4 of Modeling Procedure and Accompanying Solid Geometry

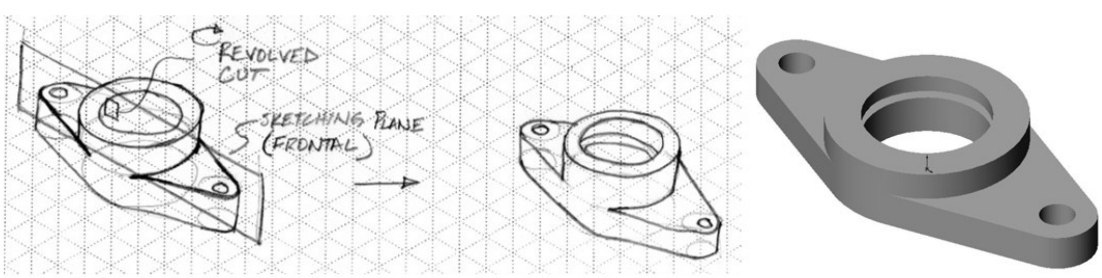

Figure 6. Step 5 of Modeling Procedure and Accompanying Solid Geometry

of information processing as well as social-cognitive learning theory. 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 CAD tool. Students must practice open-ended modeling projects to understand the inner-workings and the potential options available to them while using the tools of their profession. This type of modeling procedure also stresses the traditional value of being able to sketch quickly and accurately to convey an idea. Figures 2 through 6 depict the modeling procedure that a student might sketch while planning to model a given object and the corresponding CAD geometry which would follow such a process. It is imperative that the modeling procedure precede the CAD model so that students develop useful strategy and planning mechanisms.

This suggested modeling procedure requires the student to mentally dissect the given object (or a yet-to-be-created object) to determine its component geometric elements, and it requires them to base their decisions on what they know about geometric relationships and how those relationships force 3D features to behave. Within the context of information processing theory, this procedure allows students to construct schemata or mental models – assimilating new information to existing knowledge in a meaningful fashion (Gredler, 2001; Johnson-Laird, 1983). The "modeling breakdown" approach also exercises a student's visualization skills by asking them to sketch profiles of features, specify a known feature form, and to sketch the resulting solid geometry. Again, the modeling procedure fits well within information processing theory in that it is procedural in nature, and thereby ties declarative (factual) knowledge about geometry to the process used by tools to create it (Gredler, 2001; Hartman, 2003). Also, the sheer act of just breaking an object down into its component elemental features stretches the visual and problem solving abilities of students when the object is reasonably complex, with the latter being one of the characteristics of developing expertise (a result of the implementation of information processing theory as well as social-cognitive theory) within an individual – the ability to develop a self-monitoring problem solving strategy (Chi, Glaser & Farr, 1988). Having a modeling strategy is extremely important for the creation of a model that can be used for other purposes within the engineering design process (Branoff, Wiebe & Hartman, 2003), and this exercise forces the student to develop a strategy to account for the factors that may impact that design process. It also forces students to account for knowledge they already possess in the development of a feature order and the dissection of a model into its component features. These processes are particularly evident when asking students to create a 3D model to address a specific design outcome, and they are particularly relevant to the open-ended nature of using constraint-based CAD tools.

Conclusion

We all have reasons for how we teach. We may do things a certain way because it was the way we were taught. Our previous experiences definitely influence what we consider as common sense practice. When introducing students to 3D modeling activities, there are probably as many methods of instruction as there are instructors. Studying learning theories gives us a way to systematically examine what we do in the classroom and preserve the ways in which students learn best. In many cases we even find that there is a theoretical basis for what we have been doing. One of the most important arguments for being reflective and examining the reasons for how we educate is that it makes us better educators. It gives us a deeper understanding about how students learn our subject matter best, which in turn better prepares them to enter their chosen fields.

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