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Engineering and Technical Graphics Education; Using the Revised Bloom's Taxonomy

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Abstract. In 1948, a group of college and university examiners came together in Boston to develop a common framework for classifying student learning outcomes. From this meeting, came the creation of the most used assessment taxonomy in educational history — "Bloom's Taxonomy". For decades, professionals at all levels have used Bloom's Taxonomy as a way to identify and cite student learning outcomes, assessment strategies, and instructional objectives (Anderson et al., 2001). Educators in graphics education are no exception to this inclination and use of the popular taxonomy as it has been cited in many papers throughout the discipline's history. This paper will discuss the newly revised Bloom's Taxonomy (recently updated and redirected by the few remaining members of the original taxonomy team). The authors will explain and compare the newly revised Bloom's Taxonomy to the initial version and demonstrate how the revised taxonomy can be used in engineering/technical graphics education to bridge student learning, assessment, and curriculum development. Also, a comparison of current research in the field of taxonomy development and what is currently being pursued in the field of graphics education will be discussed.

Key Words: Bloom's Taxonomy, Theoretical Model, Engineering Graphics, Graphic Communication

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1. Introduction

In 1956, a framework for categorizing educational objectives entitled

The Taxonomy of Educational Objectives, The Classification of Educational Goals Handbook 1: Cognitive Domain

was published from the research of B. S. Bloom. Since that first publication, the book and taxonomy has been translated into over 20 languages and is considered one of the most

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significant writings that has influenced curriculum development and student assessment for the first three-quarters of the 20th century. This publication came from the research that was started in 1948 in Boston by college and university examiners to develop a way to classify student learning, evolving into a full taxonomy of learning used today for everything from curriculum development to assessment at the both the cognitive and performance levels [1].

The original group that met in Boston considered the taxonomy a work in progress; only one of three domains of learning (cognitive) was developed by the original group in 1956. Cognitive was developed to help professionals in education understand levels of learning by students given intellectual capabilities. As for the other two domains, effective domain dealing with categorizing student's emotions, feelings, and behaviors came into finalization in 1962. Graphic educators are most familiar with is the *psychomotor domain*. The psychomotor domain assesses students' manual and physical skills. Its framework was considered complete in 1972. Although the original materials were written in a wide-ranging manner for all educational disciplines, Bloom stated in 1971 that

> *"ideally each major field {sic discipline} should have its own taxonomy of objectives in its own language — more detailed, closer to the special language and thinking of its experts, reflecting its own appropriate sub-divisions and levels of education with possible new categories, combinations of categories and omitting categories as appropriate"* [4, 6].

This attempt to customize Bloom's taxonomy for individual disciplines of study has happened over the years but with limited success.

The profession of engineering/technical graphics has seen Bloom's taxonomy presented numerous times at conferences and referenced in many papers. The profession has spent a large percentage of time evaluating and implementing Bloom's taxonomy into what we teach to better assess content and processes we teach to students. In [8] within the Engineering Design Graphics Division of the American Society of Engineering Education began investigating and pursuing the development of taxonomy specifically designed for engineering/technical graphics. Although this is a multifaceted issue, the stage outcome was a targeted cognitive assessment used in introductory engineering design graphics. The Clark and Scales cognitive model follow-up [9] acknowledges and provides reasoning for further development of a more comprehensive taxonomy for engineering/technical graphics and an associated implementation strategy for the profession.

2. Review of Bloom's taxonomy

As previously mentioned, Bloom's taxonomy and its framework was originally created in 1956 as a way to categorize educational objectives. Bloom began the taxonomy construction after discussions with colleagues at the American Psychological Association in 1948. He found that 95 percent of student assessment items solely required the recollection of facts. After an eight year study with others interested in establishing a framework to improve testing, Bloom published the previously mentioned work, as the editor, a handbook entitled *The Taxonomy of Educational Objectives, The Classification of Educational Goals, Handbook 1: Cognitive Domain* [5]. The handbook began its influence in education worldwide with the cognitive domain as the starting and most common example of his work. Later in the 1960's and 1970's came details for both affective and psychomotor domains that led to later revisions of the original handbook [4].

Cognitive domain:

The broken-down and categorized levels of expertise for the first domain formed *six cognitive levels*.

- The first learning outcome level for students is *knowledge*. Knowledge is defined as remembering previously learned material. This includes the recall of information, learning specific facts or theories, learning procedures, basic principles, and methods. An example of this in graphics education would be learning facts and terminology used in the field concerning visual theory and standards used in engineering design graphics.
- The second level for learning outcomes in Blooms taxonomy is *comprehension*. This level is defined as the ability to grasp the meaning of material. It is considered one step higher than knowledge as it requires students to take their knowledge and be able to classify, translate, interpret, and estimate future trends. An example in terms of graphic communications would be to interpret graphics used in engineering and design areas such as working drawings.
- *Application* is the third level in Bloom's taxonomy. It is defined as the ability to use learned material in new and concrete situations (i.e. demonstrate skill). This category indicates that students at this level can apply concepts and principles gained in the previous two categories in order to utilize what they have learned in new situations. Although many educators see this level as a "hands-on" classification system, actually the term apply is to demonstrate mastery by applying what a student knows to a variety of different areas, not only skill. An example of application, as it relates to graphics education, is students demonstrating the ability to create a simple 3D model or a multiview projection in a fundamentals course.
- *Analysis* refers to the ability to deconstruct material into component parts to accurately understand its organizational structure. An example of the analysis level in graphic communications is students demonstrating knowledge of relationships in model constraining while being able to offer a viable explanation.
- In the cognitive domain, *synthesis* of knowledge is the second highest level of knowledge. Synthesis is defined as a student's ability to develop new and unique structures, systems, models, approaches, and ideas, based from previous knowledge gains. An example for graphics education is having students think creatively and critically about design or reverse engineering a problem.
- The highest level of knowledge in Bloom's taxonomy is *evaluation*. This level can be defined as a student's ability to assess effectiveness of whole concepts, in relation to values, outputs, efficacy, and viability. An example in graphic communications is students developing a series of working drawings/models and analyzing and assessing the work of peers.

The cognitive domain remains the most recognized of the three domains and is widely referenced in research pertaining to testing, evaluation, and student learning. Two other domains were developed after this initial domain of knowledge; these domains are considered equally important and play major roles in the assessment of students' knowledge gains [3].

Affective domain:

Bloom's taxonomy included the *affective domain* beginning in the 1960's. This domain includes assessment of students' attitudes, behaviors, and beliefs.

- The first level is called *receive*, where students are open to experiences and information.
- Level Two is *response*, where students can openly react and participate on discussion topics.
- Level Three in the affective domain is *value*. In this level, students identify worth in what they know, and express opinions about identified content.
- Level Four is the ability of students to *organize* a personal value system. This level allows students to qualify and quantify personal views, as well as state personal positions.
- The highest level in the affective domain is *internalization* or the characterization of values. Students at this highest level develop a personal philosophy. An example of the highest level in the affective domain is identifying items or concepts that are considered of lasting importance to a graphics problem and an associated rationale.

Psychomotor domain:

The third domain in Bloom's original taxonomy is *psychomotor*. It defines for assessment purposes how to classify skill development.

- The first level or basics for this domain is called *imitation*, or the ability to replicate what has been demonstrated. This is evident in traditional drafting programs where the teacher asks students to draw what they have demonstrated.
- *Manipulation* is next in the psychomotor level. This level is where students learn to follow directions in the completion of a given task. This is widely used when teaching CAD fundamentals and other software package basics.
- *Precision* is where students can demonstrate skill reliably, independent of instructor assistance.
- The next two levels in the psychomotor domain are articulation and naturalization. *Articulation* is where students have experiences in both knowledge and skill development and combine theses areas. This is generally identified in graphics as the internship level where students finalize their study.
- The highest level in Bloom's taxonomy for the psychomotor domain is *naturalization*. This only occurs over time when students develop expertise in the field of graphics [7].

Since the cognitive domain in the original Bloom's taxonomy remains the most referenced and known of the three domains, Table 1 shows Bloom's taxonomy as it relates to cognitive domain areas in a fundamentals of engineering/technical graphics course showing descriptive information and examples for each level.

3. Revised Bloom's taxonomy (RBT)

The idea that the original Bloom's taxonomy was "ahead of its time" may be true in the 1960s, but in today's educational climate it is very necessary. With the need to improve overall learning, professionals in education needed a more up-to-date hierarchy for assessing student learning and to better classify the objectives they have for both curricula and courses (personal communications with Lorin Anderson, December 6, 2006). Furthermore, with new accreditation requirements that emphasize better alignment between objectives, activities, and assessments, as well as requirement to raise learning targets, a new and improved taxonomy was needed to guide professionals in education in how this is systematically accomplished [12].

Table 1: Bloom's taxonomy as it relates to cognitive domain areas in the fundamentals of an engineering/technical graphics course

Level of Expertise from Bloom's Taxonomy	Description of Level as related to Engineering/Technical Graphics	Example of Measurable Student Outcome for an Introductory Class
Knowledge	Recall facts and terms about visual theory and standards used in engineering design graphics.	Asking questions directly related to the standards for dimensioning
Comprehension	Translate and interpret the way graphics is used in engineering and design areas.	Knowing how to apply constraints to different models; using descriptive geometry
Application	Apply methods to specific concrete situations related to engineering graphics.	Constructing a multiview from a model in 1^{st} & 3^{rd} angle projections.
Analysis	Separation of a complex idea into its constituent parts and understanding the relationship between each part.	Developing and constructing an assembly model from parts.
Synthesis	Being creative and can construct ideas and concepts from many different sources of data, including the ability to integrate areas and see patterns; all within constraints.	Using a real-world scenario, research and construct a full set of working drawing on a product.
Evaluation	To be able to make judgments and critique ideas and concepts, as well as form rationalizations.	Reverse engineer a product for improvement and present to a client.

What goes into a new and improved taxonomy? Many behaviorist, cognitive scientist, and constructivists in education believe that in designing new assessment practices, the framework of a taxonomy needs to include the following considerations. First, to guide both teaching and learning, the taxonomy must address issues related to the processes of student learning and define these throughout the model. Also, the assessment in a taxonomy must consider learning styles of students and the needs they have to better obtain information and skill development. Finally, any new taxonomy must have indicated appropriate forms of assessment for all levels within its structure [11].

4. Dimensions within the RBT

In 1995, a group of cognitive psychologists, curriculum theorists, and assessment professionals came together with the desire to revise the current Bloom's taxonomy. The changes made to the original taxonomy were grounded in contextual and conceptual concepts that are designed to make the taxonomy more clear as to what students were expected to know and do [3]. The original taxonomy was one-dimensional, meaning that the cognitive domain had the six knowledge levels, as indicated in Table 1, for assessment of student learning gains. This original taxonomy was conceived by the authors as a hierarchy of increasing complexity and was defined originally as "mental acts or thinking."

The newly revised Bloom's taxonomy is a two-dimensional model, and the knowledge levels are now called *cognitive process dimension* and fall within six categories. These new and

Table 2: Revised Blooms Taxonomy with Example Indicators for a Fundamental Engineering/Technical Graphics Course [10]

Knowledge Dimension from RBT	Remember	Understand	Apply	Analyze	Evaluate	Create
Factual	Recall the major categorical line types in the alphabet of lines	Classify types of lines based on their appearance and usage	Draw a line for each major line type within the alphabet of lines	Organize and determine the precedence of lines	Review existing drawings for proper line usage	Plan and generate a multiview drawing with appropriate line usage
Conceptual	Recognize principles and attributes of visual theory	Explain and compare parallel and prospective theories	Demonstrate how these theories are used in eng. graphics	Assess the use of visualization from a multidisciplinary perspective	Determine if appropriate projections were used in a drawing	Generate a full set of working drawing
Procedural	Recall relevant information associated with command subcategories	Classify commands by their operational function	Demonstrate the use of commands to create a model; apply descriptive geometry techniques	Differentiate between commands used to create a model	Critique a model, assessing the tree for relationships/ constraints	Generate a unique set of working drawings
Meta-cognitive	Recognize personal visual skill strengths and weaknesses	Interpret visual tests results to determine skill levels	Demonstrate a strategic understanding of how to incorporate visualizations	Conduct a visualization/ simulation and determine its anticipated or actual use	Evaluate the predictive success of a simulation	Research, design, and print a 3D model; present the model to peers

easy to understand categories are *remember, understand, apply, analyze, evaluate, and create.* The continuum exists, as in the original taxonomy that going from remember to apply is a more cognitively complex process, with create being the highest level of complexity (Table 2). The second dimension that is new and greatly enhances the revised taxonomy is *knowledge dimensions.* The four categories for the knowledge dimension are *factual, conceptual, procedural,* and *metacognitive.* Just like the cognitive process dimension, each category lies along a continuum from basic to more complex [4]. Given these two dimensions within the revised taxonomy, the major difference between the original and the revised Bloom's taxonomy (RBT) is that the revised taxonomy reflects a dual perspective on learning and cognition. By having two dimensions to guide the process of developing course objectives and planning and defining assessment at the beginning, it makes for a stronger link between the objectives for a course and the instructional practices [2].

5. The two dimensions

The *cognitive process dimension* within the new RBT begins with the

- category of *remember*. This category can be best defined as a cognitive process that requires students to retrieve relevant knowledge from long-term memory. Common terms used for objectives that are at this lowest level of the cognitive process dimension are identifying and retrieving information.
- The second category is *understand*. This level is where objectives are written that allow students to construct meaning from instruction that includes oral, written, and visual communications. Universal terms for this area applied in objectives for this category are summarizing, classifying, interpretation, and model construction.
- The next category is *apply*. In this category or level, students carry out or use a procedure that is usually "hands-on". Common terms seen in objectives that meet this category's cognitive process or classification are executing and implementing.
- *Analyze* is the next category in the cognitive process dimension. The ability to break down materials and concepts into parts and determine how each part is related to the overall structure or purpose is the definition for this category. Universal terms intended for this cognitive process are differentiating, organizing, and deconstruction.
- The fifth category is *evaluate*. Objectives that allow students to make overall judgments based on set criteria or standards would be placed within this category. Terms associated with this category or level are checking, critiquing, judging, and testing. Many engineering courses see this level as important.
- The sixth category for the cognitive process dimension is called *create*. The ability to put elements together and make a whole or reorganize elements to form new patterns or structures is the best definition for this category. Words like generating, planning, and producing or constructing are associated with this cognitive process. Most graphic communications courses try to attempt this by requiring a final project that encompass all that the students have learned during the semester.

As indicated earlier in this paper, most curriculum specialists see these six new categories in the RBT as the common replacements for the old knowledge domains, but remember, the RBT is two dimensional, so we must associate these cognitive processes with another dimension known as the *knowledge dimensions* [1].

- The first of four major types within the knowledge dimension is *factual knowledge*. Factual knowledge as it relates to all six of the categories within the cognitive processes dimension can best be defined as the basic elements that all students must acquire within a discipline (i.e. engineering/technical graphics). Examples found throughout all the cognitive processes categories within this knowledge dimension but not limited to just these are vocabulary, terminology, knowledge of specific details, and the understanding and use of symbols.
- The *conceptual knowledge* dimension can best be defined as the understanding of interrelationships among the basics of a discipline to the larger overall structure and explain how they function together. Examples for this knowledge dimension include understanding classification systems, theories, models, and general principles and guidelines used within a discipline.
- The third major type of knowledge dimension in the new RBT is called *procedural knowledge*. In this dimension, skills development is essential. Students need to know how to conduct inquiry and understand and apply techniques and methods using appropriate procedures. Procedural knowledge across all six cognitive processes includes

comprehension of subject-specific techniques and skills to complete an assignment, as well as following appropriate guidelines established for a given task. Many in our field of engineering/technical graphics see this knowledge dimension as the main form for which learning takes place in our classrooms.

- Finally, the last of the four knowledge dimensions is *metacognitive*. Students in this knowledge dimension are aware of their own knowledge level, including the knowledge and use of heuristics. Some cognitive psychologists see this major type as self-knowledge within the student and it is considered one of the hardest to assess [4].

Once you take the six cognitive processes dimension and apply these to the four knowledge dimensions, you now have a more detailed and complete form for which you can assess objectives and curricula. The two dimensions combine to create a matrix for learning and assessment, keeping in mind students' learning styles and needed skill development. Table 2

Table 3: Theoretical Model for Taxonomy Based on RBT

for Graphic Communications Areas with Example Indicators

Level/Course Area	Attainment	Apply	Development	Create	Experimentation
Fundamentals/ Introduction Graphic Communications	Define terminology related to graphics used in professional areas	Demonstrate proper placement of dimensions	Adhere to constraints in model construction and identify relations	Produce a model from a sketch plan and generate working drawings	Deconstruct a product and perform a simulated assembly
Descriptive Geometry	Recall rules of finding true length of a line, surface, or plane	Project from a given plane keeping the fold line parallel	Project and explain techniques on how to show true length in a plane of projection	Produce a top and front view to identify true length of a conical shape	Demonstrate how determination of true length can be incorporated to refuel a craft in flight
Animation	Define what a transformation is in the context of animation	Use commands of move, rotate and scale to apply a combination of transformations	Develop a hierarchal structure from a given file	Produce a sequence of static images to be used in succession	Try different file formats and input devices to save time and improve animation; simulation
Desktop	Recognize common software commands that are incorporated into design suites	Use color theory to assess visual impact in a tri-fold design	Complete a perforated tear away to be used in a tri-fold layout	Design and print a product information brochure	Conduct market research on desirable features of a tri-fold design and develop a product brochure
Web Design	Recall commonly used terminology used in script programming	Incorporate approaches that consider website usability and utility	Critically evaluate and edit an existing website	Produce an original website design	Develop a website that addresses anticipated user needs (e.g. users with disabilities)

shows examples of indicators for each of these cognitive processes and the major types of knowledge domain they fall within for an introductory engineering/technical graphics course.

6. Conclusions with theoretical model

As previously described, the newly revised Bloom's taxonomy is a more inclusive account, covering many needed aspects of assessment that were either not specified or not addressed with necessary depth in the original taxonomy. The revised and original taxonomy serve solely as frameworks. Bloom himself indicated that ideally each major field would use this taxonomy to develop their own unique objectives and language. Bloom went on to suggest that a discipline-specific taxonomy could offer assessment with greater details, with influences from experts in their respective fields, and break down the categories into sub-categories and levels of education with new groupings and combinations. As education continues its gradual transformation (largely based on evidenced-based research and new knowledge gains), so will the taxonomies used to assess students, necessitating programmatic change [4].

The authors of this paper conclude with a theoretical model for a taxonomy for graphic communications based on RBT and associated research conducted over the years. The cognitive processes for this graphic communications taxonomy or model are as follows: attainment, application, development, creation, and experimentation. The knowledge dimensions are content areas or types of courses graphic communications offers students. The model is theoretical, based on past experiences and observations within graphic communications, and generated with the hope that it will prompt further thought and research in how students are taught and assessed in their courses (Table 3).

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