# Bloom's Affective Domain in Systems Engineering Education

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## ABSTRACT

Bloom's taxonomy of educational objectives divides educational objectives into the cognitive, affective and psychomotor domains. Most descriptions of systems engineering education place almost total emphasis on cognitive domain content. This approach narrows the qualities to be developed to those described as topic areas which are taught about. The affective domain concerns the development of values and inclinations in the student. The student must develop a sense of importance of material and be characterized by appropriate responses to the material. The practice of systems engineering involves a combination of knowledge of certain information, techniques and methods and the ability to work in engineering organizations to deliver significantly complex systems. Systems engineering competency frameworks reflect various kinds of competence required for success. Some competencies follow from knowing about topics but others involve attitudes and approaches to work. This paper discusses the importance of the affective domain in systems engineering education.

**KEYWORDS**: Systems engineering education; Bloom's taxonomy; Affective domain.

## 1. INTRODUCTION

Education concerns the development of the student to achieve target outcomes relevant to a particular field of knowledge and practice. Education is commonly contrasted with training. In this contrast training is viewed as a method to develop procedural skills that enable performance of tasks in an effective manner. Conversely, education is viewed as a method to develop the student's ability to reason within the field and ability to perform complex, high level action involving judgments about situations.

Education in systems engineering aims to develop graduates who are able to apply a variety of system level analysis and synthesis methods in a manner which should normally yield satisfactory systemic outcomes. Systems engineering activity usually involves systems incorporating a variety of technologies, usually spanning multiple engineering disciplines with the goal of providing sound overall solutions to needs presented as the motivation for projects. To perform the systems engineering activity an individual needs a broad range of diverse competencies including both hard and soft skills and technology and management related foci. The range of competencies will be discussed in the next section.

A challenge in systems engineering education is that education is intended to develop graduates with the range of knowledge and skills required to commence practice. It is difficult to determine the particular competencies required for systems engineering, as a whole field, because there are a number of distinct roles that systems engineers take, such as distinguished by the roles of acquirer or supplier organizations [1], and the different manifestations of systems engineering in different industry domains. The challenge is that a systems engineering education program must provide graduates who are able to fulfill roles in many kinds of systems engineering activity, with individual graduate destinations depending upon opportunity which may arise after graduation.

## 2. SYSTEMS ENGINEERING COMPETENCIES

There have been a number of systems engineering competency frameworks developed by various organizations including INCOSE, NASA, Defense Acquisition University, and MITRE [2-6]. Each of these frameworks has been written to address the particular need that its place of origin. Therefore, there are variations between the competency frameworks with quite noticeable differences in the apparent emphasis placed on itemizing the topic areas about which a systems engineer should have knowledge and the relative importance of the soft skills and attributes.

Each of the competency frameworks was produced in a particular national and industry domain context. The consequence of the specifics of the origin of each competency framework have influenced the particular emphasis of that framework. The context of origin includes a predominant industry domain of interest to the authors of the competency framework and the particular roles for which the originating organization predominantly has a responsibility.

The major elements of the competency frameworks are described in [7], which provides significant detail to explain their distinguishing characteristics. For further explanation of the competency frameworks the reader is referred to either the competency frameworks themselves, as primary sources, or the earlier work of this author as a secondary source which explains this author's perspectives on the use of the competency frameworks.

## 3. BLOOM'S TAXONOMY

Bloom's taxonomy of educational outcomes [8, 9], summarized in Tables 1 and 2, was developed by a group of university educators with a view to guiding the objectives of higher education so that the education could provide a good integration of the expectations of student attainment through a program and the methods of teaching and assessment. The taxonomy was based on Behaviourist Psychology [10]. This theoretical foundation of the taxonomy is reflected in the taxonomy presenting a hierarchical view of the development of types of knowledge in both domains, the cognitive and the affective, which were developed by the original authors [10]. The hierarchical nature of Bloom's taxonomy embeds the assumption that students develop knowledge in steps related to kinds of knowledge and that the attainment of the higher levels in the learning taxonomy is dependent upon prior attainment of the lower levels.

**Table 1**. Bloom's taxonomy, cognitive domain [9].

| **Cognitive Domain** | |
|---|---|
| **Primary Class** | **Sub-class** |
| Knowledge | Knowledge of specifics |
| | Knowledge of the ways of dealing with specifics |
| | Knowledge of the universals and abstractions in a field |
| Comprehension | Translation |
| | Interpretation |
| | Extrapolation |
| Application | Application |
| Analysis | Analysis of elements |
| | Analysis of relationships |
| | Analysis of organizational principles |
| Synthesis | Production of a unique communication |
| | Production of a plan, or proposed set of operations |
| | Derivation of a set of abstract relations |
| Evaluation | Judgments in terms of internal evidence |
| | Judgments in terms of external criteria |

This assumption is now challenged through Cognitive Psychology which does not make presumptions about levels of learning in the manner assumed by Bloom *et al*. However, in engineering education in general and systems engineering education in particular the emphasis is on enabling students to develop knowledge which enables them to take appropriate action. This kind of knowledge can reasonably be modeled in the hierarchical manner that Blooms taxonomy assumes. The practice of engineering is built on the ability of the engineer to appropriately apply many pieces of knowledge about the material with which they are working and the methods of doing that work in the creation of new kinds of engineered product. As such the practice of engineering demands the ability to achieve the higher levels in blooms taxonomy, related to synthesis and evaluation, to develop things and demonstrate that the things developed are appropriate solutions to the needs which they claim to address. To be able to successfully synthesize and evaluate solutions to needs an engineer must achieve the kinds of thought, in relation to the subject matter of their engineering discipline, reflected in the lower levels of Bloom's taxonomy.

**Table 2**. Bloom's taxonomy, affective domain [8].

| Primary Class | Sub-classification |
|---|---|
| Receiving | Awareness |
| | Willingness to receive |
| | Controlled or selected attention |
| Responding | Acquiescence in responding |
| | Willingness to respond |
| | Satisfaction in response |
| Valuing | Acceptance of a value |
| | Preference for a value |
| | Commitment |
| Organization | Conceptualization of a value |
| | Organization of a value system |
| Characterization by a value complex | Generalize the d set |

It is important to remember that the levels in Bloom's taxonomy refer to kinds of thought rather than a magnitude of attainment. It is easy to mistakenly believe that levels necessarily refer to a magnitude of attainment, in the manner in which graded academic results reflect a magnitude of attainment in relation to what proportion of questions for which the student achieved correct answers. But the levels in Bloom's taxonomy refer to the learning achievement of breaking through to a new way of thinking which enables the kind of thinking which is reflected by the level in Bloom's taxonomy rather than the attainment of more learning.

It is the case for many students that as they progress upwards in the kinds of learning reflected by the levels in Bloom's taxonomy they attain the kind of existential enjoyment of performing at a higher level and so desire, and also have means to attain a higher level in topic areas which is they have not yet been taught to take to that higher level. This effect is discussed in Florman [11].

Therefore, in an educational setting it is important to enable students to experience, even in quite constrained subject matter, the attainment of the higher levels of Bloom's taxonomy in the cognitive domain. The result of enabling students to attain the higher levels is that they will develop an enthusiasm to achieve a similar level of satisfaction and learning or performance in their professional practice generally.

The original team developing Bloom's taxonomy identified the existence of three domains: the cognitive; affective and the psychomotor domains. The authors developed detail concerning the cognitive and affective domains, leaving the psychomotor domain unaddressed.

Many educators have found the challenge of Bloom's taxonomy to define desired levels of attainment in the cognitive domain and to develop appropriate methods of teaching and assessment to stimulate and verify learning at the various levels to have been a very powerful tool to increase the effectiveness of their graduates in a variety of fields. The effect of this challenge has been to improve educational thinking in fields such as engineering through causing educators to reason to justify their teaching and assessment methods in relation to the professional development which they are trying to provide to their students.

However, in engineering in general there seems to have remained a belief that curriculum concerns the topics about which one must learn, and the depth and kind of that learning. It is usually assumed that it is not the place of engineering educators to aim to impact in the affective domain. This common approach would suggest a conceptualization that although success in engineering is recognized to involve a number of well-developed personal attributes that these attributes are not themselves the proper subject material of engineering education.

In the systems engineering competency frameworks it is clear that a number of "soft skills" areas are included in what it takes to be successful. But the nature of "soft skills" is that they are not learned through a development of cognitive domain knowledge about them but rather through the affective, which if successfully developed leads to the individual being characterized by the relevant value set. Cognitive learning about a topic can generally be learned through study of ideas about the topic. Affective learning adds a need for some kind of immersion or experiential transformation to become different than before the learning experience.

In systems engineering it is necessary that a graduate be characterized by the belief that a systems method of perceiving and interacting with the subject matter of the work is necessarily a desirable or even preferred method for working on systems. The idea of being characterised by the belief that the systems method is the preferred method for addressing large questions is critical to the successful application of systems engineering. Otherwise, there is a significant risk that the so-called systems engineer would address needs by falling back to the single technology or single methodology approaches which they may have developed as part of their original engineering education.

## 4. LINKING BLOOM'S TAXONOMY TO COMPETENCY FRAMEWORKS

The author and members of the *Graduate Reference Curriculum for Systems Engineering, GRCSE*™, author team, which is part of the *Body of Knowledge and Curriculum for Advancing Systems Engineering*, *BKCASE*™, project performed a small exercise to determine appropriate Bloom levels for the attainment of a number of areas of knowledge through a Masters degree curriculum in systems engineering. With clarity concerning the concept that the levels referred to the attainment of the kind of thinking, rather than quantity, it became relatively easy to determine the kind of thinking that would be expected of graduates and thus to determine an appropriate level of attainment during the education program.

In relation to the affective domain in the education of systems engineers there are two areas of interest. The first area of interest concerns the development of so-called "soft skills" which enable an individual to make strong and effective contributions to systems engineering work. These are listed in table 3, which has been copied from [7] with the addition of a third column. The unshaded rows of table 3 are matters concerning which it is clear that development in the affective domain, involving recognition of value related issues, and the ability to integrate issues as they arise in two and a value structure which characterizes the individual engineer is clear. The shaded rows are attributes

**Table 3**. Attributes of effective SEs [6]

| Attribute name | Brief description | Origin |
|---|---|---|
| Intellectual curiosity | The systems engineer does not impose boundaries around their work, and is interested in external impacts. | Learned |
| Ability to see the big picture | Systems engineers understand their role, and know what has been done, what is needed and what remains to be done. | Learned |
| Ability to make system wide connections | A good systems engineer must understand the connections across the system. | Learned |
| Exceptional two-way communicator | The systems engineering must be able to understand and use the specialist language of many disciplines. | Learned |
| Strong team member and leader | Systems engineering particularly needs leadership rather than management, to deal with the novelty of projects. | Learned |
| Comfortable with change | The systems engineer must see change as inevitable and accept, and also be able to anticipate likely changes. | Learned |
| Comfortable with uncertainty | The systems engineer has suitable tools to deal with the uncertainty presented during projects. | Learned |
| Proper paranoia | Expect the best, but think about and plan for the worst. | Learned |
| Diverse technical skills | Must be able to make sound judgments across a range of disciplines and be able to discuss with experts. | Learned |
| Self-confidence and decisiveness | Must have a strong awareness of what they do and do not know. | Innate |
| Appreciate the value of process | A good systems engineer appreciates process but does not think that process is systems engineering. | Learned |

that build on a combination of cognitive knowledge and affective development which leads to personal commitment to the cognitive knowledge.

The additional column in table 3 notes that most of these attributes are such that there is a significant contribution to the development made through the learning experiences that a person has. For those who are successful in their career as a systems engineer the learning may happen at any time, before they commence their engineering education, during their engineering education, or in the workplace during their practice of engineering. Therefore, it is not essential for the education institution to actually teach the whole attainment of these qualities, but it is necessary for the educator to teach so that the student values, and is characterized by their valuation of these qualities, and has the ability to develop their ability at graduation, whatever it may be, to become profoundly good through experience.

Successful leadership in systems engineering requires that the engineer develop multiple kinds of “capital”, in the sense that Bourdieu uses the term, and the capital is developed through a combination of educational learning, workplace experiential learning and personal character [12]. The attributes presented in table 3 are related to the forms of capital which enable a systems engineer to become successful. A person who strongly exhibits the attributes either possesses or will develop each of the forms of capital which enable them to lead engineering work effectively.

It is less obvious how knowledge areas associated with the cognitive domain also have a significant affective dimension in order to be developed as a systems engineering competency. A distinctive characteristic of systems engineering emphasized in the introductory sections of systems engineering education is that it addresses needs from an holistic viewpoint where other areas of engineering give less emphasis to this issue. That is, in classical textbook systems engineering [13], work begins with the exploration of the need which is to be addressed, with an open mind as to how that need will be addressed and consequently what kind of system could be presented as an appropriate solution. This position is the foundation of the technical approach and methods of synthesis and analysis used by systems engineers to achieve appropriate solutions.

The techniques of systems engineering provide means for performing whole system related work with a view to ensuring successful and appropriate solutions. To this extent systems engineering can be described as a set of technical processes which can be framed in scientific language and using scientific results. However, approaching work from a genuinely systemic viewpoint, agnostic as to potentially appropriate designs until the need has been thoroughly explored is unnatural for most engineers whose education and inclination tends towards proposal of technology specific solutions at an early stage. Changing this habit of thought is not solely the result of knowledge about techniques capable of addressing issues from an holistic viewpoint but actually requires commitment of the individual to the belief that it is beneficial to investigate needs in an holistic manner.

A result of this need for the systems engineer to be committed to the holistic perspective in their practice is that systems engineering education can not only teach methods to perform whole of system engineering but must also ensure the commitment of graduates to pursuing an holistic approach to their engineering work. The achievement of commitment to an holistic approach is an outcome framed in the affective domain.

As said above, there are several competency frameworks developed by different groups for use in different circumstances. Whilst the organization of competency areas and the relative emphasis given to different kinds of competency in the quantity of competency elements listed in the frameworks differs greatly we will use one of the competency frameworks as representative of all. This is reasonable since all the frameworks contain reference to the same issues. Table 4 reproduces the NASA SE competencies [4]. In table 4 some of the competencies have been shaded. The shaded competencies are such that the primary emphasis in their exercise is cognitive knowledge of the method. There are two shaded competency area column cells. Both of these competency areas have all of their constituent competencies shaded. The remaining competency areas have at least one competency which is not shaded. Unshaded competency areas and competencies indicate that the effective exercise of the competency demands both cognitive knowledge of the ideas associated with the competency and the methods to perform action and some level of belief in or commitment to the subject matter of the competency in order to effectively and routinely apply that competency.

**Table 4**. NASA's SE competencies [4]

| Competency area | Competency |
|---|---|
| Concepts and architecture | Mission needs statement |
| | System environments |
| | Trade studies |
| | System architecture |
| System design | Stakeholder expectation definition and management |
| | Technical requirements definition |
| | Logical decomposition |
| | Design solution definition |
| Product, product transition, operations | Product implementation |
| | Product integration |
| | Product verification |
| | Product validation |
| | Product transition |
| | Operations |
| Technical management | Technical planning |
| | Requirement management |
| | Interface management |
| | Technical risk management |
| | Configuration management |
| | Technical data management |
| | Technical assessment |
| | Technical decision analysis |
| Project management and control | Acquisition strategies and procurement |
| | Resource management |
| | Contract management |
| | Systems engineering management |
| NASA internal and external environments | Agency structure, mission and internal goals |
| | NASA PM/SE procedures and guidelines |
| | External relationships |
| Human capital management | Technical and staffing performance |
| | Team dynamics and management |
| Security, safety and mission assurance | Security |
| | Safety and mission assurance |
| Professional and leadership development | Mentoring and coaching |
| | Communication |
| | Leadership |
| Knowledge management | Knowledge capture and transfer |

Therefore systems engineering education must provide students with the knowledge of how to perform these competencies and must also persuade them that these competencies and the values which they implement or effect are important and provide a valuable contribution to systems engineering work. That is, the educational process to develop these competencies requires attention to the development of the student in the affective domain so that the student will be characterized by significant valuation of the perspective associated with these competencies.

## 5. CONCLUSIONS

This paper has shown that systems engineering education must include objectives in the affective domain. The need to develop students in some aspects of the affective domain arises because the systems engineering competency frameworks show that successful practice of systems engineering requires a combination of cognitive skills, knowing about certain subject matter and being able to apply that knowledge in appropriate ways in projects providing systemic solutions to needs and other skills, commonly called "soft skills".

Soft skills are generally associated with elevated levels of attainment in the affective domain because soft skills achievement depends on a combination of knowledge about certain aspects of management interaction and organizational behavior and also personal ability to recognize situations in real time and to behave appropriately in most situations. Being characterized by a value system which leads to appropriate behavior in organizational and technical management situations demands significant act affective skill achievement.

The application of the cognitive skills of systems engineering demands that the systems engineer act on the belief that the holistic methods of systems engineering are the appropriate methods to use to ensure delivery of apposite systems. Without such a characterization by valuation of the methods to enable holistic approaches to engineering the systems engineer is likely to truncate work, producing less than an holistically appropriate solution.

The cognitive skills required of systems engineers involve the ability to perform a range of technical tasks associated with the synthesis, analysis and evaluation of systems. The cognitive skills appear, superficially, similar to the cognitive skills required to perform tasks within traditional engineering disciplines. However, there is a fundamental intellectual shift when using the skills in systems engineering practice. That fundamental shift is that the systems engineer is characterized by a valuation of systems level analysis and methodology as the most appropriate approach in order to produce appropriately balanced systemic solutions to needs.

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