A Psychomotor Skills Extension To Bloom's Taxonomy Of Education Objectives For Engineering Education

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ABSTRACT: Bloom's taxonomy of education objectives has been an important source for investigations of curriculum since its development. In the original taxonomy the authors addressed the issues of cognitive and affective objectives in education, and provided a hierarchy of kinds of capability in each of these domains that could be used as evidence of achievement. In addition, the hierarchy of capabilities provides a framework for correlating educational attainment with evidence of qualities that relate to abilities relevant to the performance of professional, or in the case of lower elements of the hierarchy, sub-professional work roles. The authors of the original taxonomy indicated that they believed that there are three domains relevant to educational outcomes. These are the cognitive, knowledge of and ability to work with information and ideas; the affective, ability to organise, articulate, and live and work by a coherent value system relevant to the capabilities achieved through education; and the psychomotor skills, ability to do acts relevant to the field of study. In engineering it is necessary for the student to develop skills working with the tangible stuff related to the discipline because the role of an engineer is to do either or both of development work of products and systems and to direct other people in the development and manufacture of products and systems. In roles where the engineer must personally perform work related to developmental experimentation, prototyping or contributions to maintenance and construction it is necessary for the engineer to have appropriately developed psychomotor skills to be able recognise and handle both test and developmental components and the equipment used to manipulate, work upon, or test those work pieces. In cases where the engineer's role is to direct the work of others it is important for the engineer to have appreciation of the tasks that the engineer calls upon those others to do and to have sufficient experience to understand the potential difficulties and dangers associated with the performance of the tasks. This appreciation will also provide a significant influence to the design activities of the engineer, as the engineer considers the usefulness and usability of the intended product. The paper will present a hierarchical taxonomy of psychomotor skills and discuss these skills specifically from the viewpoint of the needs of engineers.

INTRODUCTION

The authors have been engineering educators for considerable periods of time. Prior to teaching the first author had worked in the design of bore water pumping machinery and the design of power lines. The second author has worked in the design and development of microprocessor based control systems for a variety of applications. These work activities provided the authors with a combination of experiences demanding both analytical skills related to analysis of engineering problems and design, and practical skills associated with the fabrication of prototype products.

In teaching engineering the authors have been involved in the supervision of practical classes in electronics, communications, digital systems and microprocessors. In the laboratory classes the authors made many observations of student competence related to the execution of the set laboratory tasks. The laboratory tasks required students to perform a mixture of assembling electronic circuits, principally by patching together systems using pre-assembled circuit boards that provided a structure that could be multiply configured by choice of particular patching and required the connection of measurement instruments to the circuits in order to make measurements appropriate to the kind of system.

In other practical classes students were required to assemble and measure arrangements of radio frequency equipment. In these practicals the equipment, both the circuit elements and the instrumentation, was unfamiliar to students, comprising special purpose instruments and circuit elements such as waveguides and slotted lines.

The authors observed that student competence in the laboratory was not correlated with performance in standard paper tests and assignment work, nor to any other obvious factor. The obvious question is "why is this so?" Why should students who perform well in examinations exhibit uncorrelated performance in laboratory skills? The ethnicity issue may be a consequence of different emphases of the education systems experienced by different ethnic groups in their 'home' environments.

In addition, the general budgetary condition of Australian universities has resulted in a need to carefully consider costs associated with the various educational activities provided for students. Since laboratory work is expensive it is a target for cost cutting. It is appropriate to develop a clear, substantial educational justification of the activities students are required to perform in laboratory classes in order to justify the amount of laboratory work offered to students as part of their education and the consequent resources expended on this aspect of their education.

These issues coalesce leading to questioning of what laboratory work is expected of students and what the students should learn through the laboratory work. Where one has a clear understanding of what should be learned through a particular teaching and learning activity it becomes possible to design the activity in order to best target the learning of that particular outcome or combination of outcomes.

Bloom's taxonomy of educational objectives has been a popular tool for analysing and thinking about the goals of particular educational activities and whole programs of educational activity provided for students. However, Bloom's taxonomy as published [1, 2] has addressed two domains, the cognitive and the affective, but has omitted discussion of the third, psychomotor skills domain. The issues that the authors have noticed in teaching laboratory classes are closely linked to the psychomotor domain, and so this paper concerns the development of a framework of objectives in a hierarchical form related to the psychomotor domain.

BLOOM'S TAXONOMY

The original concern of the developers of Bloom's taxonomy was to provide a taxonomy suitable for the analysis of university level education [3]. This makes the use of the taxonomy in the analysis of engineering education appropriate to the intention of the developers of the tool. The developers were concerned that the majority of teaching at the time was concerned with the development of 'knowledge' and concluded that there are three domains of outcomes, the cognitive, affective and psychomotor domains.

Rote learning by students has been recognized as a problem for a very long time, with Montaigne commenting on the problem and its association with a content heavy curriculum in 1580 [4]. This problem was addressed by the development of Bloom's taxonomy [5], which provided a different approach to the determination of educational objectives based on the behaviourist perspective of identifying what the student is able to do as a result of the education [6]. The competence of the student to do things is dependant on the educational process developing certain capabilities, not only providing knowledge about things.

The dependence of Bloom's taxonomy on the psychological analysis of behaviourism makes the taxonomy open for criticism now, with the principal approach to psychological analysis being shifted to the cognitivist analysis. The behaviourist background of Bloom's taxonomy led to the structuring of the taxonomy as a hierarchy which assumes a hierarchical and cumulative nature of learning. A hierarchical and cumulative concept of the nature of learning assumes that student advancement to the next level of learning is dependant on success in the lower level. The cognitivist approach is not so simplistic.

The fact that the taxonomy concerns the behaviourist interest in the observable behaviour of the student implies a philosophy of education [7]. The implied philosophy is that education ultimately concerns the modification of the student action to be able to do certain things, those things being the outcome of the education. Therefore the taxonomy is called a taxonomy of educational outcomes when it is more obviously a taxonomy of cognitive abilities of the graduate rather than a taxonomy of educational objectives. This criticism takes the perspective that a taxonomy or description of educational objectives should consider the change in the person of the student brought about by the educational process rather than only the changes in the ability to perform classes of action brought to effect by the educational process.

The concern about the implied philosophy of education of the taxonomy, and its behaviourist background may be a result of the taxonomy filling a void, there being nothing else like it at any level of education, and it being applied to all education levels and kinds in many places, although not much in the US [8, 9]. In addressing the issue of rote learning, and in providing a mechanism and legitimation of discussion of educational objectives reflecting multiple kinds of resulting competences, the taxonomy gained the interest and attention of educators at all levels because they had no other tool enabling the broader discussion of education [10]. The more recent criticisms of the taxonomy related to the psychological theory underlying it may result from the application of the taxonomy beyond its original target field to other levels of education, which can be characterised as applying the taxonomy blindly [11]. One may reasonably believe that primary and secondary education concern development of the students in different ways than higher education, and that a different purpose of the levels of education should be present. In particular, the school levels of education deal with students at a much earlier stage of personality development and so educational objectives should reflect a different set of personal development objectives than higher education, in which young adults, generally, are educated to practice in a particular field of endeavour. In the case of higher education the primary concern relates to the need for the student to develop knowledge, attitudes and skills pertaining to the practice of work in the field. Although the taxonomy can be criticised in various ways, most authors have regarded it as very good, largely because those authors come primarily from the user community, and so approach the taxonomy as pragmatists, seeking means to assist their educational work [12].

Krathwohl, one of the original contributors to the taxonomy, presented a hierarchical taxonomy of the psychomotor domain as follows:

0 Basic movements
- 0.1 Nonlocomotor movements
- 0.2 Manipulative movements
- 0.3 Locomotor movements

1 Readiness
- 1.1 Cue sensitivity
- 1.2 Cue and behaviour selection
- 1.3 Set
  - 1.3.1 Mental set
  - 1.3.2 Emotional set
  - 1.3.3 Physical set

2 Movement skill development
- 2.1 Translation of mental images into kinaesthetic sensations
- 2.2 Production of correct behaviour

3 Movement pattern development (integrating movement and perfecting outcome)
- 3.1 Production of movement pattern
- 3.2 Perfection of movement pattern

4 Adapting and originating movement patterns
- 4.1 Adapting movement patterns
- 4.2 Selecting and adapting movement patterns

Dawson has sought to develop psychomotor domain and cognitive domain extensions to Bloom's taxonomy, based on the view that the three domains identified in the original publication were the domains that had been recognised by educators at the time [13]. Dawson provided hierarchies for several domains:

Psychomotor Domain
1. Observation
2. Trial
3. Repetition
4. Refinement
5. Consolidation
6. Mastery

Cognitive Domain
1. Knowledge
2. Comprehension
3. Application
4. Analysis
5. Synthesis
6. Evaluation
7. Decision Making
8. Implementation

These psychomotor domain extensions reflect significantly that the taxonomy has been extended in coverage to the lower levels of education in which children are at an age of needing to learn basic physical skills and coordination. The purpose of this paper is to develop a description of the psychomotor domain that is useful for laboratory work in higher education, and engineering education in particular.

The motivation for the present work is specifically the higher education issue of the development of competence in the practical skills required to perform work related to the discipline. The authors' interest in the area was prompted by several matters, all of which relate to the authors' background both in the practice of engineering and in education, both as a student and instructor.

First, the authors observed a significant difference in student ability to perform basic tasks in electronics practicals such as the tracing of wires in the patch-up of circuits. The question of whether there is a relationship of basic task competence to factors associated with the tradition of the student's academic background would seem from in laboratory observations of the authors to be worthy of further research.

Second, the question of whether electronics practicals should be conducted using preassembled circuit structures requiring students to use patching cables with standardized connectors, such as banana plugs, or basic components to be assembled on an SK-10 board. The SK-10 board is a prototyping board presenting insertion points for component leads in a matrix of connection rails with multiple connection points, enabling quick assembly of components into circuits with easy modification permitted.

Third, the need for graduate engineers to have skills to construct experimental test beds and development and prototyping models of proposed designs. This skill need demands that the graduate have a broad range of capabilities that enable the graduate to personally do a wide range of hands-on technical tasks to a sufficient level of competence, and satisfying all necessary safety and health requirements so that the graduate can effectively contribute to the construction of test and prototype equipment. In addition the graduate should have close knowledge of additional manual processes associated with the technology so that the graduate can specify work for others to do with an appreciation of the task that has really been requested and the difficulty of that task.

Fourth, the question of what learning students can make using internet based control of real instruments in a network based laboratory system. Such systems are attractive to some educators at present because they provide cost efficient means for external students to perform the same activities as internal students, neither of whom actually attend the laboratory and perform experimental work by direct manipulation of the instruments and test pieces. Network based laboratories also provide means to give practical experience at any time without the high labour cost of provision of laboratory supervision staff. This question has diverse aspects, including the nature of the student learning achieved through such systems and the motivation and satisfaction with the teaching and learning experience produced through the use of these media, and the issues associated with the provision of guidance and explanation of observations often provided by laboratory teaching staff.

COGNITIVE AND AFFECTIVE DOMAIN TAXONOMY

The original publication of Bloom's taxonomy divided educational objectives into three domains, the cognitive, the affective and the psycho-motor domains [1, 2]. The original publication omitted the psycho-motor domain from the detailed development that was provided of the other two domains. Since the time of the original publication the team led by Bloom never published such a psycho-motor domain hierarchical taxonomy. The published hierarchies for the cognitive and affective domains are outlined below, with detailed explanation available in the original publication.

The Cognitive Domain is divided:

1. Knowledge
   Knowledge of Specifics
   Knowledge of the Ways of Dealing with Specifics
   Knowledge of the Universals and Abstractions in a Field
2. Comprehension
   Translation
   Interpretation
   Extrapolation
3. Application
4. Analysis
   Analysis of Elements
   Analysis of Relationships
   Analysis of Organizational Principles
5. Synthesis
   Production of a Unique Communication
   Production of a Plan, or Proposed Set of Operations
   Derivation of a Set of Abstract Relations
6. Evaluation
   Judgements in Terms of Internal Evidence
   Judgements in terms of External Criteria

The Affective Domain is divided:
1. Receiving
   Awareness
   Willingness to Receive
   Controlled or Selected Attention
2. Responding
   Acquiescence in Responding
   Willingness to Respond
   Satisfaction in Response
3. Valuing
   Acceptance of a Value
   Preference for a Value
   Commitment

4. Organization
   Conceptualization of a Value
   Organization of a Value System
5. Characterization by a Value Complex
   Generalized Set
   Characterization

The hierarchy here is useful illustration of the manner in which the categories have been proposed as a hierarchy in which the attainment of levels is normally progressive because each level involves a higher and more complex use of the capability developed in the attainment of the levels below it. This characteristic has been discussed in some of the criticism of Bloom's taxonomy as described above.

PROPOSED PSYCHOMOTOR DOMAIN TAXONOMY

A proposed hierarchy of student learning outcomes in the psychomotor domain is presented below. The motives for development of this hierarchy have been described above.

The proposed Psychomotor Domain hierarchy is shown below:
1. Recognition of tools and materials
2. Handling of tools and materials
3. Basic operation of tools
4. Competent operation of tools
5. Expert operation of tools
6. Planning of work operations
7. Evaluation of outputs and planning means for improvement

This hierarchy leads from the recognition of the tools and materials which are the subject matter of the manual skills of the occupation through several levels of the skill in handling and using the tools and materials to effect desirable work outcomes and the ability to plan a set of work operations that will result in achievement of the desirable result to the highest level of attainment which involves evaluation of the outcomes and the planning of means for improvement of the outcomes achieved.

DISCUSSION

The psychomotor domain hierarchy, as proposed, requires elaboration to enable meaningful interpretation of the author's intent.

1. Recognition of tools and materials

   The most basic level of practical skill competence involves the ability to recognize the tools of the trade and the materials. This level of skill requires that one learn what the tools are so that when presented with a sample of a particular tool one has the ability to recognize it as such.

   In technical work there is a need to use certain materials to be worked upon as the subject matter of all practical work in the field.

   Recognition of both tools and materials is important for both effectiveness in work and safety. Recognition is necessary as the first step towards being able to make effective use of the tools or materials. Safety depends on recognition because once the tools and materials are recognized it is possible to associate the tools and materials with particular health and safety related information associated with them.

2. Handling of tools and materials

   Tools and materials are appropriately handled in certain ways. Thus particular processes for picking up, moving and setting down tools and materials must be learned. The processes are required in order that the objects can be handled without damage to either the object or other objects in its environment or hazard to any person, either the person moving the object or someone else nearby.

   Where necessary, such as in the linking of semiconductor devices and the pin-out diagrams, the student will be able to appropriately correlate information concerning parts with documentation describing those parts.

   This criterion of learning is necessary for handling of the objects with awareness of the potential problems of handling, so that the risks associated with handling of the objects can be recognized and pre-empted.

3. Basic operation of tools

   The basic operation of tools concerns the ability of the student to hold the tool appropriately for use, to set the tool in action and to perform elementary tasks that abstract tasks of work into their most basic, unitary form. The tasks that can be performed at this level are the specific detail tasks which, when assembled into a sequence, result in the completion of a piece of significant work. This level of competence concerns learning how to operate the tools and how to attend to matters of safety associated with the fundamental operational characteristics of the tools.

4. Competent operation of tools

   At this level the student becomes able to fluently use the tools for performing a range of tasks of the kind for which the tool was designed. This level is distinguished from the preceding by the student being able to assemble a significant sequence of tasks which when brought together enable the completion of designated work associated with the use of the tool. The work produced will be of a sound standard, being work that could be delivered as part of a finished product. Examples of such work in electronics would include the ability to drill holes in a circuit board consistently located correctly within the boundary of the solder mounting pads, or the ability to consistently solder all the mounts on the circuit board with mechanically and electrically sound joints with consistent solder quantity in each joint.

   Competent tool use includes being able to use the tools to achieve consistent, effective work outcomes in a manner that is consistently safe.

5. Expert operation of tools

   The ability to use tools with ease to rapidly, efficiently, effectively and safely perform work tasks on a regular basis. The expert user of the tool is able to produce the right outcome with attention being placed on the broader context of the work that is being done rather than the narrow context of the tasks being performed to do the work.

6. Planning of work operations

   At this level of competence the student is able to take a specification of a work output required and perform the necessary transformation of the description of the finished outcome into a sequence of tasks that need to be performed on the material in order to achieve the desired outcome and bring to fruition the finished product intended.

   The process of planning work operations requires an intimate understanding of the particular work operation in the required repertoire and the ability to discern matters such as the order of operations to efficiently and effectively produce the desired output product.

7. Evaluation of outputs and planning means for improvement

   At this level of competence the practitioner is able to look at a finished output product and review that product for quality of manufacture, with the ability to identify particular deficiencies and the actions which could be taken to either correct the faults or to prevent the faults through appropriate planning of the manufacturing operations.

   This level of competence parallels the 'Evaluation' and 'Characterization by a value complex' levels at the highest achievement in each of the other two domains. Again, the domain is capped by a level of achievement involving the critical review of actions that have been taken.

CONCLUSION

Despite criticism, Bloom's taxonomy of educational outcomes has been a significant influence in educational development since its first publication. The use of the taxonomy in the cognitive and affective domains has been important, both in the target field of higher education, but probably more so in primary and secondary education, where much of the curriculum development is performed by people with a significant theoretical background in education. This contrasts with higher education, in which most educators have little formal training in the concepts that underlie thinking about the educational process.

This paper has reviewed some work done in the field of the absent domain, the psychomotor domain. This work was seen to be formulated in terminology that derives from the development of elementary psychomotor skills, and seems to be largely targeted towards dealing with the issues resulting from the needs of the primary and secondary educational levels, in which the students have a significant need to develop the elements of psychomotor skills.

The present work has returned to the primary target of the taxonomy, the higher education field, and has interpreted the concept of the psychomotor domain differently, referring to the development of the manual skills associated with the performance of the professional responsibilities for which the higher education process is taken. Consequently the emphasis of the psychomotor skills described in this paper is on the practical aspects of the performance of the profession, rather than on the development of detailed physical skills as may be the case in lower age level education, where the student need is to develop physical motor function as distinct from competence in professional activities.

The present work is intended to be further discussed in the engineering education community and also to be applied to the development of practical work components of engineering programs. It is important for the practical work component of engineering programs to be designed using some kind of taxonomy of intended outcomes such as is proposed in order that the activities presented to students provide a coherent set of educational activities leading to the planned outcomes. Several outcomes should result for the education system. Engineering programs will develop graduate engineers with a coherent set of practical skills related to their discipline of study thus supporting their work as graduates. Engineering program practical work will be designed in a coherent way to provide experiences that lead to target levels of competence in particular kinds of practical skills. Coherent design of practical work will enable the more efficient use of equipment and instructor resources in the practical aspect of engineering programs because the kind and amount of experience provided will be targeted to gain the maximum effect for the input required. The result will be some improvement of efficiency, gaining a higher graduate competence per unit of resources input.

A further benefit of planning the practical component of the engineering program around some set of objectives such as suggested in this paper will be the possibility of designing assessment of the practical skills developed by students in a manner that reasonably assesses the capability of the students to perform tasks that matter in the practice of the profession.

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