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Using Bloom's Taxonomy of Learning to Make Engineering Courses Comparable

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***Abstract*— In order to increase students' mobility, it is necessary to make courses comparable, since otherwise, students could not transfer their acquired credit points from the sending to the receiving university. The European Credit Transfer System does not provide enough functionality to contribute to this purpose. It is therefore suggested to use an adapted Bloom's taxonomy of learning and new measures derived from it to overcome this obstacle. The novel measures are then applied to an example to demonstrate their usefulness.**

I. Introduction

The Bologna process aims at creating a European Higher Education Area (EHEA) [1], in which students might move from one university to another without experiencing disadvantages. It turns out that this goal provides more difficulties than it appears on first view.

One step to achieve this goal was the establishment of the European Credit Transfer System (ECTS) [2]. In order that credit points achieved from the sending institution are recognised by the receiving university, equivalence of credit points for learning modules must be stated. This is where problems arise, since the ECTS values only the amount of work that a student invests into an educational module. It does neither take into consideration content, nor learnt methodologies, nor the level of the module.

The first of these three shortcomings is not too difficult to solve, since the content of a module is normally defined in the handbook of the module in question.

Methodologies, however, are usually only scarcely described in module handbooks. In many cases, information about the level of the module even does not turn up.

Study advisors and regulation boards have thus only little chance to assess substantial equivalence of ECTS credit points achieved from another university. As a consequence, these credit points are often not recognised as being appropriate.

The aim of this article is, therefore, to demonstrate a potential solution of the problem. This is the application of a learning taxonomy, which is a well-known method from pedagogy.

II. Bloom's Revised Taxonomy of Learning

Taxonomy is a system to classify related things into categories (taxa). The probably best-known taxonomy of learning is the one introduced by the American educational scientist Benjamin Samuel Bloom [3] in its revision by Anderson, Krathwohl et al. [4], which in spite of its imperfections[1] is applied worldwide. Therefore, for the time being, Bloom's taxonomy is used as a reference for classification of knowledge, skills and competences to be achieved through the attention of an educational module.

Since most lecturers of engineering are not familiar with this learning taxonomy, it might be permitted to shortly describe it in the following subsections. Note that these descriptions are completely based on material published by Bloom and colleagues.

A. The three domains of learning

Bloom's revised learning taxonomy distinguishes three domains of learning:

- *the cognitive domain*,
  which classifies the whole of stored knowledge and the learnt processes to handle that knowledge [3], sometimes shortly referred to as *knowledge*,
- *the affective domain*,
  which classifies those areas of learning that are related to emotions, systems of values, motivation and (social) behaviour [5] , sometimes referred to as *attitude*, and
- *the psychomotor domain*,
  which classifies those areas of learning where physical movement and/or coordination are involved [6], also referred to as *skills*.

While the cognitive and the affective domain have been intensively treated by Bloom and a committee of co-workers headed by Bloom, the psychomotor domain has been subject to research mainly by other authors, e.g. E.J. Simpson [6], R.H. Dave [7], or A. Harrow [8].

B. The cognitive domain of learning

The term "cognitive" is an attribute that describes all aspects of information processing in the human mind. In the revised taxonomy, Bloom and co-workers classify this domain into two classes or "dimensions", namely into the characteristics of the information, the "knowledge dimension", and into the characteristics of the processes that are applied to the stored information, the "cognitive process dimension".

The knowledge dimension is subclassified into four categories according to Table I. These are assumed to lie along a continuum [4] from concrete (factual, category

[1] the taxa are not marked-off rigorously enough

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TABLE I
THE KNOWLEDGE DIMENSION

k	category	explanation
1	factual knowledge	basic knowledge on facts
2	conceptual knowledge	interrelations between facts
3	procedural knowledge	how to act in order to make use of conceptual and factual knowledge
4	meta-cognitive knowledge	knowledge on cognition and on one's own knowledge

number $k = 1$) to abstract (meta-cognitive, category number $k = 4$).

The cognitive process dimension is subclassified into six categories according to Table II. As it was assumed for the knowledge dimension, these categories are assumed to lie along a continuum from lower complexity (remember; category number $p = 1$) to higher complexity (create; category number $p = 6$).

Bloom and co-workers arrange these categories as in Table III, where the cognitive process dimension determines the columns, and the knowledge dimension determines the rows.

C. The affective domain of learning

The affective domain of learning organises the emotionally influenced interrelations that are associated with the process of learning. This does not only concern emotions, but also values, appreciation, motivation, and (social) behaviour, or, in other words, attitude.

TABLE II
THE COGNITIVE PROCESS DIMENSION

p	category	including
1	*remember*	recognising, recalling
2	*understand*	interpreting, exemplifying, classifying, summarising, inferring, comparing, explaining
3	*apply*	executing, implementing
4	*analyse*	differentiating, organising, attributing
5	*evaluate*	checking, critiquing
6	*create*	generating, planning, and producing

The committee of Bloom's co-workers with Krathwohl [5] as an editor has given a table that orders attributes categorizing the affective dimension.

Again, as in the cases of the two dimensions of the cognitive domain, it is assumed that this table includes an order of series with increasing degree of complexity of the process action (see Table IV), here from "receiving phenomena" to "internalising values".

TABLE III
THE DIMENSIONS OF THE COGNITIVE DOMAIN

		cognitive process dimension					
		remember	understand	apply	analyse	evaluate	create
knowledge dimension	factual knowledge						
	conceptual knowledge						
	procedural knowledge						
	meta-cognitive knowledge						

TABLE IV
THE AFFECTIVE DOMAIN

process action	explanation	example
receiving phenomena	being willing to notice something	attentively listen
responding to phenomena	react with compliance, potentially with satisfaction	participate in discussions
valuing	attaching a value to something	propose an action
prioritise values	organize values into priorities	accept professional ethical standards.
internalising values	setting priorities of values and accept them for oneself	commit oneself to professional ethics

D. *The psychomotor domain of learning*

In contrast to the above described domains, the committee of Bloom's co-workers did not give a similarly elaborate list of categories for the psychomotor domain of learning.

As a substitute, the taxa of Simpson [6], or Dave [7], or Harrow [8] are suggested frequently. Ferris and Aziz [9] have presented a very close adaptation of Simpsons [6] taxa, which is well suited to assess physical actions of engineers. It is shown in Table V.

III. Critique of Bloom's Taxonomy

Though Bloom's taxonomy is a valuable tool to help formulating learning objectives, it is not yet optimum. Some points to be criticised are shortly mentioned below.

The knowledge dimension is supposed to give an order from concrete to abstract categories of knowledge (from factual to meta-cognitive).

Unfortunately, the four categories are a great deal too coarse as it is demonstrated in [10]. Therefore, with respect to some aspects, procedural knowledge might be more abstract than meta-cognitive knowledge, or conceptual knowledge might be more abstract than procedural knowledge.

The same problem arises with the cognitive process dimension, where attributes are supposed to be ordered in a series from lower complexity to higher complexity. Is “apply” really more sophisticated as compared to “understand”?

Concerning the affective domain, the main point of critique is that it does not clearly distinguish between emotions (like fear or sadness) that are evoked subconsciously, and the feelings of more or less satisfaction due to more or less compliance of real events with expectations.

This has been recognized by many educational scientists who prefer to talk about attitudes rather than on affect.

The psychomotor dimension finally, is designed in a too specialized way. It does concentrate too much on physical movement as an action, instead of concentrating on action in general.

TABLE V
THE PSYCHOMOTOR DOMAIN AS ADAPTED BY FERRIS AND AZIZ

process action	explanation	example
recognition of tools and materials	recognize tools of the trade and materials	recognize a microscope as a tool
handling of tools and materials	knows and acts upon a sequence of steps in a process in a way that damage to objects or persons might be avoided	position the microscope without damaging it
basic operation of tools	set tool in action and perform elementary tasks	put a slide under the object lens, focus it
competent operation of tools	fluently use tools for performing a range of tasks of the kind for which the tool was designed.	fluently change objects and lenses, routinely focus the object
expert operation of tools	ability to use tools with ease to rapidly, efficiently, effectively and safely perform work tasks on a regular basis.	select best slices to observe, avoid drying out of objects
planning of work operations	take a specification of a work output required and perform the necessary transformation into a sequence of tasks that need to be performed	plan to create slices for best observation, preparation of a series of objects
evaluation of outputs and planning means for improvement	ability to look at a finished output product and review for quality, with the ability to identify particular deficiencies, necessary actions	evaluate a series of observations, identify those objects that are less suited for giving evidence of theses.

IV. A moderate adaptation of Bloom's taxonomy

In order not to overstress the usual agreement to Bloom's revised taxonomy, this model is only slightly adapted here.

First of all, the idea is given up that the taxa of the knowledge domain are ordered following their complexity. Rather the four categories are seen as categories that are acquired in the order of sequence, as they are shown in Blooms table, but that are standing side by side.

The categories in the cognitive process domain are still seen as indicators of complexity that are ordered from low to high complexity.

The affective domain and its use will not be questioned in this article. It is suggested that it will be used to describe the

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achievement of learning objectives wherever it is applicable. Examples might be the description of learning objectives in a course of engineering ethics, or in a course of legal aspects, or the description of the behaviour of a student when working in a team.

The psychomotor dimension, however, needs to be sublimated to a more abstract level! Using the taxa as in their formulation by Ferris and Aziz [9], but interpreting the term "material" as "material to think about", and the term "tools" as "processes to be applied", then Table V gains another meaning, and the psychomotor domain is transformed into a *skills-domain*. It appears however, as if levels 2, 6, and 7 would be dispensable, which leaves only 4 levels as shown in Table VI. Level 2 is dispensable, since on an abstract level, it is not too much different from level 1. Levels 6 and 7 are dispensable, since they are covered already by the cognitive domain.

TABLE VI
THE SKILLS DOMAIN

process action	**explanation**	**example**	**level *s***
recognition of tools and materials	recognize tools and materials	recognize a differential equation	1
basic operation of tools	set tool in action and perform elementary tasks	use an ansatz to solve the problem	2
competent operation of tools	fluently use tools for successful problem solving	solve problem including boundary conditions	3
expert operation of tools	ability to use tools with ease to rapidly, efficiently, effectively and safely perform work tasks on a regular basis.	select and apply advantageous numerical methods	4

With these adaptations, it is now possible to create a novel diagram which contains information about the skills level that shall be described for different sectors of the cognitive domain.

This is best demonstrated with an example that uses the information following Table VII, and that is visualised by Fig. 1.

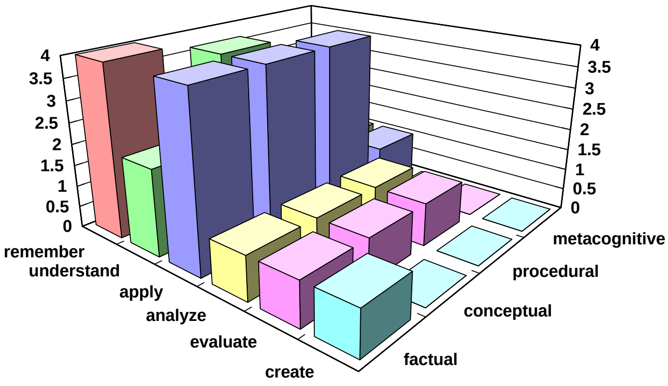

Fig. 1 Example of claims for a particular learning objective, as assessed in three dimensions: knowledge dimension, cognitive process dimension, and skills dimension.

To understand that example, imagine that a chapter on ordinary linear differential equations in a lecture on engineering mathematics is to be characterised. Additionally, think that the learning outcomes are characterized as in Table VII or in a graphic following Fig. 1. In the table and in the figure, to each category k of the knowledge dimension, and to each category p of the cognitive process dimension, a skills level s is indicated.

The given example might be a description for a part of an educational module on a bachelor's level. It is characterised by a high level of recognition on a factual basis, a good understanding of the context, in which this part of the educational module is used, and a high skills level to apply knowledge to a given situation.

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TABLE VII
DIAGRAM TO DESCRIBE THE SKILLS-LEVEL AND COGNITIVE COORDINATES OF A GIVEN LEARNING OBJECTIVE

			cognitive process dimension						
		p	1	2	3	4	5	6	
	k		remember	understand	apply	analyse	evaluate	create	
knowledge dimension	1	factual knowledge	4	2	4	1	1	1	$p_k = 3$
	2	conceptual knowledge	2	4	4	1	1	0	$p_k = 3$
	3	procedural knowledge	2	2	4	1	1	0	$p_k = 3$
	4	meta-cognitive knowledge	1	1	1	0	0	0	$p_k = 2$
			$k_p = 2$	$k_p = 2$	$k_p = 2$	$k_p = 2$	$k_p = 2$	$k_p = 1$	$(k,p) = (3,2)$

The competence to theoretically analyze the material, to understand the background, to evaluate the situation and possibly to act in a creative way, however, is rather low.

Consider in contrast the diagram shown in Fig. 2. Here, the skills level in the categories “analyze”, “evaluate”, and “create” are much higher than in the example before (apart from evaluate-factual), while in the cognitive process dimension the categories of “apply” are lower as before. The second example describes, therefore, a module on a more abstract, scientific level. It could thus be part of a module from a master course program, or one of few parts of a bachelor course program with above average requirements.

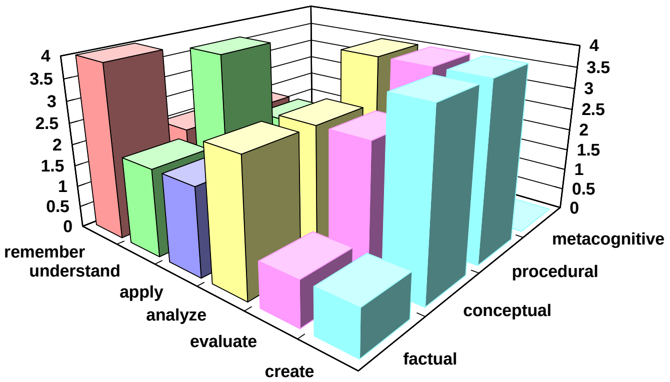

Fig. 2 Another example with a much higher skills level in deep comprehension.

The main learning objectives of an educational module might thus be characterised in detail using this extended Bloom’s diagram. Several diagrams might be necessary to characterize a more complex educational module.

However, for a concise comparison of learning modules, it might not be necessary to analyse an educational module in all its facets. Then, it might suffice to specify an educational module or its sub-modules by the most appropriate categorization of the knowledge-dimension, of the cognitive process dimension, and of the skills level.

This might be done by first determining the “centre of gravity” of skills in each row and in each column of the skills-diagram table. This has been done in Table VII, thus delivering a kind of mean values p_k for each category of the knowledge dimension, and mean values k_p for each category of the cognitive process dimension. The centre of gravity of the k_p – values is close to 3, thus showing that the main emphasis of the course program has been placed to category 3 of the cognitive process dimension – this is the process of applying knowledge. The centre of gravity of the p_k is about 2, thus showing that the main emphasis of the course program has been placed to category 2 of the knowledge dimension – this is conceptual knowledge. The skills level at the crossing point of “conceptual knowledge” and “apply” in Table VII is 4.

Thus, using the three dimensions of knowledge, of cognitive processes, and of skills, and their levels, each educational sub-module might be characterized by a triple of numbers, the *level-triple*, in which the first element describes the level of the knowledge dimension, the second element describes the level of the cognitive process dimension, and the last one describes the skills level. In the given example following Fig. 1, the level-triple would be (2,3,4), while it would be (3,4,4) in the example following Fig. 2.

Since these numbers might be different for different parts of a lecture, several diagrams and level-triples might be necessary to characterize a complete educational module.

V. SUMMARY AND DISCUSSION

It was shown how by adaptation of Bloom’s learning taxonomy, educational modules might be analysed with respect to skills levels achieved in the knowledge dimension and in the cognitive process dimension of its main learning objectives. By that method, educational modules might be compared not only with respect the workload they are causing, but also with respect to the profile and to the level of the module. For purposes of a simple characterisation, the level-triple has been introduced.

Yet this method has its weak points. The affective dimension of learning is not yet integrated in this scheme, rather it might only be considered in parallel. The knowledge dimension is probably too coarse.

Nevertheless, as compared to the application of the ECTS, it has doubtlessly considerable advantages. For the first time, assistance is given to curricula designers, lecturers, study advisors and members of the regulation boards to categorise complete educational modules.

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