A Systematic Review of the Use of Bloom's Taxonomy in Computer Science Education

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ABSTRACT

Bloom's taxonomy is a model that allows characterizing students' learning achievements. It is frequently used in computer science education (CSE), but its use is not straightforward. We present a systematic review conducted to know actual use of the taxonomy in CSE. We found that it was mostly used in programming education and to assess students' performance. A more relevant contribution is a classification of authors' difficulties. In particular, the most often reported difficulty is determining the level of the taxonomy where an assessment task can be classified. In addition, we present authors' hypotheses about possible causes of the difficulties and the solutions they adopted.

CCS CONCEPTS

• Social and professional topics~Computer science education

KEYWORDS

Computer science education; Bloom's taxonomy; difficulties.

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1. INTRODUCTION

Bloom's taxonomy is a model that allows characterizing students' learning achievements. According to Bloom *et al.* [3], learning objectives are "explicit formulations of the ways in which students are expected to be changed by the educative process". The original taxonomy [3] establishes hierarchy of six levels of learning. The revised taxonomy [1] does not establish a strict hierarchical relation between levels and it differentiates two dimensions. The cognitive process dimension is similar to the original taxonomy, whereas the knowledge dimension classifies the knowledge the student is expected to achieve.

Bloom's taxonomy is probably the most widely used taxonomy to state learning goals in computing studies. Even curricular recommendations by ACM/IEEE specify learning goals by means of the revised version of Bloom's taxonomy (more faithfully in the 2008 edition [4] and in a simplified way in the 2013 edition [6]).

However, some authors reported that the use of the taxonomy was problematic. For instance, different instructors may classify a given exercise at different levels of the taxonomy. Actually, the second author used Bloom's taxonomy in the past but, in spite of the taxonomy appeal, he found difficulties of use [10]. A few years later, a working group was created at the ITiCSE 2007 conference. In its final report [6], the group includes a comprehensive review of academic literature on different learning taxonomies, their use in computer science education (CSE) and their associated problems. The working group also proposed a new taxonomy that could be used in programming courses. However, the review of problems reported on the use of the taxonomy was not exhaustive.

Britto and Usman made a systematic review of the use of Bloom's taxonomy in software engineering education [4]. However, their analysis is descriptive and does not deepen, at least, in difficulties of use of the taxonomy.

The goal of this work is to expand knowledge of difficulties reported by authors using Bloom's taxonomy for CSE. The structure of the paper is as follows. In Section II, the methodology used for the systematic review is described. Section III presents answers to research questions, according to the review. Finally, Section IV contains a brief discussion of our findings and Section V summarizes our conclusions.

2. METHODOLOGY

In this section, we describe in detail the process followed for the systematic review. We followed the guidelines proposed by Barbara Kitchenham [12].

2.1 Research Questions

The following research questions were formulated:

- RQ1. What version of Bloom's taxonomy was used?
- RQ2. Is any other learning taxonomy used?
- RQ3. In what subject matters is Bloom's taxonomy used?
- RQ4. What is the purpose of using Bloom's taxonomy?
- RQ5. Did the authors report any difficulty of use of Bloom's taxonomy? In the affirmative case, what difficulties?

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2.2 Documentation Sources

The search was focused on the most relevant journals and conferences on CSE. At the risk of excluding some valuable publications, we expected that the results would be representative of the use of Bloom's taxonomy in CSE. We selected prestigious journals and conferences sponsored by SIGCSE, plus the journal Computer Science Education:

- Transactions on Computing Education (TOCE).
- ACM Conference on International Computing Education Research (ICER).
- ACM Technical Symposium on Computer Science Education (SIGCSE).
- ACM Conference on Innovation and Technology in Computer Science Education (ITiCSE).
- Australasian Computing Education Conference (ACE).
- Koli Calling International Conference on Computing Education Research.

2.3 Search Terms

Search terms were selected by taking into account the use of Bloom's taxonomy in computer science and in programming, as well as the possibility of other ways of indirectly referring to the taxonomy. The search string used was:

("Bloom's taxonomy" OR "Bloom taxonomy" OR
"cognitive taxonomy")
AND
(programming OR "computer science")

The search for the journal Computer Science Education was conducted in the on-line version of Taylor & Francis and, for the rest of sources, in the ACM Digital Library.

2.4 Selection Criteria

The search of the above-specified string yielded a result of 314 publications, not all of them useful. Therefore, we applied exclusion and inclusion criteria to determine relevant articles. The selection process was conducted in three stages:

- Duplicated publications were discarded, as well as results corresponding to conference proceeding volumes (without the papers). As a result, 306 publications were selected.
- We applied the following inclusion criteria: (a) the abstract referred to the use of Bloom's taxonomy, or (b) the string "Bloom" was present in the list of key words. The number of publications was reduced to 45.
- A second exclusion process was conducted given that, on analyzing these 45 publications, we noticed that some works reported the same research effort, usually presented differently (e.g. one was an extended version of another one). We decided to keep the publication containing more details related to our research. The resulting number of publications was 40.

Table 1 summarizes the process described above, with the figures resulting after each step. The list of the 40 publications finally selected can be found in a technical report [13].

2.5 Methodology of Analysis

Research questions 1 and 2 only admitted a restricted number of answers, therefore they were counted and handled statistically. Questions 3-5 were open, therefore they were analyzed qualitatively. We elaborated a matrix where the authors' comments about difficulties of use of the taxonomy were recorded. On analyzing a publication, we only considered the comments of its authors, not citations or quotations of other authors.

Table 1. Results of applying selection criteria

Document source	Found	Discarding duplicates	Satisfying inclusion criteria	Discardin g similar works
CSE	7	7	7	6
TOCE	17	17	1	1
ICER	42	39	5	5
SIGCSE	119	117	13	11
ITiCSE	86	85	11	10
ACE	30	29	7	6
Koli Calling	13	12	1	1
Total	**314**	**306**	**45**	**40**

The qualitative analysis was conducted without predefined categories, as *grounded theory* advocates [7], and proceeded through numerous iterations. The iterations may be grouped into two stages:

1. Difficulties were classified into internal difficulties (i.e. inherent to the taxonomy) and external difficulties (i.e. related to the use of the taxonomy). However, this analysis criterion did not provide a clear classification instrument, being common the uncertainty about the subcategory where each difficulty best fitted. Finally, we discarded this classification scheme.
2. We analyzed whether each commentary reported on a difficulty of use, a cause of the difficulty hypothesized by the authors, or a solution adopted by them. This classification provided greater precision, thus we adopted it.

Each stage comprised a high, undetermined number of iterations, with frequent analysis forward and backward of the 40 publications. Most analysis iterations were conducted by the first author, but the second author also was involved in the analysis. The analysis ended when both authors achieved a consensus.

3. RESULTS

We first present the results of closed questions and then we present the results of open questions.

3.1 Results of Closed Questions

RQ1 inquired the version of Bloom's taxonomy actually used by the authors. The original taxonomy was used in 30 publications (75%), while the remaining 10 (25%) used the revised version.

RQ2 was intended to know whether other taxonomies also were used. Most publications exclusively used Bloom's taxonomy (34 publications, 85%). Other publications used the SOLO taxonomy [2], either after discarding Bloom's taxonomy (4, 10%) or jointly with Bloom's (2, 5%).

3.2 Results of Open Questions

In order to interpret correctly the results of research questions 3 to 5, note that some publications do not provide answers to some questions. For instance, the authors of an article report on one or more plausible causes of their difficulties of use of Bloom's taxonomy, but they do not report on any adopted solution. Consequently, the total number of answers to each question is not equal to the number of publications selected (40).

3.2.1 Matters where Bloom's Taxonomy Was Used

In general, the publications reported the use of the taxonomy in just one course. However, three publications reported its use in either two or three courses. In total, the number of courses reported is 45. The results, classified into subject matters, are shown in Table 2.

Table 2. Subject matters where Bloom's taxonomy was used

Subject matter	Number	Percentage
CS1	23	51%
Data structures or algorithms	4	9%
Other programming courses	3	7%
Software engineering	6	13%
Other computing topics	5	11%
High school course	4	9%
Total	**45**	**100%**

The two first subject matters are self-explanatory. "Other programming courses" comprises courses on programming languages or functional programming. "Software engineering" gathers five publications reporting general courses on software engineering and one publication reporting a specialized course on requirements engineering. In "Other computing courses" we include courses on data bases, networking, security, human-computer interaction, and computing professionalism. The category "High school course" refers to courses at the high school level and the *AP Computer Science* exam.

3.2.2 Uses of Bloom's Taxonomy

We analyzed the use that authors made of Bloom's taxonomy. One of the publications reports two uses, thus we computed 41 uses in total (see Table 3).

Nearly half the publications (46%) used Bloom's taxonomy in relation to assessment. Note also that a substantial number of publications (37%) mention that they have used or have based on Bloom's taxonomy, but they do not make clear how.

In the following, categories and subcategories are explained:

- Assess students (19 publications). The taxonomy is used to measure students' knowledge. This category groups three subcategories:
  - Develop questions or problems aimed at given cognitive levels.
  - Classify questions or problems previously developed into cognitive levels.
  - Classify students' performance into cognitive levels.
- Schedule instruction (2 publications). Bloom's taxonomy is used to schedule instructional activities in a course in order to enhance students' learning.
- Specify the learning goals of a course (2 publications).
- Others (3 publications):
  - Create a new taxonomy. Bloom's taxonomy is modified to obtain a new taxonomy, supposedly more adequate for CSE.
  - Develop educational software. The taxonomy is used as a basis to develop a tutorial on how to use Bloom's taxonomy itself.

Table 3. Uses of Bloom's taxonomy

Category	Subcategory	Num.	Total in category	%
Assess students	Develop questions	10	19	46%
	Classify questions	7		
	Classify students' learning	2		
Schedule instruction	–	2	2	5%
Specify learning goals	–	2	2	5%
Others	Create a new taxonomy	2	3	7%
	Develop educational software	1		
Undetermined	–	15	15	37%
TOTAL		**41**	**41**	**100%**

- Undetermined (15 publications). They mention the use of Bloom's taxonomy without additional details.

3.2.3 Difficulties of Use of Bloom's Taxonomy

Only 15 publications (38%) report that their authors had any difficulty using the taxonomy. Let us analyze in detail the difficulties reported by their authors.

We successively present the difficulties identified, their plausible causes, and the solutions adopted to overcome them. In order to enhance the understanding of our findings, we include some quotations. Unfortunately, given the lack of space, we are unable to include a quotation for every category.

3.2.3.1 Difficulties

Three of the fifteen publications reporting difficulties cite two difficulties, therefore the total amount of reported difficulties reaches 18. We may distinguish four classes of difficulties (see Table 4), being the difficulty in classifying learning goals or assessment tasks into the taxonomy levels the most frequent (77%). In the following, the categories are described.

- Difficulty in classifying learning goals or assessment activities. It is common to consider several promising candidate taxonomy level that fit the best. Whalley *et al.* [18] comment: "... categorising programming MCQ's by cognitive complexity applying Bloom's taxonomy, has proven challenging even to an experienced group of programming educators".
- Difficulty in precisely specifying the knowledge associated to each learning goal or assessment task. The problem emerges when the instructor switches without intention between related, but not equal, concepts. For instance, Starr *et al.* [16] draw our attention about switching between "iteration" and "*for* loop"; notice that the former is a more general concept than the latter.

- Difficulty in measuring student's progress. It is difficult to know whether a student's cognitive process to solve a given problem progresses, for example, moving to upper levels in the taxonomy. Meerbaum-Salant *et al.* [14] claim: "We wanted to work with a strictly hierarchal taxonomy, enabling us to monitor students' progress, but one that matched the context of the study and its objectives."

Table 4. Classes of difficulties on using Bloom's taxonomy

Difficulty of use	Num.	%
Classifying learning goals or assessment tasks	14	77%
Specifying precisely the knowledge associated to each learning goal or assessment task	2	11%
Measuring student's progress	1	6%
Understanding the taxonomy	1	6%
TOTAL	**18**	**100%**

- Difficulty in understanding the taxonomy. The difficulty comes from having doubts about how to interpret some of the taxonomy concepts in a computing context. Thompson *et al.* [17] comment the difficulty in understanding the meaning of "applying a process" or "creating a process" in the revised taxonomy, referred to a programming context.

3.2.3.2 Causes

Authors of the publications often guess plausible causes for the difficulties they found on using Bloom's taxonomy. We classify them into five categories (see Table 5). Here, we did not find one major cause, but four main causes: need to know the educational context, limitations of the taxonomy, deficient understanding of the taxonomy, and terminology of the taxonomy. Remember that we do not express our opinions, but we reproduce opinions by the authors of the reviewed publications. A description of categories and subcategories follows:

- Need to know the educational context. The authors point out that ignorance of the way contents were instructed makes difficult to classify into a specific level of the taxonomy. Gluga *et al.* [9] remark "The example highlights the tight dependence on knowledge of the teaching context to correctly classify exam questions using Bloom.". This category of causes comprises two subcategories:
  - Different students may make different cognitive efforts to solve the same problem, since they may apply different ways of reasoning, corresponding to different levels of the taxonomy.
  - Instructors may address a particular approach to problem solving, which must therefore be known in order to properly classify the assessment into the corresponding level of the taxonomy.
- Limitations of the taxonomy. This category gathers those causes that are inherent to the taxonomy, such as its definition or its structure. It includes three subcategories:
  - Incomplete or inadequate set of levels for programming tasks. Authors think that the taxonomy levels hardly fit the concepts and tasks involved in programming [14].
  - Overlapped set of levels. The levels are not well differentiated, therefore a question or concept may be categorized at different levels by different persons.
  - Conceived to assess and not to specify goals.
- Deficient understanding of the terminology. The difficulties may be due to instructors' misunderstandings of the meaning of each level. Some subcategories are:
  - Shallow knowledge. Instructors often have beliefs and misunderstandings about the meaning of the levels of the taxonomy. Gugla *et al.* [8] say "... the use of Bloom's Taxonomy in a computer science context has generally been inconsistent. A possible reason for this is that the computer science educators performing the Bloom's classifications did not have a strong understanding and/or a common understanding of the theory".
  - Different understanding, depending on the instructors' experience. The interpretation of each level of the taxonomy, as well as the cognitive effort, are different in experienced and in novice instructors. Difficulties come when instructors with varying experience meet in the same assessment group.
  - The use of the taxonomy demands a notable memorization effort. Note that, according to the revised Bloom's taxonomy [1], there are 4 levels and 11 sublevels in the knowledge dimension, and 6 levels and 19 sublevels in the cognitive process dimension.
- Terminology used to define the taxonomy. Actually, we may consider this category a particular case of the previous one but we keep it separate, given its specific relation to language use. We differentiate two subcategories:

Table 5. Causes of the difficulties of use of Bloom's taxonomy

Category	Subcategory	Num.	Total	%
Need to know the educational context	Varying students' cognitive effort	4	8	31%
	Need to know how the contents is instructed	4		
Limitations of the taxonomy	Incomplete or inadequate set of categories	5	7	27%
	Overlapped set of categories	1		
	Conceived to assess and not to specify goals	1		
Deficient understanding of the taxonomy	Shallow understanding	3	5	19%
	Different understanding, depending on experience	1		
	Demand of a notable memorization effort	1		
Terminology	Lack of illustrative examples	3	5	19%
	Peculiar terminology	2		
Complexity of computer science	–	1	1	4%
TOTAL		**26**	**26**	**100%**

  - Lack of examples of computing that illustrate the levels and sublevels in the taxonomy. Whalley *et al.* [18] comment: "The examples given by the taxonomy's authors are not easy to translate into the programming domain. In many cases the categories within the knowledge domain, did not readily fit with concepts and tasks required in computer programming".
  - Peculiar terminology of the taxonomy. The terminology used in computing, in particular in programming, has different connotations than the terminology used in Bloom's taxonomy. For instance, the task of analyzing the complexity of an algorithm typically does not correspond to the analysis level of Bloom's taxonomy but to the application level, i.e. application of a procedure.
- Complexity of computer science. The intended cognitive level not only depends on the topics under study but also on the tool. Although different tools may have the same purpose, their complexity may vary, resulting in classifications at different levels of the taxonomy. For instance, "…in the systems modeling field, comparing the number and nature of symbols in Data Flow Diagrams (DFDs) to those in the formal specification language Z makes evident the considerable disparity between them. Whereas DFDs have only a few graphical symbols, Z has a complex mathematical notation. These differences superimpose a degree of difficulty at all levels of the taxonomy, leading to a paradigm shift between these two examples" [15].

3.2.3.3 Solutions

We gathered the solutions that some authors adopted to solve their difficulties and grouped them into categories (see Table 6). We found 4 publications that did not report any solution, 3 publications reporting 2 solutions and 1 publication reporting 3 solutions. The most frequent solution was to adopt a criterion and to apply it consistently (38%).

The categories for solutions adopted follow:

- Give guidelines of use. These authors gave two kinds of guidelines: to make decisions on the level corresponding to a given class of programming exercise, or to interpret the terms of the taxonomy and indicate how to use them in computer science. For example, Thompson *et al.* [17] redefine each level of the taxonomy based on specific examples of programming.
- Training instructors in the use of the taxonomy. For instance, Gluga *et al.* [8] conclude, after a review of the literature, that the use of Bloom's taxonomy is not straightforward; consequently, academics willing to use Bloom's taxonomy must be trained.
- Extend the taxonomy. Three kinds of solutions were grouped into this category: to extend the taxonomy with other dimensions (in particular, complexity and difficulty), extend it with an additional "higher application" level, and use it jointly with the SOLO taxonomy. For instance, the latter solution was adopted by Meerbaum-Salant *et al.* [14], who created a new taxonomy that combines some categories of Bloom's and SOLO taxonomies. Based on the specifics of their student population, they only used the understanding, applying and creating levels from Bloom's taxonomy and the unistructural, multistructural and relational levels from SOLO. The authors use such a combined taxonomy to design assessment questions and to analyze the answers.
- Change the terminology. They recommend using terms related to computing for each level of the taxonomy.
- Know the context of assessment questions within a course.
- Determine the cognitive level that students will use. They propose guessing the cognitive level that most students will achieve.

Table 6. Solutions adopted to overcome difficulties

Solutions	Num.	%
Give guidelines	6	38%
Training	3	19%
Extend the taxonomy	3	19%
Change the terminology of the taxonomy	2	12%
Know the educational context	1	6%
Determine the cognitive level that students will apply	1	6%
TOTAL	**18**	**100%**

4. THREATS TO VALIDITY

The main validity threat to this work is the coverage of relevant literature. It was the result of adopting a trade-off between wider coverage and capacity to handle a (foreseeable) very high number of publications, at least in the first stages of selection. However, we consider that the decision of limiting ourselves to most of the publications organized or sponsored by ACM SIGCSE, as well as the Computer Science Education journal, was correct. Other forums could have contributed with additional publications, especially those organized or sponsored by IEEE. However, according to preliminary search results, many of them refer to engineering education. Engineering and computing often overlap, especially in the topic of computer programming. However, we wanted to focus on computer science education.

Another threat may be the specific string search used. As an additional check of the search results, we tested whether a number of publications about the topic we were aware of had been selected. The result was affirmative in all the cases.

Another threat is the classification of difficulties, causes and solutions. To mitigate this threat, both authors were involved in the classification process. Actually, the first author did a bigger effort, but consensus was necessary to validate the classification. Consensus was not simple and, as reported in Section 2.5, we successively used two categorization schemes. The first scheme distinguished between internal and external difficulties, inspired by other classification techniques used in computing (such as pattern languages). However, we often disagreed, thus we found confusing this criterion. When we distinguished among difficulties, causes and solutions, it was much simpler to come to a consensus.

5. DISCUSSION

Some results of the systematic review match the results of our previous paper [10], as well as those of the working group led by Ursula Fuller [6], but the final overview is more comprehensive. According to the selected papers, we might be tempted to conclude that Bloom's taxonomy is the most often used educational taxonomy in computing. However, this claim cannot be supported by our study because the search string, as well as inclusion and exclusion criteria, were biased in behalf of Bloom's taxonomy. We do may claim that Bloom's taxonomy has been mostly used in programming courses and with the goal of assessing students' performance.

About one third of the reviewed publications acknowledge having used Bloom's taxonomy, but they do not even sketch for what purpose or how. Furthermore, over half the publications analyzed do not refer any difficulty of use. However, the rest of publications report severe difficulties, often suffered by experienced researchers. Both facts raise the issue of whether the use of the taxonomy often is very shallow.

The main difficulty found by authors was the classification of a learning goal, course contents or an assessment test in a cognitive level of the taxonomy. There is more disparity in the causes hypothesized about such difficulties, with four causes being the most frequently guessed: need to know the educational context, deficiencies of the taxonomy, deficient understanding of the taxonomy, and terminology of the taxonomy. Finally, we also find diversity of solutions proposed to overcome these difficulties, being guidelines of use the most frequently adopted solution.

6. CONCLUSIONS

We have presented in detail a systematic review of the use of Bloom's taxonomy in computer science education. The resulting landscape is perplexing. On the one hand, the high frequency of use of the taxonomy allows considering it a valuable educational tool, especially to assess students. On the other hand, common report of difficulties, as well as the variety of causes hypothesized and solutions adopted makes difficult to find clear lines of action to let instructors use the taxonomy with confidence. Currently, we are studying in depth the results of the systematic review to suggest plausible solutions that may (ideally) provide aids to instructors willing to use Bloom's taxonomy.

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