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Using different taxonomies to formulate learning outcomes to innovate engineering curriculum towards PBL: perspectives from engineering educators

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Abstract

Designing modern engineering curricula requires integrating the United Nations' Sustainable Development Goals (SDGs) and generic employability skills, focusing on student-centred learning, and explicitly including learning outcomes about knowledge, skills, and competences. There is the need thus for tools that help teachers and boards to address these demands and assure quality in educational processes and outcomes when revising and changing curricula. Higher education institutions have been developing different quality assurance strategies. However, from a teaching and learning practice perspective, there are concerns on whether such strategies guarantee curriculum coherence, especially in terms of ensuring progression and alignment between learning outcomes and more student-centred learning activities, such as problem-based learning (PBL).

This paper discusses the above coherence issues by addressing the following question: What are strengths and weaknesses in using taxonomies to analyse learning outcomes as mean to promote curriculum innovation and PBL implementation?

The paper takes the point of departure on formulation of learning outcomes using Bloom's revised, SOLO, and Feisel-Schmitz Technical taxonomies and in which ways they support engineering educators in re-design their courses towards PBL. More specifically, the manuscript discusses: a) the similarities and differences between different taxonomies; b) strengths and weaknesses of taxonomies to analyse learning outcomes for engineering education and PBL, taking the point of departure four engineering courses as case examples. We categorise different courses' learning outcomes using the referred taxonomies, and reflect on their suitability for categorising and formulating the learning outcomes in engineering education. The results enable discussing the suitability of the taxonomies in more generic settings, their limitations in formulating learning outcomes relevant for engineering practice, namely non-cognitive learning outcomes and transversal skills, and making recommendations towards improved curriculum alignment in engineering education for PBL.

Keywords: Learning outcomes taxonomies, engineering education, curriculum innovation, PBL

Type of contribution: conceptual paper

1 Introduction

The current societal and technological transformations induced for example by digitalisation, automation, and sustainability among others, are implicitly pushing for introducing new types of learning outcomes in classical engineering education programs. Besides a high level of technical expertise, future engineers will need more complex abilities for solving unprecedented problems while communicating and working within interdisciplinary teams. Engineers are more and more pushed towards acquiring a web of competences tying, among others, innovation, creativity, adaptability, flexibility, and dealing with a more uncertain world than before. Educational policies, institutional strategies and management boards recognise the need for active learning environments and student-centred curriculum in order to develop the aforementioned skills and competences. However, it is engineering educators and practitioners that operationalise change by, for example, revising and reformulating their courses' learning outcomes, learning activities and assessment approaches.

Problem-based, project-organised (PBL) and 'Conceive-Design-Implement-Operate' (CDIO) are examples of student-centred learning approaches that are gaining popularity in engineering education. In a PBL environment, groups of students formulate and solve real, authentic problems. PBL roots in cognitive and socio-constructivist theories, recognising students' role in constructing knowledge and predisposition towards learning as well as their experiences, prior knowledge and cognitive structures as fundamental components of how they learn (Savin-Baden and Howell, 2004; Kolmos et al, 2009). PBL is characterised as problem-based, collaborative, contextual, experiential, exemplary, participant-directed, emphasise relation theory-practice, interdisciplinary and project-organised (or case-organised). To implement PBL, institutions and teachers undertake a process of curriculum and course change, following PBL characteristics and the principles of curriculum alignment. Based on PBL curriculum examples, Kolmos et al (2009) pointed the curriculum elements and their alignment, which are (i) learning objectives and knowledge, (ii) type of problems, projects and lectures, (iii) progression, size and duration, (iv) students' learning, (v) academic staff and learning, (vi) space and organisation, (vii) assessment and evaluation. Changes in one of the curriculum aspects implies changing the others as well. From here, it is necessary to determine the different disciplinary knowledge required to solve the problem, the duration, resources needed (e.g. infrastructures and lectures), the role of teachers and students, and the assessment methods to assess the learning objective initially framed. In sum, the PBL curriculum elements are interrelated and provide a holistic representation of the curriculum. In addition, each of the elements presents a landscape of possibilities leading to a variation of PBL models designed and implemented in engineering education, at system, programme, or course levels (Barrows & Tamblyn 1980; Savin-Baden & Howell 2004; Kolmos et al. 2009).

Literature claims that PBL promotes the development of learning outcomes in all levels of taxonomies, therefore we see a need for developing practices and a taxonomy that helps the teacher to analyse the learning outcomes and from there develop more deep learning activities based on PBL. It is hard to evaluate practices without a proper framework, especially if we search for the connection between developing learning outcomes and its effect on learning activities.

Less content coverage, more time for preparation, lower evaluations, students' lack of knowledge, re-build one's identity as teacher, lack of "how-to-do" knowledge, difficulty to predict learning outcomes and ensure "quality control" are some of the barriers teachers face when changing their courses towards active, student-centred learning such as PBL (Michael, 2006). In our specific case as engineer educators, we frequently experience the reformulation of learning outcomes as a point of departure to innovate our courses and engineering programmes as one of the most challenging tasks. For example:

- how to use appropriate formats, terms, and standards, in order to avoid descriptions and formulations that may be interpreted in different ways by different stakeholders, including students and employers;
- how to make explicit and time-related inter-relations of the curriculum's different courses and modules, in order to avoid structural progression issues, such as content overlapping, misalignments and curriculum overloading,
- how to highlight "learning-ladders" (i.e. learning progression) by making expectations, roles and responsibilities explicit and clear to students (e.g. what they need to know and why, for different contexts and challenges, professionally and socially), and in order to motivate students to develop deep learning (i.e. create intention to understand, vigorous interaction with content, relate concepts with everyday experience, relate ideas with previous knowledge, relate evidence to conclusions, examine logic of the argumentation (Savin-Baden and Howell, 2004).

In the ideal situation an engineering programme is created from a future role of a competence needed or assumed. From the expected final competences learning goals and courses are created and designed to achieve these goals for the graduated engineer. Therefore, the programme design shall origin from a top-down perspective and not bottom-up, i.e. (existing) courses are put together to form the program.

There are a few conceptual pedagogical frameworks capable of supporting engineering educators in reformulating their courses' learning outcomes, developing aligned learning activities and assessment methods in order to change their courses coherently and systematically towards PBL. For example, the constructive curriculum alignment (see for example Tyler, 1949; Biggs, 2003; Cowan et al, 2004) and taxonomies to formulate learning outcomes (see for example Bloom's revised, SOLO, and Feisel-Schmitz's Technical taxonomies). In this paper, we focus on the point in the formulation of learning outcomes and their implications for active learning and PBL at course level.

According to Biggs (2003), each course builds on previous knowledge, either prerequisites from earlier courses or from learning outcomes within the course. Therefore, each course has its own hierarchy of learning outcomes .Taxonomies for formulation and analysis of learning outcomes include different types of knowledge and verbs that describe a performance of the level and type of knowledge learned. The taxonomies provide support and guidance to engineers educators to re-formulate the learning outcomes of their courses, and programmes. However, they are not clear on how to formulate learning outcomes relevant for engineering education and practice, show explicit hierarchical progression and development within engineering concepts, formulation of transversal skills and non-cognitive learning outcomes. Furthermore, it is also needed to integrate the taxonomies frameworks as part; for example, IT tools to enable educators to continuously align their courses' learning outcomes, with PBL approach and with societal and professional trends. In this paper we focus on learning outcomes taxonomies and how they can better serve engineering educators to re-formulate learning outcomes at course level. We start by describing three different learning outcomes taxonomies, namely Bloom's (revised) taxonomy, SOLO taxonomy and Feisel-Schmitz Technical taxonomies, see Section II. The taxonomies are then used as a framework to analyse the learning outcomes of four existing courses in different engineering programmes at two different universities in Norway and Sweden. The analysis is presented and discussed in Section III. We finish the paper with a conclusion section, where we reflect on the limitations of the taxonomies used and their implications to implement student-centred methodologies such as PBL.

2 Taxonomies for describing learning outcomes

In this section, we revise three types of taxonomies commonly used to describe learning outcomes and respective knowledge levels. These revisions are, obviously, rather concise and containing information pertinent only for the purposes of the discussions raised in this paper. To know more, we suggest the readers to consult the literature we refer to.

2.1 The Bloom's revised taxonomy (Krathwohl et al. 2002)

This taxonomy models learning as the intersection of a *Cognitive Process Dimension* (CPD) and a *Knowledge Dimension* (KD). Each dimension is then represented as a series of hierarchical steps, each step capturing a different level of complexity. The CPD can be described as a series of levels that go from *Concrete Knowledge* to *Abstract Knowledge* by the means of so-called *Objects* (usually a noun). For example, knowledge may be listed as *Factual*, *Conceptual*, *Procedural, Metacognitive*, and so on. Instead, the KD can be described from lower order thinking skills to higher order thinking skills using so-called *Actions* (usually a verb). Examples are *Remember*, *Understand*, *Apply*, *Analyze*, *Evaluate* and *Create* (Andersen & Krathwohl (2001 p. 46)). Importantly, the steps in the CPD include both procedural and conceptual knowledge; and since procedural knowledge may not be more abstract than conceptual knowledge in all steps, the steps in the CPD are not entirely hierarchical. The same non-hierarchical nature can be argued also for the KD, since similar reasonings apply to this dimension.

2.2 The SOLO taxonomy (Biggs & Tang 2011 p. 86ff)

The Structure of the Observed Learning Outcome (SOLO) taxonomy attempts to model whether learners capture relationships and connections or not among different learning outcomes. The resulting classification is thus in terms of complexity of the puzzle that learners construct in their mind: this hierarchy is modelled through five taxonomic levels (i.e., *Prestructural*, *Unistructural*, *Multistructural*, *Relational*, and *Extended abstract*) and a list of verbs associated to each level. More precisely,

- *Prestructural* indicates a generally insufficient knowledge about a specific learning objective,
- *Unistructural* indicates the situation where the learner has captured some few salient aspects of the learning objective, i.e. define, identify, draw, label, match or follow a simple procedure.
- *Multistructural* indicates a situation where the learner captured several aspects of the objective, but is still not able to relate them, i.e describe, list, outline, complete, combine, calculate.
- *Relational* indicates the capability of capturing the relations mentioned above, i.e. sequence, classify, compare and contrast, explain (cause and effect), analyse, apply etc.
- *Extended abstract* indicates the capability of generalizing the relations above to yet untaught learning objectives, i.e. generalise, predict, evaluate, reflect, hypothesis, theorise, create, prove etc.

The first three levels relate to a "quantitative" phase of knowledge, while the latter two to a "qualitative" one that promotes deep learning.

2.3 The Feisel-Schmitz Technical taxonomy (Feisel 1986)

This taxonomy divides all learning in technical subjects into four performance objectives. There is also a fifth, Judge, but the inventors considered it "beyond the scope of most technical education programs", and is therefore not normally taught in traditional University programs. However, the ability to solve complex problems is one of the most important competencies engineers graduates should have in order to operate in a globalised and volatile profession. This requires the ability to judge as Feisel states.

- *(ability to) Define*, i.e., learning the terminology of a discipline and be able to communicate it efficiently with others who are similarly prepared,
- *(ability to) Compute*, i.e., perform required formal computations using specified formulas or procedures,
- *(ability to) Explain,* i.e., understand the phenomenon well enough to describe it orally or mathematically at the point where creative analysis could be performed,

- *(ability to) Solve*, i.e., problem definition, analysis, synthesis, and to a considerable extent, the process of design,
- *(ability to) Judge*, i.e., to evaluate multiple solutions, select an optimum solution, evaluate supporting evidence.

Since the taxonomy is a part of a paper on creating a system for self-education, it shall be noted that the writer especially stresses learning objectives other than the explicit course goals, i.e., *orthobjectives* (objectives which bear almost no relation to the explicit goals of a course; orth=orthogonal) and *perobjectives* (a capability or attitude that is taught throughout the learning experience). A more commonly used term is transversal skills, but there are differences between them, especially for the *perobjectives*. We note that the aim of this manuscript is not to make a clear distinction or define them.

2.4 Comparing the three taxonomies to formulate learning outcomes

The three learning taxonomies have in common the following aspects:

1. They all use **active verbs** to express students' performance. The verbs do not represent knowledge per-se, but rather refer to objective and explicit behaviours that show learning is taking place. They are particularly relevant to define the activities students need to perform to learn a given content, and be assessed;
2. They all present **hierarchies and subsuming levels** of learning outcomes to capture increased complexities of different cognitive tasks. This means that the learning outcomes and respective learning activities may be organised accordingly to these developmental and progressive levels to optimize learning. It means that knowledge is not only about *know that* but also, *know how*, and *why*, in conjunction;
3. They all consider **different types of knowledge**. Namely, factual, conceptual or declarative (knowledge as content, broken into facts and principles - *know what*), procedural (derive knowledge from factual knowledge and apply to solve problems - *know how*), metacognitive (knowledge about the interplay between person, task, and strategy characteristics - *know why*) (Flavell, 1979; Crawley et al 2014; Eustace, 1999).

Importantly, the above common aspects provide some consistency among the three taxonomies. What defines each of them is thus the different use of the various verbs, the differences in the hierarchies and subsuming levels, and the different types of knowledge addressed by them.

On the other hand, the three analysed taxonomies present the following limitations:

1. **They have generic character**, i.e., they do not consider the disciplinary domain, the nature of discipline concepts and how they build on each other, with partial exceptions for the Feisel-Schmitz Technical taxonomy (Feisel 1986), suitable to formulate learning outcomes for technical fields even if not presenting an explicit hierarchical structure and types of knowledge like the other two. For example, engineering sciences require learning complex concepts that have hierarchical nature. Learning these concepts depend on a network of related concepts, or prerequisites (Eustace, 1999). Engineering curricula include many complex concepts that are both core knowledge of one course and prerequisites for others. Structuring learning in engineering programmes and courses also means organising its learning outcomes hierarchically to observe students' learning. Gagné et al (1962) revealed that learning successive "learning sets", i.e. learning outcomes, was dependent on mastering prior sets. This is particularly relevant for learning outcomes for complex concepts, and how to organise learning activities, being more centred in the teacher or being more centred in students. This is especially important for the PBL environment, where students become responsible for their own learning and construction of knowledge. There is a change of ownership, i.e. students become more active, responsible and autonomous learners, whilst the teachers are not

transmitting knowledge but rather scaffolding and facilitate students learning. Designing learning outcomes for PBL also means that it is needed to align them, their complexity and hierarchical nature, with students' and teachers' roles in the learning process.

2. **The analysed taxonomies do not consider non-cognitive learning outcomes**, such as emotional maturity, empathy, interpersonal skills and collaboration, communication, that are in demand for future engineering practice. The current trends in engineering education (e.g., industry 4.0, digitalisation, automation, and sustainability) call for a new set of skills and competences that go beyond the technical expertise. Examples of these competences are: systems thinking, complex problem solving, ethical and professional responsibility, creativity, lifelong learning, interdisciplinary collaboration, adaptability and flexibility, digital literacy, sustainable mindset (Guerra et al, 2017; Guerra and Nøgaard, 2019). It is proven that PBL promotes the development of the aforementioned skills and competences, see for example the increase of publications in engineering education research and practitioner literature, such as in the Journal of Engineering Education, European Journal of Engineering Education, International Research Symposium on PBL (IRSPBL) proceedings, and Project Approaches in Engineering Education (PAEE) conference proceedings. The three taxonomies analysed in this manuscript do not consider the non-cognitive dimensions of learning, such as emotional dimension (Illeris, 2008), therefore it is challenging to formulate non-cognitive learning outcomes, or transversal skills, under the frame of these three taxonomies.

In sum, changing engineering courses to more student-centred approaches by implementing PBL requires a reformulation of learning outcomes, organised hierarchically and designing aligned teaching and learning activities. In hybrid PBL models, where the curriculum includes lecture-based courses and PBL projects, the learning outcomes are not only structured hierarchically but also organised in more teacher-centred activities, e.g. lectures, and more student-centred activities, e.g. project work (Aalborg University, 2019). The following section discusses the use of the three taxonomies to re-formulate learning outcomes in four engineering courses.

3 Strengths and weaknesses of learning outcomes taxonomies for engineering education: four case examples

In the following we discuss the use of the taxonomies to complement the existing descriptions of intended learning outcomes of four engineering courses from two nordic universities. The aim is to use the taxonomies, and discuss their application in: (i) formulating the course goals and expected learning outcomes, (ii) describing at what level each outcome should be mastered to reach a deeper understanding, (iii) using the taxonomies for constructive alignment purposes (i.e., planning and designing exams and lessons in connection with the courses' goals), and (iv) improving the learning activities towards PBL.

3.1 Description of the courses used as case examples

The engineering courses for which we tested using the taxonomies defined above are:

C1) 1TE661, Signals & Systems at Uppsala University, 5 ECTS credits

C2) 1TE717, Digital technology and electronics at Uppsala University, 10 ECTS credits

C3) 1TE770, Analogue electronics at Uppsala University, 10 ECTS credits

C4) TTK4260, Multivariate Data Analysis at NTNU in Trondheim, 7.5 ECTS credits

These courses employ different active, student-centered learning approaches and strategies. The course 1TE661 (case C1) is usually taught within a 6 to 8 weeks teaching period in two different settings: 1) a fairly classic, traditional setup with 13 lectures and 7 tutorials, where active participation is encouraged by using clickers and small group discussions interrupting the lectures, and 2) in a setup where students are given all course material (including course script, exercises with solutions, lecture videos) and additional material such as a list of course goals specifying the requirements to pass the course, how they connect to the course material, and a week-plan suggesting what students should focus on in each course week. Then, students are divided into groups of up to eight students (by their choice) and each group is given a group tutorial of one hour each week. For details, please see Staffas and Knorn (2019). Note that, the course material and requirements as well as the course goals remains the same in both setups.

In the second course, 1TE717 (case C2), the students begin with 5 weeks of interactive lectures, exercises sessions and labs. This first part introduces the core facts and procedures related to electronics. The second part of the course consists of 4 weeks of group project work. Each group freely selects a “product” that must be developed, and a “client/consultant” (teaching assistant) is assigned to each group. The students have to systematically conceptualise, design, and implement a working prototype fulfilling the “product’s” specifications and requirements. The teaching assistant has a dual role of stating the product’s requirements and inquiring about the status of the product (client), as well as providing high-level assistance at the conceptualisation and design stages (consultant).

The third course, 1TE770 (case C3), uses a working model where most of the lectures are micro lecturing online and learning with the teacher is mainly through group work with simulations based on the course goals. In the lecture hall, focus is on what the connection is between this week’s learning goals and the real world.

Last but not least, the course TTK4260 (case C4) is a 13-weeks long course on data analysis that includes flipped classes, peer instructions, and home assignments that partially conform with the PBL approach (in the sense of pushing students to learn about a specific part of the course through solving a specific problem described during the frontal lessons by the instructors). The original intended learning outcomes for this course were written in a way that emphasized non-cognitive knowledge (especially creativity, critical thinking, and ability to work in teams), even if this was seen as a naive strategy by the instructors.

3.2 Description of the evaluation form

The three taxonomies above were used to analyse the course goals of the courses in 3.1. To better describe the methodology used to perform this analysis, the following box exemplifies the operations performed for course 1TE770 (case 3).

Box 1. Example of the form used to revise the course goals using the three taxonomies investigated in this manuscript.

Pre-existing course goal: ‘calculate the gain for a resistive OP circuit with negative feedback’

Reformulation according to Bloom’s Revised Taxonomy (BRT):

- analysis of the prerequisites: **Apply** Ohm’s law; **Apply** Kirchoffs laws; **Apply** Equation system
- rephrasing of the intended learning outcome:
    - **Understand** the consequences of negative feedback for the voltage on the inputs;
    - Express $U_{UT}(U_{IN})$ where U_{IN} is the difference of the voltage inputs on + and –. This is at the **Apply** and **Analyze** level

Reformulation according to SOLO Taxonomy:

- analysis of the prerequisites: know Ohm’s law, Kirchoffs laws, and Equation system at a **Relational** level
- rephrasing of the intended learning outcome:
    - reach a **Multistructural level** connecting the consequences of negative feedback for the voltage on the inputs with $U_{UT}(U_{IN})$ where U_{IN} is the difference of the voltage inputs on + and –

Reformulation according to Feisel-Schmitz Technical (FST):

- analysis of the prerequisites: be able to **Explain** Ohm’s law, Kirchoffs laws, and Equation system
- rephrasing of the intended learning outcome:
    - be able to **Compute** the consequences of negative feedback for the voltage on the inputs;
    - be able to **Explain** $U_{UT}(U_{IN})$ where $U_{IN}$is the difference of the voltage inputs on + and –

3.3 Summary of the reflections for the different taxonomies

Reflections on using Bloom’s Revised Taxonomy (BRT)

Strengths: Being quite famous, there exists quite some material about this taxonomy; this means that it is feasible for teachers to look for aid in interpreting the verbs defining the various taxonomy levels. Also, it is likely to be included in teacher training courses due to its popularity and widespread use.

Weaknesses: Analysing relevant intended learning outcomes using Bloom’s notation was generally experienced as difficult and arbitrary. Specifically, the level “*understand*” puzzled some of the instructors of the courses above. We note that in Bloom’s original work he used “comprehend” instead, which might make some sense why we experienced that “understand” should (could) be at a higher level in the Cognitive process dimension. On top of this, ”evaluate” was considered below “*apply*” as another example. To put it simple: the number of verbs (and its hierarchical order) was confusing the teachers. The main problem experienced with this taxonomy can be thus summarized into its unsuitability in handling progression in content. This makes it hard to build “as-is” in Higher Education (a result that is in line with Brabrand and Dahl 2009).

Reflections on SOLO taxonomy

Strengths: The levels are clearer than for the BRT, and they are perceived as capturing progression in a course in a more natural way. The taxonomy is perceived moreover as helping connecting different learning environments (i.e. TLA's) with the various intended learning outcomes. We also note that the various instructors perceived that to reach the Qualitative phase having a clear intuition of the context surrounding the TLAs and intended outcomes became more important.

Weaknesses: The descriptions of the levels are perceived as rather abstract, which makes it hard to get a consistent categorisation among different teachers. The perception is also that this taxonomy is not easily applicable for non-operational competencies (communicative and activities), and thus that it is not easily applicable to non-cognitive outcomes. Like the BRT, thus, this taxonomy suffers in capturing progression in content and does not consider the prerequisites.

Reflections on Feisel-Schmitz Technical taxonomy

Strengths: All the teachers of the courses above perceive the levels to build up on each other in an intuitive and clear way. As noticed also for the SOLO, many of the learning goals are reached on a low level (perhaps too low), which helps the teacher realise how to improve the course descriptions (and the course itself). The taxonomy is perceived as much more appropriate to describe engineering education; for example, engineering teachers can relate immediately to the fact that one can compute something without being able to explain it. Another positive side of this taxonomy was the fact that it was possible to define the levels independently from the definition of the prerequisite knowledge.

Weaknesses: Some levels seem to be dependent; more precisely, *Explain* & *Judge,* and *Compute* & *Solve*. The common opinion of the teachers was that the *Judge* should be seen as a more complex version of *Explain*, while *Solve* should be a more complex *Compute*. However there was some discretionality in the intuitions of the teachers, making it almost impossible to distinguish the levels of learning in an objective way.

3.4 Concluding remarks

Somewhat surprisingly, the Knowledge dimension of BRT very much resembles the Feisel-Schmitz taxonomy: Define / fact; Compute / procedural; Explain / conceptual; Solve, Judge / metacognitive. On the one hand, this points to contradic-tions and conflicts between the two taxonomies (in the sense that FST should in principle be mapped to the Cognitive Process dimen-sion), and on the other hand it feels natural that specific categories of knowledge objects and mostly associated with specific levels of cognitive skills. Further, none of the taxonomies is specifically devised for the special environment of the intended learning outcomes of the courses above. Additionally, the above reflections highlight the relevance of the disciplinary domain in formulation of learning outcomes, which lacks in BRT and SOLO whilst FST makes it more intuitive and clear for teachers to use it in their technical fields - this is probably related to which conceptual meaning verbs have and what they enclose in engineering practice. In sum, a taxonomy for engineering education needs also to be contextual, i.e. relatable with 'language' and practice. However, such FST is not without limitations, namely in showing the hierarchical levels of learning and non-cognitive outcomes. In conclusion, it is needed to develop a taxonomy that brings together the strengths of the three taxonomies and includes the non-cognitive, transversal skills that 30 years ago were not perceived relevant to engineering education. Furthermore, the limitations of the taxonomies also affect in which ways PBL is integrated in the courses, namely the difficulties in designing activities which would be student-centred, and which would be teacher-centred. Consequently, other curriculum elements such as type of facilitation, problems and learning progression would also be challenging to define. In sum, taxonomies pose limitations in defining which PBL approach would be more suitable for a given course, its learning, to create a coherent and aligned curriculum, both in its written form (i.e. course descriptions), operationalised (i.e. what teachers do in practice) and experienced (i.e. what students experience in practice)forms.

4 Conclusion

Although the paper addresses one or two courses from different programmes, there is a clear strategy on how to build curriculum coherence since the coherence start with building up the hierarchy within the courses from the prerequisites (from earlier courses), and how the learning outcomes become prerequisites (or graduated expertise) for later learning outcomes and courses. This bottom-up approach comes from the decided fact that the programme learning goals are established and broken down to courses and their learning goals.

As a premise, we note that none of the taxonomies was developed considering the specific environment of the courses. All the authors agree that the FST is the most intuitive and useful in categorizing and describing the intended learning outcomes of the considered courses. However, adding these taxonomic descriptions did not significantly help making the learning activities more student-centred or PBL oriented. This is deemed to be due to the difficulty of connecting the different learning outcomes with learning activities and environments. Therefore, a common perception was that using a taxonomy for classifying, improving and rewriting the intended learning outcomes may benefit from some generic extension that enables to connect the learned content to its place in the curricula of the course/program (probably most importantly the program).

The developed intuition is that to promote deep learning and synthesizing effective PBL activities there is the need for taxonomies that are effective in revising and complementing courses. The envisioned taxonomy should nurture the progression of the program where teachers see how their taught knowledge is used in a further context, and in this way promote collaboration possibilities as themes, problems or project based, also within the teaching body.

The discussions around the creation of this manuscript led also to thinking at the following future works: how can we guarantee a method for investigating curriculum coherence? The intuition is that capturing cognitive abilities is easier than capturing non-cognitive ones. There is thus the need for taxonomies (and associated workflows) to express non-cognitive learning outcomes as transversal skills. It is the authors' belief that the envisioned taxonomy and workflow shall be clear, non-interpretable, and making sense in a self-standing way.

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