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In Pursuit of Greater Coherence Between Learning Outcomes and Competence Development for Successful Teaching of Engineering

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Abstract. Although learning outcomes are widely used in higher education in programme design, most course developers end up considering only the cognitive domain while overlooking the affective and psychomotor domains, the other two musketeers of the taxonomy of educational objectives. Similarly, in planning programmes for competence development, the focus is usually narrowed to the instrumental competence dimension, with relatively less attention given to how interpersonal and systematic competences might be developed. This results in poor alignment between learning outcomes and competences, including subject specific and generic or key competences. This occurs both at module and programme level. In order to address this, course developers need a more holistic and systematic way of programme planning, especially where the ultimate goal is to attain technical and transversal competences needed for the workplace. This paper draws on an Erasmus+ capacity building in higher education project in Thailand's non-university tertiary education sector (RECAP 4.0) to explore how curriculum developers may be supported in dealing with this challenge. During the project, ten modules were designed to support the professional development of higher education teachers in areas related to teaching enhancement, curriculum development, and various engineering topics. Developers were provided with a competence development template designed to support greater alignment between planned learning outcomes, intended competences, teaching activities and assessment plans. The template invited them to reference more than one domain as appropriate when writing each learning outcome, indicate the intended performance level for each of the domains, as well as the competence(s) to which the learning outcome contributed. The results show how such a template may support optimum coherence in curriculum design.

Keywords. Competence development, Bloom's taxonomy, transversal competence, engineering education

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Introduction

There has been an increasing emphasis on competence development in professional higher education, driven by the need to ensure graduates are adequately prepared for the demands of their professional practice [1]. This is the case for engineers, as it is for other professions.

Competence refers to the application of knowledge, skills and attitudes in a particular situation, often ill-defined such as in the workplace. Although differences exist in how competence is conceptualised, there is a widespread understanding that it involves a combination of cognitive, psychomotor and affective learning. Three types of generic competences may be identified: instrumental, interpersonal and systemic [2]. Coherence is needed between these competences that graduates ultimately need in their work and the learning outcomes used to get there, where coherence refers to systematic connection or consistency.

However, despite the increased emphasis on competence development and a recognition that it relies on a range of different knowledge, skills and attitudes, the learning outcomes that feature in engineering programmes tend to be drawn overwhelmingly from the cognitive domain. When writing learning outcomes, programme developers rely overwhelmingly on the taxonomy for the cognitive domain, developed by a committee under the leadership of Benjamin Bloom [3], commonly referred to as Bloom's taxonomy. Yet, this does not reflect the reality faced by graduates in the workplace where performance requires a range of cognitive, affective and psychomotor learning. This mismatch between what a programme is designed to do and the professional needs of graduates results in a loss of programme coherence and effectiveness.

Coherence is also required between learning outcomes, teaching activities and assessment. Teaching activities must be geared towards the intended learning, which should also correspond to the learning to be demonstrated in the assessment. There is also a need for the teaching and assessment to cater for the learning at the right level in terms of challenge or complexity. While the learning outcome may convey some information about the intended level of performance, this may not always be so clear or explicit. Rubrics may indeed be developed at assessment stage to provide precision. However, keeping the relevant taxonomic levels to the fore in the programme development process may also be useful for further supporting programme coherence.

All of this points to the need for programme developers to be mindful of how greater programme coherence may be achieved – by attending to the multi-domain nature of learning when writing learning outcomes (not just cognitive, but also affective), ensuring alignment between teaching, learning and assessment, and conveying the performance levels needed in explicit terms. Supporting programme developers in this endeavour can help ensure greater coherence between programme design and the kind of competence development needed for the 21st century workplace.

Drawing on an Erasmus+ capacity-building project currently underway in Thailand (RECAP 4.0), this paper examines how programme developers in engineering education may be supported in planning for greater programme coherence through the use of a backward-mapping approach to programme development. This requires developers to first identify the competences and then work backwards to formulate the learning outcomes and plan the teaching and assessment activities.

1. Competence development and programme coherence

The increasing emphasis on competence development has highlighted the need for optimum programme coherence. Both these issues are addressed here in turn.

1.1. Competence development

Competence is generally assumed to be prerequisite for adequate functioning on the job [1,4]. It may be expressed in subject specific or generic terms, the latter being geared towards employability and citizenship. Of the three types of generic competences that may be identified, attitude is important for the second and third kind, i.e., interpersonal and systemic:

- Instrumental competences: cognitive abilities, methodological abilities, technological abilities and linguistic abilities;
- Interpersonal competences: individual abilities like social skills (social interaction and co-operation);
- Systemic competences: abilities and skills concerning whole systems (combination of understanding, sensibility and knowledge; prior acquisition of instrumental and interpersonal competences required) [5].

Competence may therefore consist of integrated pieces of knowledge, skills and attitudes [6]. In fact the triad of 'knowledge, skills and attitudes' has featured for a long time in the discourse, corresponding respectively to the cognitive, psychomotor and affective domains. In practice, it is the cognitive domain that has been used most in programme design, which is equated with knowledge. Less use is made of the affective and psychomotor domains, even though these also formed part of the framework proposed by the committee led by Bloom in 1956. In fact, Bloom himself was later involved in the development of the taxonomy for the affective domain [7].

Even in the more recently-introduced triad of 'knowledge, skills and competences' that has now gained currency in the discourse, attitude is understood as being part of skills and competences. It is indeed true that skills refer historically to the psychomotor domain. However, Argyle [8] was among the first to propose that skills may also have an affective dimension given that engaging in social interaction also requires an organized, skilled performance, analogous to psychomotor skills. Two major groupings in such interpersonal skills are communication skills and relationship building skills [9]. Attitudes are therefore considered to be, 'an important component of vocational competence, distinguishing it from 'mere' knowledge and skills' [10]. The following definition of learning outcomes also conveys the centrality of attitude for competence development:[2]

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[2] Paradoxically, it is true that in other parts of the ECTS users' guide, there is less acknowledgement of the affective component. For example, the definition for learning outcome is primarily cognitive and psychomotor, i.e., knowing and doing, with no provision for affective learning: 'Learning outcomes are statements of what the individual knows, understands and is able to do on completion of a learning process' (ECTS Users guide, p. 10).

> *Learning outcomes are specified in three categories – as knowledge, skills and competence. This signals that qualifications – in different combinations – capture a broad scope of learning outcomes, including theoretical knowledge, practical and technical skills, and social competences where the ability to work with others will be crucial. (ECTS Users Guide, p. 20)*

Despite competence encompassing attitudinal and affective learning, it is the cognitive domain that has dominated programme design. In fact, the introduction of the knowledge dimension in the revised taxonomy for the cognitive domain may simply further reinforce the view that knowledge is primarily about cognitive processing only [11]. The addition of a taxonomy table, with a horizontal and vertical dimension draws attention to the cognitive processing levels as before, but now includes in addition the kinds of knowledge being mobilised, i.e., factual, conceptual, procedural, and metacognitive. The latter two kinds are of relevance for our discussion here and are defined as follows:

> *Procedural Knowledge is knowing how to make or do something. It includes methods, techniques, algorithms, and skills. It also includes the criteria one uses to determine when to use appropriate Procedural Knowledge. Finally, Metacognitive Knowledge is knowledge of cognition in general as well as awareness and knowledge of one's own cognition, it includes strategic knowledge, task knowledge, and sell-knowledge.*

Procedural knowledge is knowledge of how to do something and may therefore be considered to include psychomotor domain. However, while the definition of metacognitive knowledge does include 'self-knowledge' and therefore includes elements of affective learning, the more extensive treatment of this kind of learning in the affective domain [7] is missed. It means that the revised taxonomy for the cognitive domain on its own does not capture the full extent of the affective learning that may be relevant. This relative neglect of the affective domain becomes problematic given the increasing importance of generic or transversal competence development, for example, team work, intercultural competence, initiative, enthusiasm, risk-taking, and consensus building.

1.2. Programme coherence and curriculum alignment

A second issue to be considered is the coherence between the required competence development (along the lines of what has been outlined above), and the learning outcomes in the professional higher education programmes. As part of the professional accreditation process in engineering, for example, higher education institutions (HEIs) are required then to map their own programmes against relevant professional standards. HEIs may also pursue programme coherence as part of their own internal quality assurance effort.

There must also be alignment between learning outcomes, teaching activities, and assessment. These issues are generally discussed within the context of constructive alignment [12,13] although the essentials can be traced back to Tyler [14], and developed later by Shuell [15].

Constructive alignment requires an optimum correspondence between learning outcomes, teaching and learning activities, and assessment using a learner-centred approach. It is based on the twin principles of constructivism in learning and alignment in the design of teaching and assessment. Learning is constructivist, where it involves students constructing meaning through relevant learning activities, as opposed to more expository forms of teaching and knowledge transmitted. Alignment refers to the correspondence between the intended learning outcomes, the teaching and learning activities, and the assessment tasks used to verify that the intended outcomes have been achieved. The pursuit of constructive alignment has led to the development of the SOLO Taxonomy - structure of the observed learning outcome - using five hierarchical levels that range from incompetence to expertise [16]. As with other taxonomies, the learning outcomes display similar stages of increasing structural complexity, regardless of the academic discipline, so that the new knowledge becomes gradually integrated into a structural pattern. SOLO provides a systematic way of describing how a learner's performance grows in complexity and can be used to describe where students should be operating, and where they are actually are operating.

Constructive alignment may be pursued through a process of backward mapping, as featured in the Understanding by Design (UbD) curriculum planning framework [17]. Backward mapping, which can be traced back to Tyler's seminal work Basic Principles of Curriculum and Instruction [14], begins with the end in mind, i.e., the desired results (goals or standards), then considers the evidence of learning (performances) required by the standard, and finally the teaching needed to equip students to demonstrate this learning in the assessment [17]. Although designed with compulsory schooling in mind, the principle and methodology involved has relevance for any sector. As well as being used in initial programme development, backward mapping may also be used as part of a curriculum mapping exercise to check for existing programme balance and coherence. Checking for coherence between what is planned, taught and assessed also provides the basis for a much richer educational experience, and addresses the criticism levelled at rational approaches to curriculum planning that it curtails the spontaneity, dynamism and richness of truly educational encounters by being overly prescriptive [18]. Backward mapping is a particular approach to curriculum mapping undertaken to check and plan for greater programme coherence [19]. This promotes transparency for students and staff, as well as coherence and efficiency of programme content, teaching and assessment approaches [20].

Drawing on a curriculum design process undertaken as part of the Erasmus + RECAP 4.0 project, this paper seeks to show how a process of curriculum mapping at the initial programme design stage, using a course design template, can support developers in ensuring greater coherence in their programme development. Working with developers in this way makes it possible to observe how they plan for coherence and whether they unduly confine themselves to certain kinds of competence, most notably, instrumental competence, favouring the cognitive domain to the detriment of the other domains, particularly the affective domain. It also shows the benefits of having a template where all the programme component parts are considered in tandem.

2. Methodology

As part of the RECAP 4.0 project, a series of ten graduate-level modules were developed to enhance the professional development (PD) of teachers in the non-university tertiary education sector in industrial engineering in Thailand. It focused in particular on their capacity for teaching knowledge and skills related to Industry 4.0. The professional development courses related to teaching enhancement, curriculum development and topics in industrial engineering. This was delivered using a train-the-trainer model, delivered initially to a group of 12 Thai trainers by the course developers. These trainers were all teachers employed in faculties of engineering in three project HEIs, having accepted to participate, following nomination by the Dean. The professional development was designed to develop their competence in teaching methodologies as well as their engineering subject knowledge. For each course, trainers received 15 hours training, 90 hours of follow-up coaching, and their own self-practice and study. At the end of the training, the course developers nominated two trainers from among the 12 to deliver the course to larger groups of ‘trainees’ based in either Rajabhat universities (previously functioning as Rajabhat institutes, and before that colleges for teacher training) and Rajamangala universities (promoted from the vocational-technical colleges) and focusing on programmes in science and technology.

The courses themselves were developed by a small number of expert developers drawn from Thai and European universities. These were experts in the subject disciplines, i.e., whether in Education (for teaching enhancement) or in engineering. A competence assessment template, developed by the work package leaders, was provided to developers to aid in programme design. In the template, competence was defined as ‘a quality of being able to apply a set of knowledge, skills, attitudes, and abilities to successfully perform ill-defined tasks in a defined work setting’ (RECAP 4.0 definition). The template comprised six parts for completion by programme developers as follows:

I. Module Competence: desired abilities of trainees after completion of self-practice and coaching
II. Module Learning Outcomes: describing what a trainee will be able to do either after the initial training or after follow-up coaching
III. Learning Assessment After Training Session
IV. Competence Assessment After Coaching Session
V. Summary

For each course, developers were to indicate in the template: (I) the overall competence to be developed using the instrumental, interpersonal and systematic categories; (II) the module learning outcomes, referenced to the three learning domains where relevant, i.e., cognitive, affective, and psychomotor, the competence to which the learning outcome contributed, as well as the taxonomic performance level required; (III) and (IV) the manner and timing of the assessment for each learning outcome, i.e., once the 15 hours training was complete, or later when the follow-up 90 hours of coaching was concluded; (V) course summary. This relied on a backward mapping approach therefore starting with an identification of the intended gradate competences.

Developers were invited to submit the completed templates to the work package leaders and use the feedback provided in an iterative process (involving more than one revision where necessary) to revise their drafts before arriving at a final version.

3. Results

The following section explains how this process was undertaken for one of the modules, Product Design and Development. The two competences identified by the developer were:

C1 Put the product design and development process into practice in a systematic manner (Instrumental, Systematic)

C2 Collaborate with others in the design and development of a product (interpersonal)

The task facing the developer was to identify the competences firstly and then formulate the module learning outcomes (MLOs), showing how they were geared towards one of the competences. The obligation to align outcomes to the overall competences to be achieved, and given the multi-faceted nature of these competences, had the effect of producing learning outcomes that were multi-domain, and not just cognitive. As argued above, traditionally, learning outcomes tend to generally emphasise the cognitive, with less attention given to the other domains, particularly the affective.

Table 1. Extract from the competence assessment form for Product Design and Development

No.	Description	Learning Level according to cognitive, affective, or psychomotor domains	Related Competence	Assessment period (T: Training, C: Coaching)
MLO 1	Demonstrate understanding of implementing product design and development process	• Understand • Responding	**C1**	**T**
MLO 2	Demonstrate understanding of the utilization of product design tools and techniques	• Understand • Responding	**C1**	**T**
MLO 3	Participate actively in product design and development activities	• Responding	**C2**	**T**
MLO 4	Identify sound business opportunity by using Blue Ocean Strategy	• Apply • Valuing	**C1**	**C**
MLO 5	Develop a suitable mission statement according to an identified business opportunity	• Apply • Valuing	**C1**	**C**
MLO 6	Apply product design and development systematically	• Apply • Valuing	**C1**	**C**
MLO 7	Appreciate working in a team environment	• Valuing	**C2**	**C**

Developers also had to indicate the intended performance level for each of the domains. In the example presented here, these were all at the lower order level. For example, the first module learning outcome, ('Demonstrate understanding of implementing product design and development process'), required the student to demonstrate understanding of the product design process. This learning outcome contributed to the first competences (C1) ('Put the product design and development process into practice in a systematic manner'). But in order to develop this competence successfully, there was more than just cognitive processing required. It is for this reason that the developer also identified the affective domain. This then called for teaching activities and assessment of a kind to encompass affective learning.

The requirement to identify the taxonomic performance level – in this case the responding level – adds further precision, in conveying what is needed to demonstrate achievement of the learning outcomes so that the corresponding competence may be developed to a minimally satisfactory level. In the example just cited, learning outcomes at this (responding) level convey acquiescence or satisfaction and interest in active response and participation on the part of the student. Performing at this level is necessary in order to develop the competence in question, i.e., put the product design and development process into practice in a systematic manner. The requirement to indicate the level also helps in planning for an active student role.

Identifying a performance level also helped in planning the time frame for the assessment of the outcome. Outcomes which involved understanding in the cognitive domain and responding in the affective domain could be assessed after the initial 15 hours training. Outcomes requiring the student to apply learning (in the cognitive domain) and to show a value for the new learning (in the affective domain) were generally assessable after the coaching stage, during which students would have opportunities to use the learning gained and transfer it to other contexts. Thus, for example, MLO 4 which required students to 'Identify sound business opportunity by using Blue Ocean Strategy' could be best assessed after the coaching.

4. Discussion and analysis of results

The results show how such a template supported efforts toward achieving optimum coherence in curriculum design. The various drafts produced by developers give insight into how they understood and operationalised curriculum alignment and competence development, with regard to their own modules. They needed to think carefully when indicating how each learning outcome mobilised more than one learning domain, as well as the performance level involved. Even where a learning outcome may be predominantly cognitive in focus, there is also potential for affective or psychomotor learning in order to better support the competence development. In other words, there was a need to be more explicit regarding the contribution of each learning outcome toward an overall competence, in order to ensure focus and coherence in the programme.

The template therefore supported designers in formulating a sharper and more useful wording in the learning outcome. Being mindful of the multi-domain nature of learning also addresses the criticism frequently levelled at learning outcomes that they promote a reductionist approach to learning, leading to 'significant gaps in knowledge, learning and teaching quality and to 'significant epistemological and pedagogical insights that remain hidden and inarticulate' [21, 22]. The greater attention afforded to the affective learning in the template broadens the epistemological basis of the intended learning outcomes.

The results point to the value in exploring the benefits, through further research, of other taxonomies as an addition/alternative. One issue worthy of investigation concerns the cognitive domain and the kind of knowledge mobilised within that domain. Biggs and Tang [23] note that in higher education programme there has been a tendency to privilege declarative rather than functioning knowledge: 'Curricula in many universities are overwhelmingly declarative with teaching methods correspondingly expository' [23]. There suggests merit in exploring how the newly-added knowledge dimension that accompanies the revised taxonomy for the cognitive domain [11] might enhance programme coherence, and whether they encompass knowledge that is educationally and professionally relevant. In fact, the pursuit of greater curriculum alignment was one of the reasons that prompted the revision of the taxonomy. Students may focus on surface learning strategies that may bring examination success, but do not enable them to solve complex problems once they graduate. Similar to Anderson and Krathwohl [11], the taxonomy from Fink [12] emphasises metacognition and also includes more affective aspects in the human dimension.

Finally, the UbD framework presented earlier also shows how a unique taxonomy can be used to achieve an integration between cognitive and affective. The framework includes six different 'facets of understanding' based on the view that students truly understand when they can do so in all six facets, i.e., explain, interpret, apply, have perspective, empathize, and show self-knowledge. Treating learning in an integrated taxonomy may be more conducive to achieving the coherence required. This may be more effective in producing rounded programmes where graduates develop the range of knowledge, skills and competences needed in today's world.

5. Conclusion

The results show how programme developers could be supported through the provision of a competence assessment template to better safeguard and ensure programme coherence during programme development. This was based on a backward mapping approach, where developers first identified the desired competences and then worked backwards to the formulation of learning outcomes, assessment and the taxonomic level of performance expected, as well as the teaching activities. The developers used feedback on successive drafts before finalising the programmes.

The successive drafts give insight into how developers understood and operationalised curriculum alignment and competence development. This was conducive to a sharper learning outcome that reflected the diverse learning needed for competence in the workplace, i.e., instrumental, but also interpersonal and systematic, and to avoid loose or unfocused and imprecise formulations in the learning outcomes. The process highlighted the merit in using a competence assessment template with accompanying support from curriculum experts. While the beneficiaries of the project reported here were higher education teachers of engineering in Thailand, such a template could also be used for programmes aimed at other groups, for example, engineers in industry, or indeed other professional areas. In the absence of mentors or experts to support them, the template could be constructed for independent use.

Overall, the research points to the need for programme developers to be mindful of the multi-domain nature of learning outcomes, alignment between teaching, learning and assessment, and expected performance levels. Curriculum mapping exercises such as this have the potential to ensure greater coherence, develop the competence of programme developers themselves, and make rational curriculum planning more effective.

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