Assessing Learning Outcomes and Engineering PBL Project Reports

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ABSTRACT

All over the world, higher education, in particular engineering education, is changing in response to rapid changes of society and its new challenges. Many attempts have been made to define new types of relevant knowledge, competences and skills. One of the initiatives is the TUNING-AHELO framework, which is a conceptual framework of expected/desired learning outcomes in higher education introduced by the OECD. Engineering is one subject area in a feasibility study of whether it will be possible to test learning outcomes globally.

The Problem and Project-Based Learning (PBL) approach is a widespread learning methodology in engineering education. At Aalborg University, Denmark, the PBL methodology is organized into projects in which students work collaboratively in small groups during an entire semester to solve ill-structured problems and submit project reports to document the learning achieved. According to research on the Aalborg PBL model for engineering education, students achieve several types of knowledge, skills and competences in this learning environment and it is claimed that students acquire interdisciplinary and complex knowledge due to the more open learning approach. The studies have been based on data from employers, faculty and students; however, the purpose of this article is to develop a methodology for the content analysis of project reports. The research question is if the TUNING-AHELO framework can be used as a framework for the analysis of PBL reports and if students will achieve the knowledge and competences that are defined in the TUNING-AHELO framework in a PBL curriculum.

The methodology applied in this study has its point of departure in the TUNING-AHELO framework and adjusts this to the content analysis of project reports. Three randomly selected project reports are analysed and, for this purpose, content analysis grids were built based on the TUNING-AHELO conceptual framework and applied to the students' final project reports. The study concludes that the TUNING-AHELO framework can establish a relevant framework for the content analysis, and the analysis of the three reports shows that the students actually achieve the learning outcomes that are explicitly formulated. The analysis also shows that the students learn more than captured by the TUNING-AHELO framework in terms of interdisciplinary and complex knowledge.

Keywords

Project-Based Learning, Problem-Based Learning, Engineering Education, TUNING-AHELO framework, Learning Outcomes

1. INTRODUCTION

Many studies of PBL have shown that PBL students, when compared to students conducting traditional studies, achieve a significantly higher degree of process skills and competences, whereas the scientific content knowledge is at the same level [1][2]. The research methodology used in these comparative studies is based on knowledge tests and constructs from traditional studies encompassing single discipline courses and individual learning approaches. A comparative study based on knowledge and competence constructs deriving from PBL-oriented curricula has not yet been done [3].

Looking at the research carried out on PBL studies, there is a dominance of data collection among stakeholders: students, academic staff, managers, employers, etc. Not very many studies, if any, have been looking at the learning outcomes demonstrated in the project reports. The analysis of the project reports is a step further in the direction towards the full analysis of the outcomes of PBL studies. Project reports serve as the documentation of students' learning outcomes of the project process. The reports do not mirror the process entirely, as the reports normally do not describe the many experiments and uncertainties experienced by the students. Furthermore, the reports made on the late semesters will usually not explicitly describe the process skills and competences such as collaboration, project management, search for knowledge, learning from external contacts, etc. The process skills and competences can be analysed implicitly as a well-organized report could reflect an integrated collaborative process. However, as the process skills and competences are well documented, our purpose is rather to analyse the scientific content knowledge. The project reports contain the scientific knowledge: the problem stated, the problem analysis, methodological considerations, the designs, the problem solving procedures and appendices with relevant documentation of the scientific learning process.

There is not just one model which can be applied to the content analysis of project reports, and we have been looking for models that can be adjusted. We have chosen the TUNING-AHELO model as the overall framework [4]. The AHELO project is an OECD project with the purpose of developing an instrument to

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assess learning outcomes globally. An ongoing feasibility study takes place and one of the subject areas is civil and mechanical engineering. The TUNING-AHELO framework can become a very important player in the future with impact on the assessment of students' learning outcomes [4].

Searching for a framework for the analysis of PBL projects, it would be a natural choice to initiate the analysis with the TUNING-AHELO framework to clarify if this can be used and/or adjusted to analyse the learning outcomes from the PBL reports. Table 1 shows the learning outcomes of the TUNING-AHELO framework and their distribution in four complementary strands of work.

Table 1. Tuning-AHELO conceptual framework of learning outcomes (adapted from [4])

Tuning-AHELO conceptual framework of learning outcomes	
Basic and Engineering Sciences	**1.** The ability to demonstrate knowledge and understanding of the scientific and mathematical principles underlying their branch of engineering
	2. The ability to demonstrate a systematic understanding of the key aspects and concepts of their branch of engineering
	3. The ability to demonstrate comprehensive knowledge of their branch of engineering including emerging issues
Engineering Analysis	**4.** The ability to apply their knowledge and understanding to identify, formulate and solve engineering problems using established methods
	5. The ability to apply knowledge and understanding to the analysis of engineering products, processes and methods
	6. The ability to select and apply relevant analytic and modelling methods
	7. The ability to conduct searches of literature, and to use data bases and other sources of information
	8. The ability to design and conduct appropriate experiments, interpret the data and draw conclusions
Engine ering Design	**9.** The ability to apply their knowledge and understanding to the development of designs to meet defined and specified requirements;
	10. The ability to demonstrate an understanding of design methodologies and to use these methodologies
Engineering practice	**11.** The ability to select and use appropriate equipment, tools and methods
	12. The ability to combine theory and practice to solve engineering problems
	13. The ability to demonstrate understanding of applicable techniques and methods and their limitations
	14. The ability to demonstrate understanding of the non-technical implications of engineering practice
	***15.** The ability to demonstrate workshop and laboratory skills*
	16. The ability to demonstrate understanding of the health, safety and legal issues and responsibilities of engineering practice as well as the impact of engineering solutions in a societal and environmental context, and to commit to professional ethics, responsibilities and norms of engineering practice
	***17.** The ability to demonstrate knowledge of project management and business practices, such as risk and change management and be aware of their limitations.*
Generic Skills	***18.** The ability to function effectively as an individual and as a member of a team;*
	***19.** The ability to use diverse methods to communicate effectively with the engineering community and with society at large*
	***20.** The ability to recognize the need for and engage in independent life-long learning*
	21. The ability to demonstrate awareness of the wider multidisciplinary context of engineering

Learning outcomes can be assessed during or at the end of the learning process, where they can be classified as process-related or product-related. In table 1, the learning outcomes numbered as *fifteen (15), seventeen (17), eighteen (18), nineteen (19) and twenty (20)* are closely related to the process of learning; therefore their assessment in the reports can be quite difficult. The TUNING-AHELO document is not clear about how to operationalize the learning outcomes and how to determine which indicators and taxonomies can be used in the analysis. We have not developed indicators in the sense of assessing the depth of achievement of the learning outcomes, but we have used the 21 learning outcomes as overall pointers. In any future development of the TUNING-AHELO framework, it is important to develop indicators in order to: (i) create learning environments to achieve the TUNING-AHELO learning outcomes (for example, Project-

Based Learning); and (ii) align these with, for example, assessment (for example, formative assessment).

2. METHODOLOGY

This study aims to understand if the TUNING-AHELO framework can be used to analyse PBL reports and if students will achieve the knowledge and competences defined in the framework in a PBL curriculum. The methodology applied in this study is a content analysis of randomly selected project reports with the purpose of assessing which learning outcomes the students achieved in their final project reports [5].

The study conducted had the following phases: (i) the construction of the analysis grids based on the TUNING-AHELO conceptual framework (framework used as a coding system); (ii) the selection and contextualization of three project reports (in English) written by students from the Master's programme "Master of engineering in water and environment" and found in the Aalborg University database (see table 2); (iii) the reading and application of the analysis grids to the reports selected.

Table 2. Context of the documents analysed

Report	A	B	C
Title	Analysis of different methods to remediate the pollution in Hjørring	Water quality status and future perspectives of Mariager Fjord	Investigation of a Possible Hot Spot Oil Pollution Site and its Effect on Groundwater Quality
N.º of pages	114	112	85
N.º of students	5	5	5
Semester/ year	7th/ Autumn 2009	8th/ Spring 2010	7th/ Fall 2009
Theme(*)	Soil and ground water pollution	Lake and coastal marine ecosystem	Soil and ground water
Methodology used	The methodology used included: (i) field work, with *selection of wells to collect water to conduct slug tests*" and "*collection of undisturbed and loose soil samples in the field close to the hot spot*"; (ii) laboratory experiments with water samples to "*measure oxygen and benzene removal rate"*, and "*soil to measure different parameters*"; (iii) "*consideration of certain concentrations of benzene in the plume area and risk assessment (STIG)*"; (iv) "*establishment of GMS modelling based on the experimental results to determine the transport and degradation of the pollution plume during time*" (p. 13).	The methodology used included: (i) literature study; (ii) analysis and monitoring data (involving analysis of the monitoring data of 1997 of Mariager Fjord); (iii) field and laboratory work (field measurements regarding turbidity, depth, salinity and temperature and the collection of water samples for laboratory analysis for nitrogen, sulphur, phosphorus, dissolved oxygen); (iv) numerical modelling (box model, MIKE 21 and MIKE 3). The methodology used aimed to: (i) "*use monitoring data for building the models of the fjord*", (ii) "*and to evaluate different scenarios for the change in water quality in future*" (p. 7).	The methods used were: (i) site mapping using field work and laboratory work (screening measurements of water levels and hydraulic conductivity by slug tests from selected borings and data supplied by COWI and NIRAS; contaminant concentration in water samples; determination of oxygen, total nitrate and phosphorous contents); (ii) risk assessment (use of STIG-model; collective mass of MTBE and BTEX´s are estimated; degradation rates estimated based on literature; etc.); (iii) water resource modelling (3D groundwater model developed; model's calibration and validation; modelling different scenarios, etc.) (p.6).
Problem stated	The overall objective of the project is to create *"an oxygen map to measure future pollution risk in the Hjørring area, and a tool to prevent further pollution* ", resulting from the leaking of the underground storage tanks, underlying "*the necessity for monitoring and remediation technology*", (…) and the "*problem of how to set up an actual remediation process which is still very complex*" (p. 5-7).	*Investigate the historical background, present status and future perspectives of the Mariager Fjord, using different methods* (p. 1).	*In this project, the pollution around the gasoline station at Georg Jensens Vej in Hjørring was examined as a possible source of the measured concentrations of pollution in the drinking water wells in Bagterp 600m south of the site* (p. 1).

Target groups	Study board of Chemistry, Biotechnology and Environmental Engineering (Department of Biotechnology Chemistry and Environmental Engineering, Aalborg University, Aalborg). Aalborg University, Companies, Municipalities; etc.	Study board of the Department of Biotechnology, Chemistry and Environmental Engineering and the Department of Civil Engineering at Aalborg University, Aalborg. Aalborg University, Companies, Municipalities; etc.	Study board of the Department of Biotechnology, Chemistry and Environmental Engineering and the Department of Civil Engineering at Aalborg University, Aalborg. Aalborg University, Companies, Municipalities; etc. The project is mainly aimed at people who are interested in oil pollution in soil and groundwater especially with regard to Risk Assessment and modelling of transport processes.

[(*)]General themes approached in all projects of the same programme being the problem different in each, all the themes are different each year.

The content analysis grids were composed by five categories of analysis: the five groups of learning outcomes of the TUNING-AHELO framework (basic and engineering sciences, engineering analysis, engineering design, engineering practice, generic skills) (see table 1). Under these five categories, twenty one subcategories were defined corresponding to the twenty one learning outcomes of the framework (see table 1). These twenty one subcategories were numbered, as shown in table 1, and these numbers were used as codes in the analysis of the project reports. The three reports were read and every time a learning outcome was identified, the corresponding number was written in the report in the left-hand margin of the page.

This process of analysis allowed us to collect information regarding: (i) to which extent learning outcomes were present in the reports; (ii) in which parts of the report (e.g., introduction, conclusion, etc.) they were present; (iii) the inter-relation and inter-dependency among learning outcomes (e.g., the achievement of one learning outcome depends on and/or implies the achievement of others).

3. RESULTS AND DISCUSSION

The analysis of the reports was an iterative process in which we developed and adjusted the model to the analysis of the learning outcomes in the project reports. All the reports were structured in a common way: introduction (problem identification and statement; purposes and aims); analysis and design (problem-solving process; problem analysis and design methods); and conclusion (identification of possible solutions as scenarios, reflection and decision-making). After the first analysis, in which we had identified the 21 learning outcomes of the TUNING-AHELO framework, we found a pattern in the way in which the outcomes appeared in the project reports. Therefore, we started by categorizing the 21 learning outcomes into three groups, as presented in table 3.

Table 3. TUNING-AHELO learning outcomes and their presence and organization in the project reports

Group 1 ***IMPLICIT* LEARNING OUTCOMES**	**Group 2** ***HOLISTIC* LEARNING OUTCOMES**	**Group 3** ***SPECIFIC* LEARNING OUTCOMES**
Learning outcomes: 15 17 18 19 20	Learning outcomes: 1 2 3 4 5 9 12 21	Learning outcomes: 6 7 8 10 11 13 14 16
Mostly related with problem analysis/ solving (overlap)		Mostly related with problem solving

The first group, called *implicit* learning outcomes, belongs to the engineering practice and generic skills and concerns the learning outcomes achieved during the process of learning and, therefore, their presence was difficult to assess in the reports. On the other hand, the reports indicated that these learning outcomes could be achieved by the students during the process, e.g., in the structure and integration of the entire report as well as in the written communication. The *holistic* learning outcomes, group two, encompass learning outcomes from all five TUNING-AHELO categories and these are dependent on the achievement of other learning outcomes. These can be characterized by the inter-relation among them and the project report can be seen as a holistic educational product. The third group, referred to as *specific learning outcomes*, consists of the categories: engineering analysis, design and practice. These learning outcomes were related with engineering analysis and design and were achieved by the students in order solve the problem and propose possible solutions (see table 1 and 3).

In the following subsections, the three cluster systems and the analysis of the reports are explained in more detail.

3.1 Learning outcomes from Group 1: Report *implicit* learning outcomes

The learning outcomes numbered as fifteen (15), seventeen (17), eighteen (18), nineteen (19) and twenty (20) composed the group number one. These learning outcomes were developed during the problem solving process in which the students: (i) demonstrate that they have skills related with laboratory work and workshops (learning outcome 15); (ii) have learned how to manage time, resources, knowledge, team work, etc., in order to solve the problem and write the project report (learning outcome 17); (iii) have to solve problems regarding team work, such as conflicts, achievement of goals, agenda, etc., and align these with their individual work and aims (learning outcome 18); (iv) have to use methods to contact and communicate with team members but also municipalities, companies, university staff, etc. (learning outcome 19); (v) learn and have awareness of independent life-long learning (learning outcome 20). Some indicators that these learning outcomes were achieved can be found in the reports.

For example, the three reports also presented laboratory and workshop descriptions of the work performed and the planned aims, thus revealing the presence of skills related to laboratory work and workshops (learning outcome 15). In fact, the reports also included descriptions of fieldwork and a fundamental method for solving the problem defined. In report C, this description was less detailed than the ones presented in reports A and B (which had an appendix for the purpose).

The project reports were the product of a team work in which the students demonstrated their ability to manage a project, to solve a real problem and write a report together (learning outcome 18, work as a member of a team).

A written report is a means of communication, which presents a clear structure and in which a problem is formulated and solved, supported by a literature review, the analysis of previous studies, simulations, fieldwork, laboratory, etc. The report C, for example, referred to the contact with the companies COWI and NIRAS to provide more detailed data (learning outcome 19).

3.2 Learning outcomes from Group 2: Report *holistic* learning outcomes

The achievement of the learning outcomes numbered as one (1), two (2), three (3), four (4), five (5), nine (9) and twelve (12) was seen in all the reports as a continuum and a holistic product of the learning process. These learning outcomes referred to the ability (i) to demonstrate knowledge and understanding of the scientific and mathematical principles (learning outcome 1); (ii) to demonstrate a systematic understanding of the key aspects and concepts of their branch of engineering (learning outcome 2); (iii) to demonstrate comprehensive knowledge of their branch of engineering including emerging issues (learning outcome 3); (iv) to identify, formulate and solve engineering problems (learning outcome 4); (v) to apply knowledge and understanding to the analysis of engineering products, processes and methods (learning outcome 5); (vi) to apply their knowledge and understanding to the development of designs to meet defined and specified requirements (learning outcome 9); (vii) to combine theory and practice to solve engineering problems (learning outcome 12); and (viii) to demonstrate awareness of the wider multidisciplinary context of engineering (learning outcome 21).

The main purpose of the project reports is to identify, formulate and solve engineering problems. Therefore, the three reports are initiated with the identification and formulation of a problem from a real and ill-structured situation (learning outcome 4) (see table 2), where: (i) the situation, as being real, has defined and specific requirements and is contextualized (learning outcomes 9 and 21); (ii) a plan to solve the problem stated is developed, including the analysis of previous methods, processes, solutions, and the development of new methods to meet the specific conditions, aims and requirements provided by the context (example of experiments, fieldwork, modelling, etc.) (learning outcome 5, 9, 12 and 21); and (iii) the entire project (from the problem formulation to the solutions proposed) is supported by the understanding and use or application of knowledge of engineering science, from their branch and others subject areas such as equations (reports A, B and C), ecological relations in rivers (report B), bacterial metabolism (report A and C), the impact of pollution on public health (report A, B and C), etc. (learning outcome 1, 2 and 3). Apart from having the "*ability to demonstrate awareness of the wider multidisciplinary context of engineering*" (learning outcome 21), students work in this context. All the reports also present an analysis of the previous intentions of public authorities to solve the stated problem and thereby demonstrate an awareness of their limitations as well as the engineering methods and models used to solve the problem (learning outcome 5). For example, report A states that, from 1995-1997, authorities proceeded "*in-situ purification of groundwater pollution (vacuum extraction)"* (…) and later on with *"active carbon"* (p. 9). In report B, it can be read that "*MIKE 3 is a computer model that can be used for modelling lakes, estuaries, bays, and other marine systems where the 3D component is an important factor*" (p. 47) and the "*MIKE 21 flow model with a flexible mesh that was used in this project was based upon the mesh in the MIKE 3 constructed early in this project, in combination with the MIKE 21 model concerning Mariager Fjord, which was constructed in 2001*" (p 48). Report C states that "*Hjørring Vandselskab A/S has received a dispensation for the cleaning of their drinking water with activated carbon for a five-year period terminating in 2014. This means that if no solution to the problems with contaminated groundwater is found, Hjørring Vandselskab A/S is forced to close the contaminated wells and this poses a serious threat to the adequate supply of drinking water."* (p. 4); and in the project "*the Bagterp water extraction site is to be evaluated by conducting a Risk Assessment*" (…) in which the "*applicability and credibility of the newly developed STIG (Simple Transport In Groundwater) model are to be evaluated*" (p. 5). In the conclusions of the reports, future perspectives and recommendations regarding the problem solving methodology, possible solutions, and costs are also introduced.

In sum, this approach of the solving process combines not only theory and practice at the level of laboratory or fieldwork, but also the use of multidisciplinary knowledge to design and meet the defined requirements presented by the situation and context to solve a problem. These learning outcomes show some inter-dependency and inter-relation in a way that the achievement of one learning outcome implies the achievement of others, and vice versa. For example, the structure of the reports and the way in which the projects were managed show that the presence of one of these learning outcomes also implies the presence of the others.

3.3 Learning outcomes from Group 3: Report *specific* learning outcomes

More specific learning outcomes are more closely related to engineering analysis and design; therefore, they appear in some specific sections and subsections of the project reports. These learning outcomes refer to the ability (i) to select and apply relevant analytic and modelling methods (learning outcome 6); (ii) to conduct searches of literature and use data bases and other sources of information (learning outcome 7); (iii) to design and conduct appropriate experiments, interpret the data and draw conclusions (learning outcome 8); (iv) to demonstrate an understanding of design methodologies and an ability to use them (learning outcome 10); (v) to select and use appropriate equipment, tools and methods (learning outcome 11); (vi) to demonstrate an understanding of applicable techniques and methods and their limitations (learning outcome 13); (vii) to demonstrate an understanding of the non-technical implications of engineering practice (learning outcome 14); (viii) to demonstrate an understanding of the health, safety and legal issues and the responsibilities of engineering practice and its impact on a societal and environmental context, and to commit to professional ethics, responsibilities and norms of engineering practice (learning outcome 16).

In the reports, two different elements regarding learning outcome 6 are pointed out: one regarding relevant analytic methods and the other regarding modelling methods. The three reports present as a first methodological approach: (i) a fieldwork to collect samples and field data by using appropriate equipment and tools for the purpose (for example, reports A and C present drills to different depths to collect samples of soils and water and, in report B, water samples were collected from different depths and zones from rivers that flow to different rivers and on to Mariager Fjord); (ii) samples collected in the field were used in laboratory experiments to determine different and specific parameters for further use in modelling; and (iii) the analysis of the data collected and the conclusions made for the next stage of the problem solving process. These methods are followed by subsections regarding the discussion and reflection of the results obtained and how they relate to the overall problem solving process. In sum, the reports show a progression of the learning process like "*know that*", "*know how*" and most of all "*know why*" of the methodological approach used by the group [6]. In a second methodological approach and from the data collected and analysed, the reports present simulations and modelling, including the calibration of the models presented (report B). For example, all the reports present three scenarios and, in addition, risk assessment was presented in A and C.

4. REFLECTIONS

The research questions of this article ask whether the TUNING-AHELO framework can be used as a framework for the analysis of PBL reports and if students will achieve the knowledge and competences that are defined in the TUNING-AHELO framework in a PBL curriculum.

Working with the TUNING-AHELO framework in a content analysis has been a remarkably interesting process and learning from this research indicates that the TUNING-AHELO framework can be used as a framework for analysing project reports. However, in a content analysis, the very first analysis showed that the long list of learning outcomes seems to be too fragmented. We found that three clusters of learning outcomes could be defined and used as a more analytical model for the content analysis, i.e., implicit, holistic and specific learning outcomes, respectively (see table 3).

These clusters of learning outcomes are based on the five categories of learning outcomes defined in the TUNING-AHELO framework: 1) Basic and Engineering Science, 2) Engineering Analysis, 3) Engineering Design, 4) Engineering Practice, and 5) Generic Skills [4]. Several of the learning outcomes overlap each other and, in the content analysis of a text, which does not involve interactive dialogue, it might be important to re-organize and re-structure the learning outcomes (see figure 1).

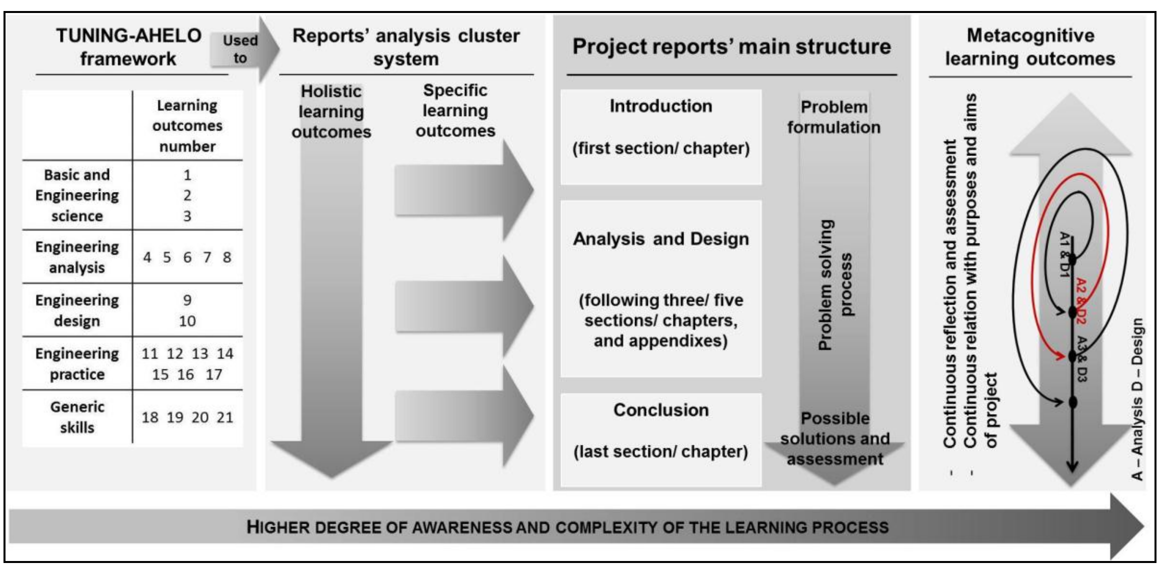

Figure 1. Overall view of the learning outcomes achieved in the projects' reports

Thus, instead of defining 21 different learning outcomes, this analysis has shown that the learning outcomes may be combined into fewer groups of learning outcomes. Furthermore, the students do not only achieve the learning outcomes from the TUNING-AHELO, other learning outcomes are also achieved which imply a higher and complex level of learning (metacognitive), developing a deep awareness, for example, of the problem solving process through the continuous reflection and assessment and use of knowledge in relation to a context. The group named *implicit learning outcomes* (group 1) refers learning outcomes achieved during the learning process and therefore they are not present in figure 1.

The further analysis shows that there might be a need for a further development of the framework in order to capture the PBL reports. In the analysis of the reports, it became quite clear that the framework did not capture the complexity of the learning process, such as the continuous reflection and assessment of the problem solving process and its relation with the final purposes (metacognitive learning).

Therefore, figure 1 forms part of our main conclusion for the methodology; that the TUNING-AHELO framework cannot be used as an analytical framework without adjustments and re-modelling of the learning outcomes. These adjustments are important as the learning outcomes were identified in all phases of the project report; i.e. the introduction, the analysis and design in the problem solving process, and the assessment. Even in the project report, it is clear that the students have developed a series of metacognitive learning outcomes which reflect the coherence and the continuous relation among purpose, problem identification, methodology, design, solution, and conclusion.

According to Shepard *et. al.* [6], traditional engineering curricula focused on the learning of fundamental concepts, applying these to standard problems and the articulation of the concepts in mathematical language (*know that*), but very few opportunities exist for developing higher levels of thinking achieved by, for example: (i) learning how to generate models, to analyse problems (*know how*), (ii) learning how to analyse, model and apply these to the context of engineering practice, which is fundamental for analytical problem solving (*know why*). In a more innovative learning environment, such as in a Problem Based Learning curriculum, it is possible to achieve all these dimensions of engineers' education as well as to move on to the "*know when*", when students explore the engineering principles, theories and concepts and use these intentionally in the problem solving processes.

This has been a first explorative study to work with the TUNING-AHELO framework for a content analysis and there are still questions left for a further development of the methodological framework. If learning outcomes should be studied in full scale, the content analysis should be supplemented with interviews and observations to cover the full picture. On the other hand, the content analysis gives a much more scientific content focus, which is often missing in the studies of PBL which are more focused on the learning process itself. The results of these three analyses of project reports fully indicate that the student seems to learn what the TUNING-AHELO framework intends and also acquire knowledge beyond the described learning outcomes

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