Webb's taxonomy for the development of competencies in undergraduate students

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ABSTRACT:
The results of project-based learning methodology (a larvae population analysis), applied in the subject "Research Methods" are presented. This work was carried out in during 12 weeks among third quarter petroleum engineering students, during this time they had to develop a variety of academic competencies; these competencies are measured in terms of Webb's taxonomy, which classifies four levels of learning (the higher the level of learning the higher the academic requirements) and whose structure is better designed for engineering students. The class was divided into 4 teams of 5 people. Four checklists (one for each level) and a rubric (divided into quartiles) were designed for the final report, which are given to the students at the beginning of the course. The results indicate that the students could reach levels I and II without difficulties (although instructor close supervision is required), though for levels III and IV various complications arose because level III wasreached until 9th week, and level IV was only reached on average 80%, that is, not all the activities entrusted were covered. However, it could be observed that the students progressed continuously in their academic performance during the execution of the project. Analysis of the data reveals that in the final report, the development of skills fall in 3th quartile (need help, 80% of the teams) which represent a good result for the methodology.
Keywords: *Checklist, competency development, project-based learning, rubrics, Webb's taxonomy, science education.*

INTRODUCTION

The competency-based model is centered on the student (Tobón, Pimienta, & García, 2010) and requires three basic attitudes: collaboration, autonomy and responsibility. This indicates that students must be responsible for their own learning (they become active subjects), for this reason they must learn to work collaboratively and, for this purpose, the teacher is required to promote a good learning environment that motivates them to achieve the objectives. Being competent means being able to effectively and responsibly solve the problems you face (Bernal, 2006), so the purpose of high level education must be to develop individual competencies and, to get that, a curricular design that ensures the gradual and systemic competencies construction is required. Training in professional skills is one of the essential objectives of the current university teaching; however, it should be noted that these competencies arise at the workplace and not in academics; from it, Mertens (2000) has initiated an investigation oriented to find scientific criteria that determine the labor performance of people. For Boyatzis (1982), competencies constitute the set of characteristics of a person directly related to the correct execution of a job. Other definitions such as Rodriguez, Hernandez, & Diaz (2007), indicate that professional competencies bring with them the integration of knowledge, skills and attitudes that allow a high quality professional performance. In academics, it must be guaranteed that students are able to integrate knowledge, skills, attitudes and responsibilities that professional profiles demand.

Besides, in engineering teaching there is an apparent tension between two necessary aspects; on the one hand, there is a rapidly growing area of technical knowledge and, on the other hand there is a growing recognition that young engineers must have a good personal look, sufficient knowledge and skills that allow them to well function in real teams and that are capable of producing real systems and products (Crawley, Malmqvist, Lucas, & Brodeur, 2011). Engineering programs must demonstrate that their graduates will have the skills to:

a) Apply knowledge of mathematics, science (physics, biology, chemistry) and engineering
b) Design and conduct experiments, as well as analyze and interpret data
c) Design systems, components or processes to achieve desired goals with real restrictions
d) Work in multidisciplinary teams
e) Identify, formulate and solve engineering problems

f) Communicate effectively

The skills mentioned by Crawley can be developed adequately if a methodology such as project-based methodology is used, which will be described in the next section.

The project (Tuning, 2006), points out that in the generic elements of a cognitive and motivational order are included, expressing themselves through the so-called instrumental competences, which are methodological or procedural in nature, e.g. capability to analyze, organize, plan, and manage information. The systemic competences related to autonomous learning, adaptation to new situations, creativity and leadership are also mentioned.

PROBLEM STATEMENT

Since the beginning of polytechnic universities, the educational model implemented is competency based framework that has, among their demands, the development of generic and specific competencies that are useful in the academic and working life of students. It is common to observe that most of students (in the Polytechnic University of the Gulf of Mexico) have difficulties to reach certain learning objectives because they have not adequately the skills and abilities necessary for good academic progress. In a concrete way, it is known that they have difficulties to work as a team, plan, write a text, elaborate hypotheses, analyze data and draw conclusions. This research seeks to enable students to develop such skills through the execution of a real project (within the research methods subject) and with the application of a series of rubrics, based on Webb's taxonomy. The rubrics are designed to analyze the behavior of the students before the entrusted project, and clearly indicate the actions and skills that should be considered; from the simple data collection to the elaboration of the central hypothesis.

THEORETICAL FRAMEWORK

Project-based learning (PBL) is student-centered, has its roots in three constructivist principles: learning in a specific context, learners are actively involved in the learning process and must achieve their goals through social interactions and share their knowledge with others (Cocco, 2006). It is considered as a particular type of research where the learning context is provided through authentic questions and real problems (Al-Balushi & Al-aamri, 2014) that lead to meaningful learning. The essence of PBL is in the construction of a final product, a "specific artifact" in which students present their new knowledge and attitudes towards the problem under investigation - they can often present videos, photographs, representations, models and other artifacts. (Holuvoba, 2008). The handling of research questions is the center of the PBL principles. The recommended criteria (Menzies, Hewitt, Kokotsaki, Collyer, & Wiggin, 2016) to elaborate the questions are:

a) Be feasible
b) Be contextualized
c) That make sense
d) That they are ethical

Progressing through their course, students should continually review the questions, try to answer them and reflect on what they are doing (Bell, 2010). Emphasis should be placed on the importance of PBL focusing on success skills, such as: critical thinking, self-regulation and collaboration, as well as emphasizing that topics must be authentic and related to real-world problems. We must consider projects that promote learning and that focus on the curriculum, not peripheral to it. It should be clarified that the project is not the culmination of learning but is the process through which learning takes place.

PBL Instructional focus

The PBL has its roots in constructivist theories of learning, so students are invited to be involved in building of knowledge, deepening in research and / or developing critical thinking skills and solve problems. A real project can have different solutions and methods to reach them. Teachers must initiate the PBL by cultivating in the students the need to know or the desire to learn, and for that they must motivate them to commit themselves to the project. Collaborative learning should be supported, since it is an essential element of the PBL.

Evaluation is a critical issue for PBL educators, often evaluation does not measure the cognitive results that deep learning is intended to produce. However, it must be recognized that evaluation plays a critical role in learning when it is used for reflection in students. This should reveal how well they have learned what we want them to learn through our teaching strategies. For this to happen, the evaluation, the learning objective and the teaching strategy must be well aligned so that they reinforce one another. To ensure that these three components are aligned (Gutiérrez, de la Puente, Martínez, & Piña, 2012), the following questions should be asked:

- Learning objectives. What do I want my students learn at the end of this course?
- Evaluation: What kind of tasks could reveal that students achieved the learning goal I have set?
- Teaching strategy: What kind of activities inside and outside of class could reinforce the learning objective and prepare students for the evaluation?

If the evaluation is not aligned with the learning objective or with the teaching strategy, this could break the learning and motivation in the students. The group evaluation depends on the assigned objectives, both to the process and to the products related to the skills to be evaluated. The process must be evaluated, not just the product. These objectives should be pointed to the students by means of a rubric and suggest them the self-evaluation regarding their contribution to the team work. Students should evaluate their team skills to which they contribute throughout the process in which they are emphasizing. The process could include listening respectfully, considering diverse opinions, effectively handling conflicts when different ideas arise, keeping the group together before and during meetings, promises of delivery, appropriate distribution of resources, analysis and writing.

WEBB's TAXONOMY

One of the models most used to classify the cognitive level of students is the taxonomy of (Bloom, Engelhart, Furst, Hill, & Krathwohl, 1956), it identifies six levels within the cognitive domain, from the simple reminder of facts (the lowest level) to further increase the complexity of the levels, which is classified as evaluation. More recently, (Webb, 2002) proposed a new taxonomy called Webb's Depth of Konwledge in which four levels are defined (from the most basic to the highest) of complexity that are necessary or required in the curricula.

Webb's taxonomy for science

Level 1. Remember and reproduce.- At this level, information such as facts, definitions, terminology or simple procedures must be remembered. Verbs such as identify, remember, recognize, use, calculate and measure can be used. The solution of simple problems that involve the use of a pre-established formula is also considered.

Level 2. Skills and concepts.- Students must make decisions in order to solve the problem or answer a question. Verbs can be: make observations, collect, classify, organize, plot and compare data. These actions involve more than one step.

Level 3. Strategic thinking.- Activities include drawing conclusions from observations, citing evidences and developing logical conceptual arguments; explain phenomena in terms of concepts; use concepts to solve non-routine problems. This section includes the interpretation of mathematical models.

Level 4. Extended thinking.- The tasks have a higher and more complex cognitive demand. Various connections must be made – relating ideas within the respective area or between other areas – and select an approach among various alternatives on how the situation can be solved. Level 4 requires complex reasoning, design of experiments and planning, and probably requires an extended period of time for the investigations required in its objectives, or to carry out a procedure in an evaluation. At this level, the elaboration and testing of hypotheses must be taken into account, as well as obtaining complete and adequate conclusions of an analysis being carried out.

METHODOLOGY

The Project Based Learning methodology was used to develop general skills in a group of third-semester (1^{st} year) petroleum engineering students, which guarantees working with real data of a real problem. In learning objective set for the development of this proposal, students are expected, by the end of the course, to be able to follow established procedures, collect, organize and graph data, interpret mathematical models, make predictions, elaborate hypotheses test and conclusions based on the data obtained, as well as working as a team. The evaluation, to determine if the learning objective was reached was through a rubric and four checklists, which were designed based on Webb's taxonomy. Five teams of four students were formed, who worked collaboratively to achieve the assigned goals during a certain period. At the end of each week, feedback was given in classes about the activities carried out; this had the intention that in the following week all of them could be completed without difficulties. The assigned project was the analysis of the growth behavior of a Tenebrio Molitor larval colony (150 individuals), such population was divided in two equal parts which were feed with two types of food: oats and plastic flakes, in such a way that the growth of each population was compared at the end of the data collection. The activities assigned for each week are shown in the checklists in Annex 1. During the first three weeks various actions are carried out involving a series of simple steps; for the next three weeks the level of complexity is increased, requesting for the mathematical model that best describes the population behavior; the calculation of the growth rate was annexed in the following three weeks (taking as a reference the mathematical model found); and for the last three weeks the hypothesis test of the data was requested. At the end of the project, the students submitted a report (two weeks later) analyzing the behavior of the larval population which was evaluated with the rubric of Annex 2. A qualitative-descriptive statistical analysis of the activities done by the students was carried out, and with this, it was possible to determine if the students reached the learning objective stated in the PBL. The weightings of the rubric were divided into quartiles as follows:

1. Quartile 1 (Q1): Wrong (numerical value 1, the lowest)
2. Quartile 2 (Q2): Inadequate (numerical value 2)
3. Quartile 3 (Q3): Need help (numerical value 3)
4. Quartile 4 (Q4): Adequate (numerical value 4, the highest)

At the end of the course, an analysis of the data collected from the rubric is performed to determine the quartile that represents the level of learning achieved by the group. It is worth mentioning that this report will show the behavior of the students during the development of the project, that is to say, their developed abilities, not about the result of the behavior of the larvae itself.

ANALYSIS and RESULTS

Table 1 show the percentages reached in the fulfillment of the activities to be carried out every certain period (first column), which consists in three weeks (first row). In this table it can be seen that at the beginning of each period (first week) students could not complete 100% the activities to be performed, however in the second week it increases; reaching 100% in week 3 (Period 1 - 3). During this period, it could be observed that the students did not reach 100% because they did not analyze carefully the checklists (Annex 1) and at other times it was due to forgetting. Due to the follow-up carried out by the instructor during the whole period (feedback), at the end of the last week of each period all the activities were accomplished. However, in period four, the activities to be carried out were more demanding since they required more complicated operations and mathematical analysis (compared with the beginning of the project). Table 1 indicates that period four was the most complicated, since they did not reach the indicated goals, on average only 80% of the total tasks could be achieved. The activities (skills) with which they had more difficulties were interpreting the mathematical models; this during the first three periods, however with the passage of time all those tasks (skills) could be achieved. During period four, the most complicated activities (and that could not be completed) were the interpretation of the final model and the hypothesis test.

Table 1. Percentage of weekly tasks reached

Period	Week 1	Week 2	Week 3
1	66	83	100
2	75	85	100
3	67	78	100
4	70	70	80

From all this, we can see how, in each period, the fulfillment of the weekly activities are achieved progressively. In the last period, 100% of the tasks were not achieved, especially the hypothesis test and the interpretation of the final model. These activities are considered as complex in Webb's taxonomy (Level IV). On the other hand, Table 2 shows the results of the evaluation of the project reports; for this purpose, the rubric of Annex 2 was used. The rubric consists of seven parameters, weighted in four levels; the lowest one is weighted numerically with number one and the highest is weighted with a value of four. From these values, it has been found that 80% of the teams are placed in the "Need help" weighting (quartile 3), which means that their reports can be used as acceptable, even if some items need to be improved, such as the description of the methodology; in other cases, the general objective and the conclusion need to be re-writting. That is, some missing aspects were detected but that can be corrected by adding more evaluation time. On the other hand, 50% of the teams reached an "Adequate" level, interpreting it as a well-prepared and structured report. From these results, it can be said that students reached levels I, II and III of the Webb taxonomy without difficulties; However, level IV could not be achieved satisfactorily, which implies some changes in the proposed methodology must be made, so that all the levels proposed can be achieved.

Table 2. Rubric data to evaluate the final report

	Team 1	Team 2	Team 3	Team 4
General objective	3	4	3	4
Research questions	3	3	4	4
Hypothesis	2	3	4	4
Methodology	1	1	3	3
Mathematical model	4	4	4	4
Data table and graph	3	3	4	3
Conclusion	3	3	3	3
Total	19	21	25	25
Percentage	67.85714	75	89.28571	89.28571
Quartile	Q3	Q2	Q4	Q4
Average Quartile	**Q3**	**Need help**		

With the development of this project, the students were able to develop skills such as: collaborative team work, collecting and sorting data in a table, plotting and finding the mathematical model that best fits the data and elaborating and testing hypotheses.

CONCLUSION

At the end of the assigned project (around 12 weeks) each team delivered a report of the results obtained, this report was useful to confirm the results found in the weekly evaluation rubrics. It should be noted that for the last week of study (corresponding to the week of evaluation for level IV) all the teams met 100% with each of the activities framed in the previous levels. With this analysis we can say that during the development of this teaching methodology students could start from the application of very simple procedures to achieve more complex processes, such as those marked at level III (level IV could not be 100% reached). It should be emphasized that level IV reached an average of 50% in compliance with the activities entrusted, so it is feasible to achieve 100% by making some adjustments in the methodological procedure. The rubrics used have allowed a continuous assessment throughout the learning process, which in turn allows self-assessment to improve this process. In this way, it has been observed that the project-based learning methodology allows developing generic skills such as making observations and collect, classify, organize and compare data; explaining phenomena in terms of concepts and using it to solve non-routine problems, among others. Such skills or actions correspond to level III in Webb's taxonomy. It is assumed that in order to satisfactorily reach Level IV, students require a greater follow-up in their procedures, perform a deeper feedback as well as allow more time for the execution of the project. The most complicated actions for students are related to the interpretation of the mathematical models that adjust the data obtained and the verification of their hypothesis.The results also indicate that by means of the rubric to evaluate the final report of the students, 80% of the teams are located in quartile 3 (Need help) which represents a good result in the skills to be developed in a generic way. It is also noteworthy that team collaboration was essential for the correct data collection and to fulfill all the activities entrusted, this motivated a collaborative work. So we can assume that students were able to develop some skills such as analytical skills, organization and planning; that are fundamental in the competencies model and that are necessary for working life.

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ANNEX

Annex 1.

Checklist for levels I- IV in Webb`s taxonomy. To level I, its work from point 1 to 6.To level II, from point 1 to 7; for level III from point 1 to 9; and for level IV from point 1 to 10.

Number of weeks		
Procedure to manage the larvae population	yes	no
1. Remove all the larvae from the container		
2. Each population will be placed (separately) on a scale to measure its weight.		
3. Measure the weight of the food.		
4. Record the measurements and organize it into tables.		
5. Substitute dead pupae or larvae for another larva		
6. Graph data and exchange data with other teams		
7. Interpret the mathematic model.		
8. Predict the velocity		
9. Produce hypothesis test		
10. Submit an answer to the research question		

Annex 2. Rubric for the final report

Rubric to evaluate the final report. Seven points in consideration and, weighting from 1 to 4.

	Wrong (1)	Inadecuate (2)	Need help (3)	Adecuate (4)
General objective	There are not objective.	The variables of interest are not shown in the objective.	The variables of interest are presented but what, what and how are not indicated.	The relationship between the variables of interest is presented. It indicates what, how and what for.
Research question	There are not research question.	Research question is not coherent with the general objective	Research question is not complete	Research question is factible and coherent with general objective
Hypotesis	There are not hypotesis	Hypotesis is not coherent with the general objective or research question	The hypotesis is incomplete and relations among variables are not present	The hypotesis is complete, coherent with general objective and research question, and relation among variable appear
Methods	Methodology are not present	The methodology are not adecuate or is incomplete	Methodology is adecuate but not coherent with general objective	The method is complete and all the steps to follow to reach the objective are clearly indicated
Mathematic model	Mathematic model are not present	The mathematic model are not coherent with collected data	The model is correct but the interpretation is not adecuate	The model is correct and the interpretation among model and variable are adecuate
Tables and graphs	There are not tables and graphs	There are no mathc among tables and graphs	Tables and graphs are correct but, physical units are missing	Tables, graphs and physical units are correct and coherent
Conclusion	There are not conclusions	Conclusions are not coherent with data	The conclusion is good but, the relationship among variables not appear	The conclusion is coherent with data and the relationship among varables are clear

