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Performance and authentic assessment in a mechanical engineering course

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ABSTRACT: Performance and authentic assessment is presented in this article as an option to promote the development of the skills specified in a mechanical engineering course. The study was conducted from a qualitative research perspective for a group of 22 students in their final semesters in a course on the design and simulation of machine elements. A performance rubric was designed to estimate progress and provide feedback. Among the main results was that performance levels, some of them higher than expected, could be detected, allowing students to appreciate in detail their progress in proficiency levels related to skills required for graduation. In this article, the process of designing the assessment is discussed, and its scope in determining learning outcomes.

Keywords: Competency-based educational model, performance assessment, authentic assessment, degree qualifications profile, higher education

INTRODUCTION

Engineering education at present needs to be enriched with challenging and authentic activities to allow students to collaborate with peers from the same or diverse disciplines. This aims to promote problem-solving and the creation of solutions based on the needs of the economy and society. Society demands that engineering education is characterised by being interactive, collaborative, student-centred, and that it facilitates lifelong learning [1]. Students, who are the products of such a regime, will be innovative and able to contribute to the development of new technologies that can improve the welfare of society [2]. A challenge is how to measure or estimate the development of such competencies.

In the past two decades there has been a debate on the manner in which student assessment in engineering programmes has evolved and been strengthened. Attempts have been made to apply innovative methods to increase the efficiency and effectiveness of assessment methodology [3].

One of the goals sought from better assessment practices in engineering training is for graduates to be able to confront the challenges of their field, knowing how to perform when making their own decisions, e.g. using cutting-edge technologies in manufacturing processes; selecting new materials; and applying knowledge in the areas of mechanics, electronics, programming and control and specialised software.

Based on an understanding of the learning process and how knowledge is acquired, engineering education should include a set of learning experiences that allow students to develop in-depth knowledge by developing their personal, technical and professional skills; these skills can be applied to a wide range of engineering projects [4]. One of the ways to organise the teaching-learning process has been through the use of competency-based education (CBE) to mimic real-world problem-solving, so as to consolidate skills development. The CBE presents students with a series of problems and challenges that allow them to exercise fundamental, skills such as decision making, problem-solving, teamwork and creative thinking [5].

When working within the CBE framework, the performance and authentic assessment becomes a fundamental element to estimate the skill development of students. The assessment is of the knowledge gained through the cognitive work required by the discipline. For this to be achieved, students require involvement in learning dynamics that favour the formation of connections between knowledge and its uses in practice. This is intended to build a deep understanding of the subject in the hope that they will not only be able to make decisions regarding its use, but also know how to communicate clearly and in a well-argued manner [6]. Performance assessment favours continuous improvement through timely feedback that students receive from the teacher throughout a project or a complex task. Thus, the performance assessment process can help educators reduce the gap between knowledge and application [7], serving as an aid to help engineering students understand the skills they have mastered and those they still need to develop [8].

In addition to performance assessment, the authentic assessment offers students opportunities to learn through real situations, which should be designed according to their level of progress in the curriculum. The insertion of the reality factor in projects or complex tasks helps them to advance in the development of their learning skills and in knowledge of the subject [9]. Therefore, the performance and authentic assessment has a direct impact on promoting deep reflection on their practices and demonstrating their progress throughout their studies, allowing them to successfully enter the job market.

> *Students who perform meaningful and relevant assessments tend to participate more fully in learning and therefore tend to achieve higher goals because they see meaning in what they are doing* [9].

A successful project design based on performance and authentic assessment needs to be supported by theoretical teaching in class, involve multiple activities, promote learning and teaching among participants, and reflect local values, standards and controls [10]. In addition, it should be based on significant and concrete learning according to the level of qualification, which is then reflected in the tasks that students must carry out to demonstrate their competency [9].

The preparation of an authentic problematic situation requires the determination of criteria for performance measurement. In this sense, assessment rubrics are among the instruments that can be used since they allow for the articulation of task expectations by specifying criteria and quality levels. In addition, they becomes a guide for students to develop and demonstrate competencies to reach a specific level of achievement, so that they have the potential to learn through a student-centred assessment [11]. Furthermore, as a fundamental part of the performance assessment process, the integration of feedback increases the potential of the process, because it brings students closer to the expected performance [12], providing indications of expected performance in the learning process.

> *Feedback is considered essential in the development of performance and professional experience because it helps to build knowledge and skills* [13].

The establishment of performance levels in instruments such as rubrics, as well as a detailed definition of what is expected at each level helps students to adopt standards and learning approaches in which they plan, monitor and evaluate their own performance and progress toward the expected result. This means that to be useful, comments for improvement should be informative, continual and consistent with the task. Thus, the quality of the feedback depends on the evaluating experience of the educator, for which continuous practice is required to promote its improvement in support of the development of the expected skills [13].

A conceptual, essential element that allows for operationalisation of the performance process at different levels is the use of learning taxonomies [7]. A taxonomy allows for the establishment of gradual progress in the cognitive, psychomotor or affective-emotional domain, as the case may be. Marzano and Kendall’s new taxonomy, which has its foundations in Bloom’s taxonomy, is a taxonomic proposal focused on thought processes. It postulates an integral theory of learning, based on the most recent brain research [14]. Four levels of processing are arranged into a hierarchy:

1. Retrieval tasks ask students to access the information exactly as it was originally presented.
2. Comprehension requires interpretation of information and aims to internalise it.
3. Analysis involves extending knowledge as new relations and applications are discovered.
4. Knowledge utilisation focuses on using knowledge to tackle other authentic tasks.

Having a flexible hierarchical nature means that

> *…cognitive levels are differentiated according to the degree of cognitive control or intentionality of the thought processes necessary to complete a task* [15].

Likewise, they allow for a careful scaffolding approach in instruction as the student progresses in the learning unit [14]. Knowledge utilisation focuses on using knowledge to tackle more authentic tasks and systematically targets higher-order thinking levels; for example, through questions focused on thinking about the developing skills [15].

Using this taxonomy allows the teacher to be more consistent in their task as an evaluator since they can more accurately identify the differences in the progress of each student, and design learning activities/assessments that aim for the development of higher-order thinking skills. The use of this taxonomy provides a clear, functional delineation between lower and higher order thought; it is a tool to provide more specific comments to students. It also serves as a natural tool that helps the teacher to systematically build a course incrementally and develop the expected thinking skills within the students [14].

In reviewing performance and authentic assessment, and considering the use of taxonomy as a frame of reference Chisholm reported on an assessment process in a higher education economics course using taxonomy as a tool to naturally guide students to higher levels of thinking [14]. They identified the most appropriate cognitive level for each course objective and defined the specific steps that each student must take to reach the desired level of comprehension and mastery. They prepared formative assessments and corresponding summative tests. In the process, they considered the design and use of a roadmap that included the course objectives, resources and linked assessments.

The students were given specific comments on their learning process and enriched comments that allowed them to self-assess, while monitoring their success/failure in each item to be assessed. The impact on skill development was evident; they were able to adjust their own learning strategies to achieve their goals for the course.

Finally, it should be noted that the performance evaluation process has an impact on teaching activity. The educator can take a reflective and critical stance, as well as consider the reason and purpose of the assessment; who is served by the assessment; and what will be done with the results [16], while connecting everything with the stipulations of the degree qualifications profile.

METHOD

Design: from the perspective of qualitative research.

Context: this study was conducted in a course for the design and simulation of machine elements for the following majors: automotive design engineering; electrical mechanical engineering; and mechatronic engineering; at a private higher education institution in Mexico.

The competencies established for the course were:

- Disciplinary competency: design the fundamental elements that make up a mechanical transmission, addressing the engineering, ethical and environmental aspects.

- Transversal skills: citizenship and sense of the profession to support the rule of law from an engineering viewpoint.

Participants: the research was conducted with 22 students and the professor of the course who had 20 years of experience in the subject and had previously received training on performance and authentic assessment.

Instruments: A performance rubric was designed. The instrument went through a content validation process based on expert judgment. The rubric allowed for the generation of assessment reports with the support of the Competere computer program, a tool that helps the systematisation process for the delivery of performance and authentic assessment results within the framework of a CBE model [17].

The process of determining performance levels, given its close relation to thought processes, was done in accordance with Marzano and Kendall's new taxonomy [18]. The proposal was to identify where one is and where one wants to go in the teaching process, identifying the different levels to which one can be introduced, according to the performance expected. Based on this, the mental operations involved in the rubric design were as follows:

Level 1 - Retrieval;
Level 2 - Comprehension;
Level 3 - Analysis;
Level 4 - Knowledge utilisation (research, experimentation, problem-solving and goal specification).

Table 1 shows the performance rubric. The shaded levels are those determined to be the expected performance.

Table 1: Performance assessment rubric for the course.

Performance assessment rubric						
Competencies to be evaluated		Sub-competency name in the system	Retrieval	Comprehension	Analysis	Knowledge utilisation
Disciplinary and transversal competencies	Disciplinary sub-competencies	Short names	Level 1	Level 2	Level 3	Level 4
Design the fundamental elements that make up a	Applies mechanical design methodologies in	Applies design methodologies	Knows the main mechanical design	Uses mechanical design methodologies	Properly solves a mechanical transmission	Evaluates the solution of a mechanical transmission

mechanical transmission, taking care of the engineering, ethical and environmental aspects	an intentional and organised manner for the identification, analysis and solution of mechanical transmission problems		methodologies applicable for the solution of a power transmission	to identify a mechanical transmission problem	design problem by applying various machine component development methodologies	problem by making intentional and organised use of different design methodologies that allow for the proposal of design alternatives from which the best possibilities are chosen
	Detects strengths and opportunities of the original design proposal and rethinks the solution to optimise it, considering restrictions for space, cost, manufacturing, environment, etc, in order to choose the one that has better performance possibilities	Detects strengths	Identifies the strengths and weaknesses of a design proposal	Understands the role played by the strengths and opportunities of a design proposal in order to choose the one with the best possibilities	Associates the design proposal's strengths and opportunities with possible behaviours that allow for the best possible choice	Evaluates the strengths and opportunities of the design proposals, considers alternatives and chooses the one with the best possibilities
	Performs measurements that allow for data interpretation and results analysis to assess the performance of the mechanical design proposal	Takes measurements	Recognises the main parameters that can be measured by instruments and tools to describe the performance of a mechanical design proposal	Uses instruments and measuring tools that allow for an understanding of the performance of a mechanical design proposal	Analyses the performance of a mechanical design proposal, taking measurements that allow for its observation	Evaluates the possibilities of success of a mechanical design proposal by taking measurements that allow for the evaluation of results and the inference of consequences
	Uses specialised software to calculate and simulate machine components and present their results	Uses software	Describes characteristics of machine elements using specialised software, both for simulation and presentation	Uses specialised software to calculate machine components, prepare reports, and present results	Specifies data and details of machine components through the use of specialised software that allows for their differentiation from similar alternatives, report preparation and presentation organisation	Does not apply

Professional role of engineers in society and citizenship	Explains the meaning and purposes of their profession and professional associations and the social needs that must be heeded to improve the quality of life for the benefit of society and support the rule of law in the country	Explains their profession	Identifies aspects of the role that engineering plays within society	Explains, through a report, the role of engineering in society, their responsibilities as professionals, and how they support the preservation of the rule of law	Draws his or her own conclusions and generalises regarding the repercussions of engineering on improving the quality of life of society and their responsibility in preserving the rule of law	Does not apply

Procedure

a) Both the competency and sub-competencies related to the degree qualification of the engineering major were defined. These were proposed around the design process of fundamental elements that make up a mechanical transmission, ensuring that the engineering, ethical and environmental aspects were addressed. Five sub-competencies to be evaluated by means of a performance assessment rubric (Table 1) were established:

   1. Applies mechanical design methodologies in an intentional and organised manner for the identification, analysis and solution of mechanical transmission problems.

   2. Detects strengths and opportunities in the original design proposal and rethinks the solution to optimise it, considering restrictions on space, cost, manufacturing, environment, etc, to choose the one that has better performance possibilities.

   3. Performs measurements that allow for data interpretation and analysis of results to assess the performance of the mechanical design proposal.

   4. Uses specialised software to calculate and simulate machine components and present results.

   5. Explains the meaning and purpose of their profession and professional associations, as well as the social needs that must be met to improve quality of life for the benefit of society, and supports the rule of law in the country.

b) The authentic assessment was created. It comprised the design of a mechanical transmission for a coal conveyor and assembling a trapezoidal belt transmission like those used in a clothes washer or an industrial wall fan. The intention was for students to calculate the capacities of this transmission, use industrial catalogues to select their components, and then do the corresponding assemblies to achieve their operation, verifying the accuracy of their calculations and adjusting the design.

c) It was decided to perform the performance assessment process for all students in the group based on the performance assessment rubric collectively prepared by experts from the institution’s engineering school.

d) Three stages were determined for the performance estimation process:

   1. The following sub-competencies were evaluated two times at the beginning and the middle of the semester: applies design methodologies, detects strengths;

   2. The following sub-competencies were evaluated once in the middle and the end of the semester: uses software and explains the profession;

   3. The following sub-competency was evaluated once at the end of semester: takes measurements.

e) To review the feedback from the students, the feedback reports were issued using the Competere software, which were delivered one week after the assessment process was carried out.

RESULTS OF THE ASSESSMENT REPORTS

From the assessment reports, the following was noted (see Figures 1 to 5):

For the sub-competency *applies design methodologies*, 4.5% of the students managed to advance from level 1 to level 4, expert profile; 54.5% were able to progress from level 2 to level 4; and 41% rose from level 2 to level 3.

In the *detects strengths* sub-competency, 4.5% of the students rose from level 1 to level 4, expert profile; 22.7% passed from level 2 to level 4; 31.9% advanced from level 3 to level 4; 13.6% went from level 2 to level 3; and 27.3% remained at the same level of competency: 3.

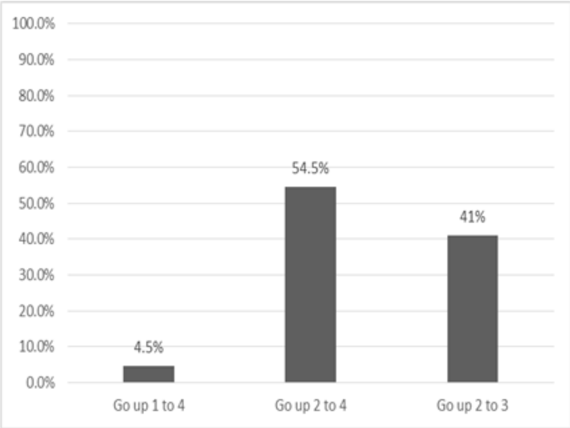

Figure 1: Applies design methodologies.

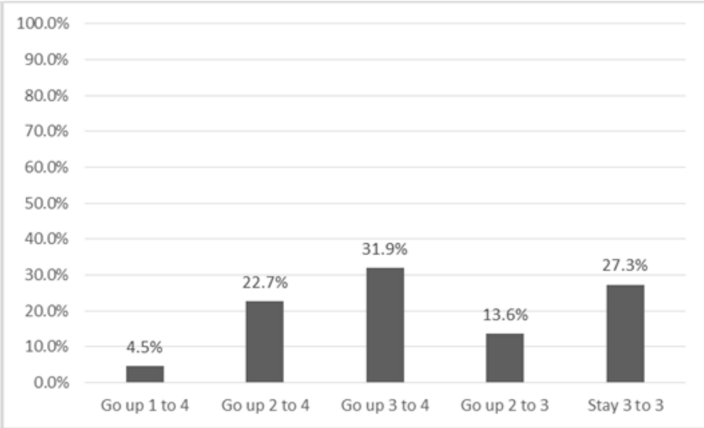

Figure 2: Detects strengths.

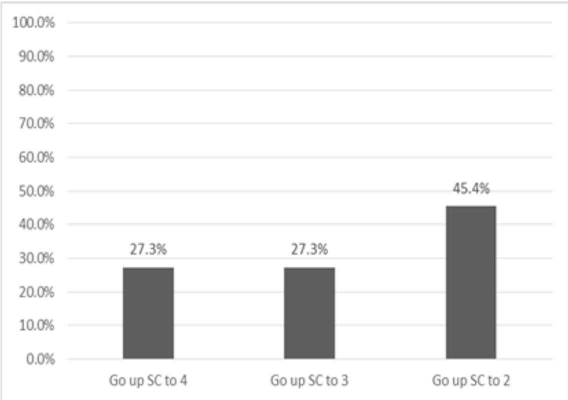

Figure 3: Takes measurements.

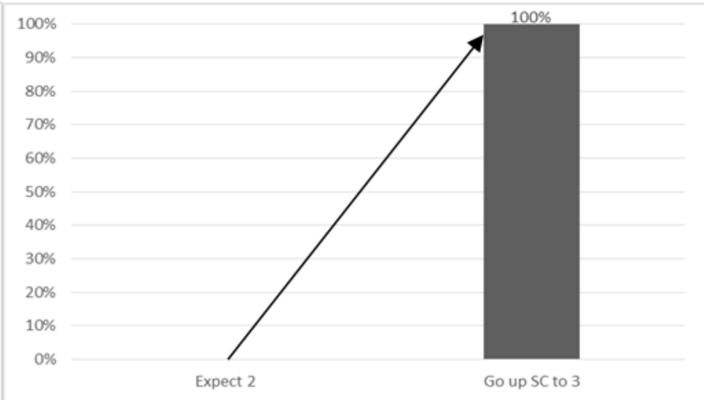

Figure 4: Uses specialised software.

In the sub-competency *performs measurements*, 27.3% of the students achieved level 4, expert profile; 27.3% achieved level 3; and 45.4% reached level 2.

For the *uses software* sub-competency, the teacher expected the students to achieve level 2; however, 100% of the group members achieved level 3, expert profile.

As for the sub-competency *explains their profession*, 13.6% of the students achieved level 2 and 86.4% achieved level 1. There were none at level 3: expert profile.

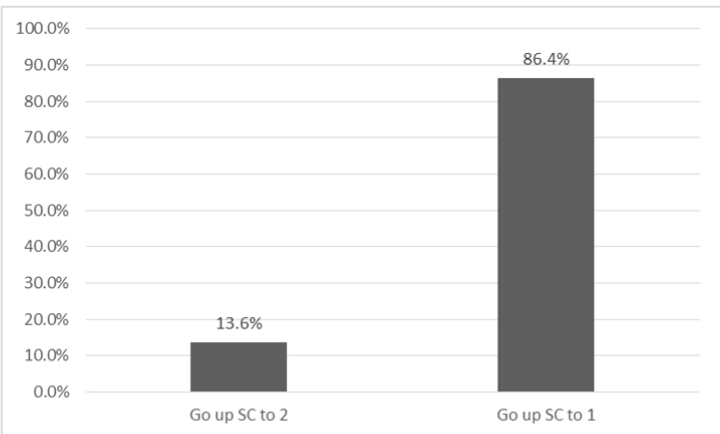

Figure 5: Explains profession purpose and benefits for society.

Regarding the expected levels of learning, after concluding the assessment process for the five sub-competencies, it was noted that not one student's competency level went down after the first evaluation, and only in the *detects strengths* sub-competency did 27.3% of the students stay at the same level (27.3%).

The sub-competency *explains their profession* is an area for improvement since participants only achieved levels 1 and 2. At this stage, students are in the learning phase and are not yet able to make generalisations on the impact of engineering on improving the quality of life and their responsibility in preserving the rule of law.

Examples of feedback provided to students are given in Table 2.

Table 2: Examples of feedback given by the teacher.

Sub-competency	First evaluation	Second evaluation
Applies design methodologies	Clearly identifies the problem and understands what needs to be done to solve it	Uses different methodologies, evaluates design alternatives to choose the best possibilities
Detects strengths	Identifies the weaknesses of the first proposal and properly corrects them	Evaluates the advantages and disadvantages of the different proposals and chooses the best possibilities
Takes measurements	SC: this part of the project has yet to be done	Takes measurements that allow the results to be assessed and the consequences and chances of success to be inferred
Uses specialised software	SC: this part of the project has yet to be done	Very good use of specialised software for modelling the problem, exploring alternatives and presenting results
Explains the profession's purpose and benefits	SC: this part of the project has yet to be done	Identifies the role of engineering in society, but does not identify the professional association that regulates the product in this project

The feedback issued by the teacher for each assessed sub-competency helped students to know their strengths and opportunities, allowing them to advance through levels of competency in each assessment within the development process.

CONCLUSIONS

Pending the continued implementation of the assessment for other groups, it can be noted that the feedback process reported here had a positive influence on the student's learning and the instructor's teaching [14].

The students were from a course on design and simulation of machine elements. The study was undertaken from the perspective of performance and authentic assessment and with the support of a feedback report, the use of a taxonomy and an assessment rubric [1][2][6][13]. This study was within a framework of an educational model based on competencies [9].

Students were able to reflect on their strengths and areas of opportunity [5][11]. Feedback was the means for students to improve their information processing levels and to generate strategies to allow them to reach the expected level of performance in the competencies. This takes students toward the use of knowledge acquired in the course to address real tasks. Students, in this study, were to utilise knowledge to design the elements that make up a mechanical transmission [2][6].

The results show that the instructors were able to gradually bring the students closer to a degree qualifications profile [12] and detect students who require individual support. Instructors were able to adjust their planning and teaching strategies according to the advances in competency levels achieved by the students [2][15].

Thus, it is concluded that the proposed assessment process is useful to facilitate the achievement of the competencies indicated in the degree qualifications profile [2]. It provides an alternative way to understand how student performance develops throughout a course of study.

Future research could review feedback methods to integrate the various components that make up the disciplinary competencies in increasingly diverse environments. That could provide an understanding of other cultures and the integration of disciplines in a global context. In addition, it is necessary to continue reviewing how this type of assessment process can be implemented in the classroom to corroborate the benefits of authentic performance assessment.

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