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ENGINEERING DESIGN PROCESS LEARNING OF UNDERGRADUATE MECHANICAL ENGINEERING STUDENTS: A CASE STUDY ON THE UFSM COURSE

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Abstract. *Mechanical engineering students shall perform in several industrial segments; however, traditional engineering training lacks activities involving the application of this knowledge in real industry problems. In the current scenario, where students have remote classes, engineering learning and theory-to-practice applications become even more complex. Therefore, creating means that allow students to develop actionable knowledge becomes fundamental to the engineering learning process. Bearing this in mind, the aim of this work is to display an example of engineering design process, to instruct mechanical engineering students. The problem in consideration by the course is designing an aluminum can press machine to reduce the storage space occupied by empty aluminum cans and prepare them for recycling. The research method for this work is a case study of a real problem given within a course subject of mechanical engineering, the Integrated Design class. The course syllabus includes design management, material selection, computer aided design and engineering (CAD-CAE), failure mode and effects analysis (FMEA), with completion by prototype construction and review. The results describe the engineering design process applied to build aluminum can press machines where students apply the theoretical-practical knowledge from the course. Students managed and performed the engineering design process of their solutions by the application of an engineering design methodology that comprises project planning and design execution activities. Students designed and built the aluminum can presser aiming at low-cost prototypes with reused materials and carried out simplified tests adapting to the current remote education scenario. The course results show the contribution of the Integrated Design course to the learning process of Mechanical Engineering students. The coronavirus pandemic starting at the time of the first course offer has forced all presence activities to be cancelled, and then to be replaced with remote activities in a low contact environment. Students managed to apply theoretical knowledge to a real problem through the engineering design methodology proposed. Besides, students showed to develop their theoretical-practical skills through designing and building their prototypes. Lastly, the Integrated Design subject course allowed students to perform tasks similar to those required in a product engineering professional environment.*

Keywords: *Engineering Learning, Design Process, Product Design, Integrated Design.*

1. INTRODUCTION

In the last years, engineering education has changed drastically from the perception that the traditional training lacks activities that involve the application of this knowledge in real problems. The industry needs newly graduated professionals who are better prepared for the job market, to reduce the time and resources invested with training. However, the current pandemic scenario requires students to attend remote classes; consequently, engineering learning and theory-to-practice application suffer from further complexity. In many cases, teaching laboratories are far from students and educators and sometimes even inaccessible due to presence restrictions. Therefore, creating means that allow students to develop actionable knowledge becomes fundamental to the engineering learning process.

Currently, the teaching of engineering design process (EDP) has been presented and discussed by several researchers, university educators and instructors who work in the field of engineering education (Kurowski and Knopf, 2006; Kadlowec *et al.*, 2007; El-Madany and Al-Bahkali, 2009; Mangold and Robinson, 2013; Cohen and Katz, 2015; Han and Shim, 2019). There is literature about product design development and EDP with contributions to engineering education in the design area (Back *et al.*, 2008, Pahl *et al.*, 2005; Baxter, 2011; Romano, 2013).

Courses including the EDP in their practice allow students to develop design skills by following a prescriptive methodology, where the technical systems can be planned, designed, produced, assembled and tested. In this practice, in addition to technical skills, students can develop personal skills, such as self-management, time management, communication skills, both written and oral presentation, among others (Cohen and Katz, 2015).

Knowledge about the EDP works as an important learning framework for engineering students, for it helps build confidence in the decision-making process to develop optimal solutions for a defined objective. This has been shown to be a successful tool when applied to students in the classroom (El-Madany and Al-Bahkali, 2009; Mangold and Robinson, 2013; Han and Shim, 2019). In the training of mechanical engineering students, the educational experience of theoretical components and their practical application is essential to help them develop design management and leadership skills, as well as the art of solving technical problems, good communication, organizational skills, among others (El-Madany and Al-Bahkali, 2009).

Designing a product just by theory without the practice experience is ineffective because many details are learned by working on design (Kurowski and Knopf, 2006). In addition, encouraging creative and critical thinking is an essential factor for training engineers. New teaching methods are needed to foster creativity in engineering education (Tekmen-Araci and Mann, 2018). We believe that EDP knowledge should be introduced in courses and classrooms within engineering degrees to unite theory and practice, thereby contributing to improve learning about the design activity and encouraging innovative creativity in engineering education. Thus, students will be better prepared and with more experience to start a professional career in the industry.

This paper shows an example of an engineering design process developed by students in a course subject of mechanical engineering at UFSM called “integrated design class”. The problem presented to the students was the development of a technical system for pressing aluminum cans to reduce the storage space occupied by empty cans. For this, the course syllabus includes design management, material selection, computer aided design and engineering (CAD-CAE); failure mode and effects analysis (FMEA), with completion by prototype construction and review. The body of information supporting the study in this paper comprises student work on the solutions they developed alongside student feedback on their self-evaluation about their readiness to undertake engineering design practice in industry. The objective of the paper is then to assess the contribution from the Integrated Design course regarding the goal of preparing engineering students for professional practice.

2. COURSE OVERVIEW

An undergraduate engineering curriculum comprises several courses; some of them require practical activities to make a significant part of their content or teaching plan. The Integrated Design course provides one of the subjects in the undergraduate degree in Mechanical Engineering at the Federal University of Santa Maria (UFSM). The primary aim of the Integrated Design course is to execute and manage the design of technical systems through the EDP, under guidance of a design methodology, with applying the knowledge obtained in the courses previously attended and along with those in progress. The evaluation on students’ learning is carried out through the presentation and defense of a technical project report.

The course is intended for 7th term students with a workload of 45 hours, of which 30 hours are reserved for practicing on the engineering design process. The partitioning of coursework time has been planned with considering a full-physical presence approach, yet the coursework has been first implemented in an all-remote approach through the Moodle learning environment alongside synchronous meetings through the Google Workspace platform. The coronavirus pandemic starting at the time of the first course offer has forced all presence activities to be cancelled, and then to be replaced with remote activities in a low contact environment. This required all participants to adapt to the new dialogue format.

The course syllabus includes topics related to the field of mechanical design, such as: design management; material selection; CAD-CAE; FMEA; and prototype construction and review. This program is presented as a theoretical component of the course and includes the phases and tools that help students in understanding the EDP and building confidence in their engineering skills. Students are supposed to implement the knowledge acquired from these units into a project to develop a prescribed type of product. The course includes a milestone schedule for partial deliveries throughout the course, to guarantee the progressive evolution of the project. The Integrated Design course was planned to provide students an opportunity to gain a global empirical viewpoint about the product design activity, ranging from the identification of a product need, progressing to the evaluation of a prototype.

The course path between these is guided by design methodology prescriptions (Pahl *et al.*, 2005; Back *et al.*, 2008), that provide groundwork for students’ creativity and critical thinking. At the end of the course, the student shall be able to perform professionally in the development of industrial products and related topics. The course is structured to elicit the abilities that students have through the design methodology groundwork that is included in the theoretical content. While previous courses emphasize getting students to know what engineering disciplines exist and the knowledge they comprise, the Integrated Design course focuses the integrated application of engineering knowledge into a design process framework set with basis on a prescriptive design process model. Therefore, the Integrated Design course is planned to enable students as professional players within product development processes (PDP) performed in industry.

The coursework plan is designed in a way so that students can perform the intended activities within its content: a theoretical part with knowledge about engineering management and practice, followed by a practical scope of work that students will carry out through developing a product. The scope of work prescription departs from a technical need and provides guidance about the design activities students are supposed to perform. This explanation includes the work by the teaching team into eliciting students' knowledge that shall be applied onto developing the product along with the work performed by students into developing the product.

2.1 Course content and scope of work

The Integrated Design coursework is set in two parts: a theoretical part on engineering knowledge, and a practical part about performing a prescribed scope of work. The teaching team starts the course with an overview on the topics of engineering knowledge included in the course content:

- Project planning and management: how the project is to be planned and reported,
- Materials selection in design: how to select the materials for product components;
- Product design and construction: how to design and build component geometries in CAD;
- Failure Mode and Effects Analysis: how to consider functional reliability and failure in design; and,
- Product prototyping techniques: how to make the prototype that renders the satisfaction of the need.

Also in the first meeting, the teaching team embodies the scope of work of the practical part of the course to the students in the form of a product design request. For that purpose, the product design request presented by the teaching team first involves the intended product that students will develop. Students shall develop a mechanical system, which:

- It meets a technical need within a sustainable development goal;
- Its knowledge can be acquired by internet search and observations;
- Its architecture includes an ensemble of mechanical working principles;
- Its dimensioning involves mechanical engineering fundamentals; and,
- Its design and construction are feasible through the duration of the course.

Besides the type of product and its generic characteristics as meeting the criteria above mentioned, the product design request includes the scope of activities that students shall perform to get the product designed and built. Students will start over from the product design request into first planning their activities through the course and performing preliminary research about the technical need and its market. Students perform this activity with support of project management knowledge that is included in the course content, alongside coaching by the teaching team about how to communicate aspects of the technical need – which justify in first place why the product is to be developed and communicate the premises on which such development shall be carried out.

The process follows based on understanding of the technical need, and on students' communication of development premises so they can set their creative process in motion. This begins with their establishing technical functions to fulfil the need in global and partial indenture levels (preferably in a flow-based approach, but likely also in a hierarchy-based approach), and proceeds through setting the working principles that will perform the intended functions and communicating the manner through which working principles shall be implemented. This includes a preliminary design of the intended components with a bill of material specification.

A third step in the product construction process taking place is the geometric component and assembly design that is carried out through using CAD software. There, students shall establish the product construction layout and its architecture. Besides, students also establish mechanical interfaces by this stage, through setting design constraints within and between components, and defining how the assembly is to be carried out by the means of mating approaches being set by the means of the CAD application. This phase also includes establishing the basis for students to generate the technical drawings of components and perform preliminary 3D rendering of the solution.

The development process proceeds through a review stage under which the teaching team coaches students to approach the reliability of its technical functions by using the FMEA technique. Here, students review the construction work they performed so far through following the FMEA thought pattern to understand what would go wrong through the operating lifecycle of the product. They are supposed to communicate the weak spots of their product design and communicate the actions they intend to perform into solving them. This design step is likely to result in design changes that shall be established and fixed prior to proceeding with their work towards the final phase, which entails the prototyping of the product.

The last phase of the project through the Integrated Design coursework is the learning and usage of prototype construction techniques, including additive manufacturing. At this stage, students can report on their creative and review work leading to their current design proposition and figure out the prototyping approach they think is feasible to meet the project schedule. This prototyping by students involves both work into rendering the product from the current version of their virtual design and manufacturing the components and assembling them to the physical prototype. It is often the case that prototyping will be done in the way students think is best feasible on their own constraints – the closer to real they can get the prototype the better quality will be attributed to their prototyping work.

Besides the prototyped product, on virtual rendering as well as on physical assembly, students reach their final milestone in the coursework with presenting the whole of their work through their course.

This will work as the final evaluation step by the teaching team, who converts five design milestones into two grades that will result in an average grade that will apply to the whole course according to the scoring system at UFSM. The teaching team is available, providing the course groundwork, coaching the students through the design process, and performing evaluation and feedback activities by the milestone presentations as defined in the product design request. The goal with the Integrated Design course is to challenge students into applying their engineering knowledge into the design and development of a mechanical system. Successful students will ultimately deal with professional challenges in industry and advanced studies with more confidence on their capability to deliver the solutions society needs.

3. STUDENT AUTHORED DESIGNS

Students got their design work started after receiving the product design request on the purpose of pressing aluminum beverage cans for recycling. The variety of solution principles designed by the students for pressing beverage cans includes the following proposals:

1. Direct manual pressing: the operator feeds a single beverage can onto a slot, grabs a handle to directly apply the compaction force to press the beverage can (Figure 1a);
2. Mechanic manual pressing: the operator feeds a single beverage can onto a slot, grabs a handle in a mechanism that applies the compaction force to press the beverage can (Figure 1b, Figure 2, a and b); and,
3. Mechanical drive pressing: the operator feeds several beverage cans onto a feeder channel for positioning into a chamber where a motor-driven piston will press every can to a storage bin (Figure 3, a and b).

The concepts with manual drive aimed at residential or low-volume applications, to which students identified the following priority needs: safety, durability, low cost, easy cleaning, usability, maintenance, lightweight, size variability, and ergonomics.

Figure 1 presents two student concepts, with direct manual pressing and mechanic manual pressing. Concept 1 (Figure 1a) is designed for use with placement over tables or workbenches, with effecting compaction by manual engagement of a handle directly linked to a pressing surface that is constrained within a chamber. It works by pressing one can at a time over a beverage sump drawer that can be removed, with an estimated cost of R\$ 191,70. It is manufactured with AISI 1020 steel, weighing 3,8 kg. Then, concept 2 (Figure 1b) is intended as a wall-mounted solution fixed through fasteners, compacting one can (up to 473ml) at a time. It works by the means of a lever equipped with a rubber grip and a return spring, pivoted to a piston whose force effect presses the can lever over a retaining ring, with an estimated cost of R\$ 147,00. It takes a volume space of 245 mm x 245 mm x 400 mm and weighs 12 kg.



Figure 1. Rendering of Concept 1 (left, Ferreira, 2020) and Concept 2 (right, Zulian, 2020) for manual pressing of aluminum beverage cans.

Figure 2 presents other two student concepts with the principle of mechanic manual pressing. Concept 3 (Figure 2a) is intended as a wall-mounted solution in the same way as Concept 2, with the difference of bringing a bottle-opening cutout feature at its base. It works by pressing one aluminum can (up to 473 ml) at a time by the means of a manual lever drive with rubber handle that slides over a vertical-constrained piston. The mechanism of this concept has the fewest components to the effect of compacting the beverage can over a surface, under which a liquid sump is designed to allow for dispensing the excess liquid, with an estimated cost of R\$ 33,70. It is manufactured in AISI 1020 steel, weighing 1,3 kg. Concept 4 is also intended as a wall-mount solution (Figure 2b), with providing a sloped feeding channel to accommodate a few cans before their compaction. It works by pressing one aluminum can (up to 720ml) at a time, by the means of a manual lever drive that is sliding-pivoted to a piston running within a horizontal chamber. Excess fluid will run off from the chamber through a cutout feature by its wall-facing end. It is manufactured in AISI 1020 steel to a cost of R\$ 40,96.

Students who pursued the mechanical-driven concepts found these needs upon their seeking a professional market with significantly higher throughput. The motor-driven concepts aimed at higher volume and professional applications such as recycling cooperatives or service organizations with high throughput, to which students identified additional priority needs to those for low-volume applications: effective compaction, and reasonable storage space.



Figure 2. Rendering of Concept 3 (left, Flores, 2020) and Concept 4 (right, Lima Júnior, 2020) for manual pressing of aluminum beverage cans.

Concept 5 works in this approach (Figure 3a), where the operator manually feeds the cans to a vertical+sloped channel leading to the pressing chamber where a double-action pneumatic piston will press one can at a time. The fluid power system driving the piston features a control panel and emergency stop command facing sideways, which enables operator awareness at the pressing process. Each pressed can will fall to a hopper through a cutout opening at the fixed end of the pressing chamber. The system shall occupy a space of 1,50 m long by 0,80 m wide, weighing 92 kg. Concept 6 works with a similar feed system, where the operator manually feeds the cans to a sloped channel – adjustable to the maximum can size – through which beverage cans will roll with towards a pressing chamber. A motor-driven piston through a slider-crank connection will press one can at a time, that can be controlled through a control panel by the table surface featuring on/off switch, emergency stop button and operating indicator light. The pressed cans fall from a cutout opening by the fixed end of the chamber to a wheel-mounted hopper that can be removed for unloading. The system shall occupy a space of 1,01m long by 0,72m wide, weighing 80,6 kg.

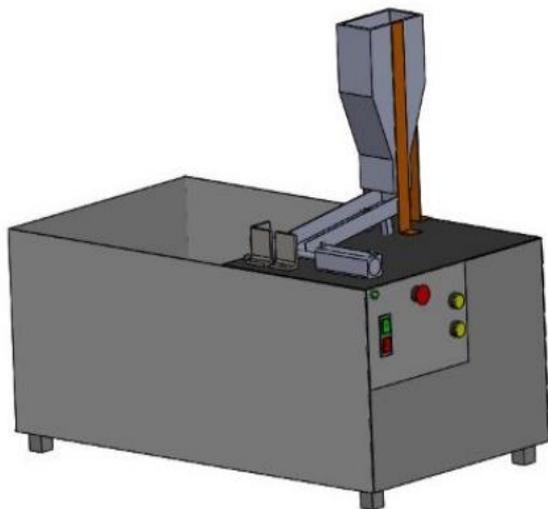


Figure 3. Rendering of Concept 5 (Silva, 2020) and Concept 6 (Baratto, 2020) for mechanized pressing of aluminum beverage cans.

The concepts in display show diverse ways of responding to the product design request, with unique mechanism and construction layouts, and individual approaches to solving the problem of pressing aluminum cans. Their creations embody their quests at needs they observed from their own experiences besides the requirements elicitation process within the course. For manual and mechanical-driven solution principles, the construction variants in display demonstrate the engineering design process as a project comprising a temporary effort to make deliverables aiming at the solution of a problem. (PMI, 2017).

4. RESEARCH APPROACH

This paper presents insight collected through an academic case study within a single undergraduate-level mechanical engineering course (Yin, 1994). The data collection approach comprises the following inputs:

1. Document analyses of student reports about functional requirements, identifying functional characteristics of their prototypes against functional requirements in the scope of work;
2. Remote online questionnaire applied to students after a full-semester course through Google Forms elicit and quantify alumni feedback:
 - a. 15 coursework rating questions with Likert scales between one star (little impressed) and five stars (significantly impressed); and,
 - b. Three (3) questions with written answers eliciting general student opinion about the course and its remote approach, and suggestions for future editions.

The document analyses applied to all solution concepts provided by the students; the response rate for the questionnaire was 100%. This means that student input is considered over the whole population of course attendants, regarding both student results from the coursework and student feedback after the course has been completed. After considering these elements, this paper includes a discussion on the factors regarding how the coursework performed against the goals established for the study.

5. RESULTS AND DISCUSSION

The engineering design process learning of mechanical engineering students can be expressed in several angles: it is a choice of the teaching team to focus on eliciting students' feedback, for the purpose of identifying their impressions about the coursework and its characteristics. The students' response is elicited in form of coursework ratings regarding aspects in three themes developed along 15 questions, and written statements about the product theme, the remote approach and the coursework in general.

5.1 Construction features

One interesting aspect of the course is the diversity of designs about the scope of functionality and the use of working principles. While the pressure-driving features display different form and arrangements, there is some commonality between the solutions regarding the functional and mechanic strategies to getting the cans pressed. A morphological chart (Zwicky, 1967; Pahl *et al.*, 2005) in display by Figure 4 enables the comparison of functionality and principles employed by students, about how they approached the product design request into making a product with confidence about its operation readiness.

	Manual	Mechanic manual			Mechanic driven	
Concepts /Functions	1	2	3	4	5	6
<i>Feed empty can</i>	Single can feed at pressure chamber	Single can feed at pressure chamber	Single can feed at pressure chamber	Single can feed inlet	Single can feed inlet	Single can feed inlet
<i>Channel empty can</i>				Multi-can slope channel	Funnel, sloped multi-can channel	Size-adaptable multi-can slope
<i>Host empty can</i>				Single-can pressure chamber	Single-can pressure chamber	Single-can pressure chamber
<i>Drive piston to empty can</i>	Direct handle, manual action,	Pivoted lever, manual action	Sliding lever, manual action	Sliding-pivot lever, manual	Fluid power cylinder, double action	Electric motor, crank-slider
<i>Dispense beverage</i>	Removable sump drawer	Not found	Draining sump chamber	Not found	Not found	Not found
<i>Remove pressed cans</i>	Manual setback and removal	Manual setback and removal	Manual setback and removal	Manual setback and removal	Chamber cutout and gravity fall	Chamber cutout and gravity fall
<i>Store pressed can</i>	Not found	Not found	Not found	Not found	Fixed storage bin	Movable storage bin

Figure 4. Morphological chart of solution principles for pressing of aluminum beverage cans.

The morphological chart above shows all solution principles pressing a single can at a time, with some specifics about the action driving the piston towards inside the chamber to press the aluminum cans, about its being horizontal or vertical, and on how the movement is constrained inside the piston. Another aspect is the presence of complementary features such as a sump for dispensing excess beverage, and a separate storage bin for pressed cans – notably on mechanical-driven can pressers.

5.2 Alumni feedback: ratings

The course work ratings include 15 questions with Likert rating scales between 1 (one star – little impressed) and 5 (five stars – significantly impressed) and 3 (three) questions with written answers. The Likert scale questions are organized around the themes of self-evaluation and confidence (questions 1 to 4 and 13), scope of work practice support (questions 5 to 9), and theoretical problem-solving support (questions 10 to 12, then 14 and 15).

The alumni feedback on self-evaluation and confidence (Figure 5) shows students with an overall positive attitude about gaining expertise and learning the way forward through the EDP, with the totality of results showing at least four stars. In these criteria, students display a feeling of confidence regarding the expertise and skills they gained into engaging further design tasks in the future. At the same time, the students' feedback raises the experience criteria related to confidence in their capability to development processes and supportive contribution from the coursework: these are matters they found reasonable value from the course with at least half of the views above four stars, yet with some three-star ratings, which is worth mentioning.

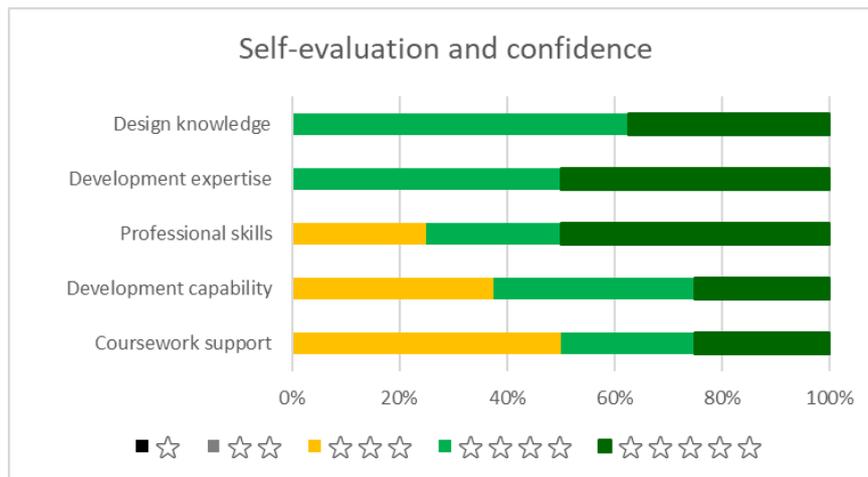


Figure 5. Students' feedback about their self-evaluation and confidence in facing design tasks.

The feedback on scope of work practice support (Figure 6) shows positive student feedback about the support to practicing the topics given on through the course, with most categories showing at least 50% of four- and five-star ratings. Materials selection shows the best rate of coursework support, followed by planning and management alongside failure modes and their effects. At the same time, the students' feedback calls attention to component modeling and prototype building – applicable to later design phases of the engineering design processes – meaning that the coursework experience could be better. Component building and failure modes' activities found similar three-star ratings, whereas prototype building displays a significant group feeling they gained less support. While all students managed to yield digital prototypes, physical prototyping was severely hampered during the pandemic due to social distancing restrictions.

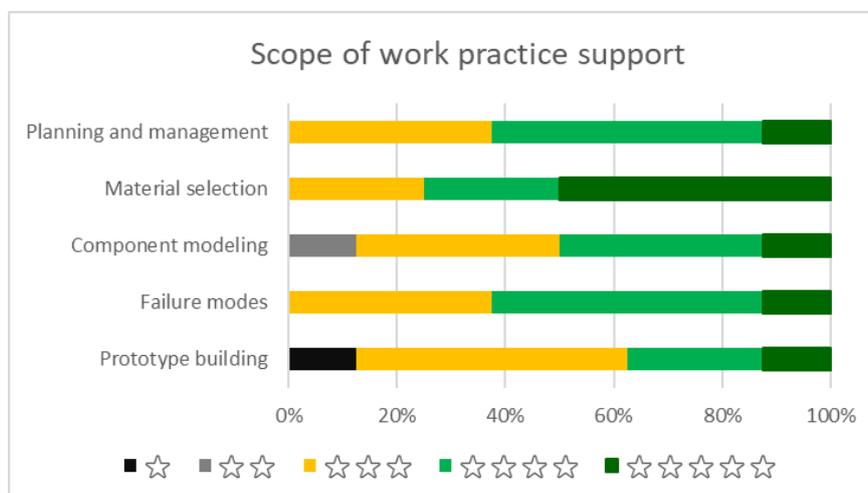


Figure 6. Students' feedback about scope of work practice support from the course.

The feedback on theoretical problem-solving support (Figure 7) shows students with positive feedback the relevance of the coursework to mechanical engineering formation, and about the valuable new knowledge they learned on the course that they were not aware of from other courses, with most categories showing at least 50% of four- and five-star ratings. They see the contribution from theory to their problem-solving ability in a similar, mostly positive perspective. In these criteria, students display their impression about the relevance of the course and its support to their solving engineering challenges. At the same time, the students' feedback raises the criteria related to engineering judgment and verification and validation, meaning that the coursework feels a little bit short about judgment and decision-making in engineering. These skills were assigned with mostly three-star ratings with at least 50%.

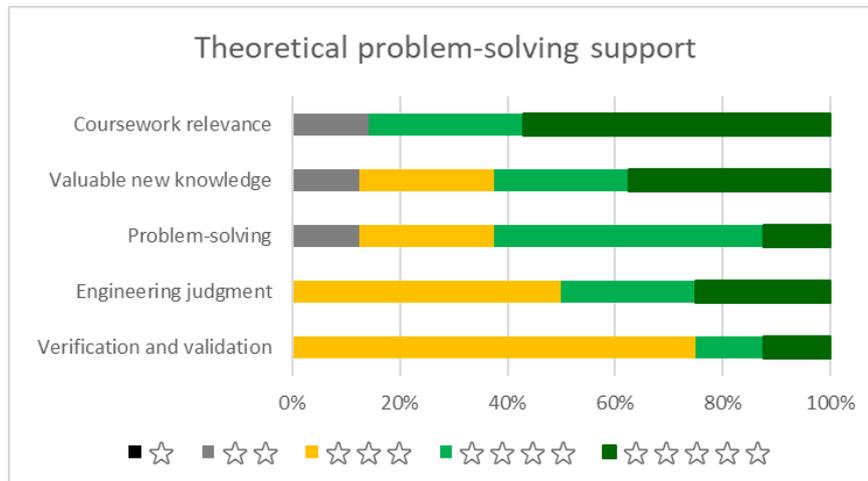


Figure 7. Students' feedback about scope of work practice support from the course.

The matters where students' feedback display paths for improvement relate to the degree of support offered by the theoretical part, regarding their capability to execute the EDP, and the theoretical contributions to their confidence in engineering judgment and their ability to develop and validate a new product. In these criteria, only 25% of students gave five stars, while a percentage of 40% or more gave three stars. Furthermore, the highest levels of dissatisfaction were observed the course contribution regarding the PDP problems solution and the product design validation. Nevertheless, the global percentage rate of student feedback reaches around 78%. The authors consider this a high satisfaction rate, especially considering that it is the first time that the course is offered.

5.3 Alumni feedback: written responses

Students' feedback elicitation also works in terms of open questions with written answers, where students display their views about the intended product, the difficulties with remote learning and their general feedback about the course. All course attendants answered these questions. Regarding intended products to subsequent classes, students suggested the following themes:

- Internal research and facility needs inside the university campus;
- Value-making needs for unemployed and vulnerable people;
- Cultivation and transportation needs for small farming businesses; and,
- Freedom for their own to choose the product being developed.

In reference to improvements on the coursework, students suggested the use of case studies to improve the assimilation of theoretical content. In addition, it was recommended an integration of the Integrated Design course as a continuation of the preceding course on Product Design Methodology (6th term), so that the design process starts on the Design Methodology course to be completed by the Integrated Design course. Besides, the pandemic situation where presence contact was not allowed had its effect on course performance, the problem being the lack of personal experience because of the remote communication. This also caused fatigue because of some long video sessions and created challenges to time and schedule management. Access to prototyping resources was also difficult.

5.4 Discussion of results

The discussion about the coursework results can be framed around the development of engineering competences, which is the end objective for the Integrated design course, and by extension, for the mechanical engineering degree. While one cannot expect the course to assure all fundamentals on its own, the potential from its contribution cannot be overstated. R&D expertise offers principles to coaching and developing engineering talent that apply to training the EDP to mechanical engineering students.

These principles relate to the following aspects of engineering and R&D practice (Marini, 2019):

- I. Roadmapping the problem-solving path to implement the solution,
- II. Getting confidence with handling and using engineering tools,
- III. Sense-testing and teamworking with colleagues and expert peers, and,
- IV. Keeping a close eye to the place where the action happens.

There is no single course to which assign the role of building up these skills in engineering students; it is rather the case that people develop these abilities along their formation and even through their professional life. At the same time, the Integrated Design coursework is designed so that to support students in developing these abilities to engage problem-solving challenges they will certainly face in their professional life. The Integrated Design course shows a strong record about roadmapping and engineering tools because most of the theoretical support relates to these aspects – planning and management, material selection, component modelling, and failure modes, relate to methodology and tools that engineers use to make and improve solutions. However, sense-testing and place of action abilities were flawed: sense-testing was hampered because of the lack of experience with remote learning and missing opportunities to collaborate (solo-work) and provide feedback.

The limitations in teamwork and sense-testing were reflected in the way students met the product design request. Strategy gaps were identified from coursework results, regarding functional requirement and side-effect misses, besides design fixation resulting from the effect current products displaying available and operating working principles which would thus play the role of design anchors (Jansson and Smith, 1991; Youmans, 2011). The short development time along the difficulties in communication created a tendency to satisficing at an implementation level considering the main aluminum can flow, with basis on current solutions. Student teamwork could lead to the discussion of improvements to capacity (two cans at a time, or more?) and the combination between working principle sets for completing their solutions to functional requirements. More emphasis on sense-testing and feedback would help avoiding the miss of functional requirements, such as the failure to include features for dispensing with the excess beverage possibly within the incoming cans, letting excess beverage leak off the chamber.

While students mostly agree to the relevance of the Integrated Design course, they also feel there is a long way forward to confirming their skills to engineering judgment (is it functional, safe, reliable, ready, fit for purpose, ...?) and to verify and validate the designs (does it perform to requirements, does it meet customer needs?). Lessons from R&D experience shows that such skills grow through sustained peer engagement (Ericsson, 2010; Marini, 2019); the cases reported in the R&D study took at least one year of continuous engagement, whereas the coursework must be completed in a single semester. The needs for improving the output on advanced design phases such as component modelling, failure modes, and prototyping, aim at supporting students' confidence to engineering judgment and the ability to verify and validate the designs. These aspects are leading to changes in the current coursework, such as the allowance for teamwork, and the decoupling between the theoretical subjects and the practical scope of work. This decoupling could open creative coaching possibilities where students should be able to engage in sense-testing about how to satisfy the requirements once provided with enough theoretical understanding.

6. CONCLUSIONS

The results from the Integrated design coursework performed by Mechanical Engineering students at UFSM display the capacity of undergraduates to apply engineering design knowledge to a real problem through the proposed engineering scope of work. By including a prescribed design methodology, the scope of work communicated through the product design request and by teachers' feedback through the course enabled students to demonstrate their theoretical-practical skills in designing and building their prototypes.

The alumni feedback survey demonstrates students' confidence in their knowledge and their sense of meaningful experience with implementing the scope of work, including the support provided by teachers' explanations; advanced and thus more complex topics are worthy of better communication. Future work shall consider analyzing the engineering knowledge roadmap through course subjects towards their application in the integrated design course, and verifying student teamwork performance with basis on coursework transactions and student feedback.

In general, engineering students managed to apply theoretical knowledge to a real problem through the engineering design methodology proposed. Besides, students showed to develop their theoretical-practical skills through designing and building their prototypes. Lastly, the Integrated Design subject course allowed students to perform tasks in similar manner to those required in a product development environment. The results from the course in a low-contact context during the pandemic point out the potential of the course in preparing students for engineering digitalization.

7. ACKNOWLEDGEMENTS

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