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PAPER

Tractor Stability for Agricultural Engineering Students: Learning Through a Project-Based Task

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ABSTRACT

Most of the fatalities in the agricultural sector in developed countries are related to machinery use, particularly tractors overturning. Despite its importance, a lack of practical teaching about this topic has been detected in the Agricultural Engineering curricula. For this reason, an active learning activity was planned within a teaching-innovation project. The objective of this project was to design a structure as new teaching material to implement and use it to determine the tractor's center of gravity coordinates. This teaching-innovation project was organized in two stages: 1) The design of proposals by students following previously established requirements, and 2) A practical exercise to analyze tractor stability. Each stage involved students from two different Agricultural Engineering degree subjects. Before the second stage, the professor performed the structure's final design based on previous proposals and later built the structure. Five different ramp design proposals were received and graded in the first stage. A positive correlation between peer review and the professor's grades was found. During the second stage, the ramps were used in another subject, in which the grades obtained in the related practical exercise were significantly higher than those in the previous year. However, no improvement was found in the final exam grades despite tasks in both stages complying with several general competencies required to pass each subject.

KEYWORDS

project-based learning, active learning, tractor overturning, design competition, peer review, teaching innovation

1 INTRODUCTION

Annual fatal accidents in agriculture, forestry, and fishing ranged from 362 to 481 in the EU during the 2017–2020 period [1]; this is the last updated report on these types of accidents in Europe. In the Canadian agricultural sector, around 70% of fatalities are related to machinery [2]. In the USA, tractor accidents are also considered a major contributing cause of death in agriculture [3]. Thus, accidents due to machinery used in agriculture are a serious issue. Tractors are considered the

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leading cause of agricultural work-related fatalities in many industrialized countries, and rollovers frequently account for more than 50% of fatal accidents caused by tractors [4]. However, there is no official database that records accidents caused by tractor overturning. Therefore, data are only available from the scientific literature: 118 fatalities per year in Italy due to tractor overturning (period 2008–2019) [5] or 65 yearly fatal accidents in Spain (period 2010–2019), most of them associated with tractor overturning [6].

Tractor overturning accidents can be reduced through an adequate rollover protection structure (ROPS) design and by improving driver information and training [7]. These measures can be very cost-effective, considering that only in New York State do these accidents cost more than 6 million dollars, while a public intervention program to increase ROPS use could cost about 1.8 million dollars [8].

Thus, safety training to reduce tractor-overturning risks is basic to avoid fatal accidents. In this sense, educational actions are usually addressed to agricultural workers [9], with specific attention to foreign workers who could misunderstand hazardous pictograms [10]. Furthermore, occupational safety and health are perceived as challenging issues by farmers [11]. All of the above reasons suggest that future agricultural engineering programs should heavily focus on this topic. Moreover, the development of new educational tools and strategies applicable to farm safety would support safe working practice adoption and could help to improve the professional competencies of graduated students and the number of students that pass the course [12].

Safety training related to tractor-overturning risks is rarely aimed at engineering students, since it is considered that these future workers will not drive tractors and, therefore, will not require these skills; agricultural engineering courses usually include only some theoretical content about tractor stability. However, graduates in agricultural engineering could play an important role in reducing this type of accident since some of them will eventually become farm advisors or extension educators. Therefore, it seems essential to improve the risk awareness and safety culture in agricultural engineering studies concerning this type of accident.

Active teaching methods are increasingly being used in Science, Technology, Engineering, and Mathematics (STEM) disciplines in higher education since they usually improve student motivation, competencies acquisition, and class participation [13]. In this way, the learning process could be conceived as a path to be discovered by students under the professor's supervision. This learning process might be different for each student, and it should not be seen as only an information accumulation process, but as a self-discovery process of laws and principles that adjust to every subject. Along this learning process, the acquisition of competencies and abilities must always be assessed beyond students' self-report data focused on specific subject-related knowledge [14]. However, these activities are time consuming for professors, who must teach and research. Initiatives such as CDIO (Conceive – Design – Implement – Operate systems and products) are aimed at contributing to the improvement of engineering education and establishing a recognized research field [15].

Besides active teaching, project-based learning can also be used as a transition process for students in the last courses before graduating and entering the job market. In project-based tasks, the professor acts as a coordinator but does not lead the project promoting students' independent learning. This method usually improves the learning process perception by students [16] and increases both grades [17] and scores in satisfaction surveys [18]. Furthermore, new technologies such as augmented reality [19], or 5G networks [20] can enhance students' competencies.

In many cases, the development of materials for active or passive teaching is carried out only by professors, who let students use these materials but do not involve them in their development. If these materials are correctly designed, they can remarkably improve the percentage of students who overcome the task or master the subject [21]. A further step in the educational process is to involve students in the development of new materials and their subsequent use by themselves or by other students [22].

The aims of this study were to explore innovative methodologies that improve the teaching of tractor-overturning prevention in agricultural engineering degrees and to develop new materials that could be later used for farm education and extension programs. Students were involved in their entire learning process in the context of a teaching-innovation project, including the design of new material to study rollover, its usage, and even the evaluation of their classmates.

2 METHODOLOGY

This study was conducted on two subjects of the Agricultural Engineering degree program at the University of La Rioja, which consists of four academic years. These two subjects were Agricultural Machinery (3rd year) and Quality Systems and Work Safety (4th year). The teaching-innovation project consisted of two phases:

- *First stage:* the professor requested a project-based task for the students of the Agricultural Machinery course, which consisted of designing a ramp (or a pair of ramps) that enabled any conventional tractor to get up on it. The ramps would include embedded scales to weigh the front or rear axle of the vehicle. Due to the COVID-19 pandemic, this first phase was prepared to be carried out without any classroom activity.
- *Second stage:* the professor performed the final design of the structure, considering the proposals by students. Afterwards, an outside company built the structure, and it was then applied to conduct a practical exercise in the Quality Systems and Work Safety course to illustrate rollover risk and its prevention.

This project-based task and the subsequent application tried to improve students' involvement in their own learning process and to meet a previously detected teaching need. The hypothesis was that if students could participate in a real design project that produces teaching materials for themselves, they would be more concerned about the task, the development of competencies would be enhanced, and the resulting grades would improve. Moreover, both project stages were designed to improve student competencies included in the corresponding learning guides of the subjects (Table 1). This project was expected to improve students' outcomes and grades.

Table 1. Compliance level of general competencies in each stage of the teaching-innovation project

Project Stage and Subject	General Competencies of the Learning Guides	Compliance Level
Stage 1: Agricultural Machinery	Analysis and synthesis	Yes
	Organization and planning	Yes
	Problem-solving	Yes
	Decision-making	Partially
	Critical reasoning	Partially
	Application of theoretical knowledge to practice	Yes
Stage 2: Quality Systems and Work Safety	Analysis and synthesis	Partially
	Problem-solving	Yes
	Software knowledge	No
	Critical reasoning	Partially
	Quality commitment	No

Notes: Three levels of compliance were established: *Yes*, if the skill was fully achieved through the project stage; *Partially*, if the skill was achieved to a limited extent but needed further work; and *No*, if the skill was not trained at all.

2.1 First stage: ramp design proposals by students

A project-based task involving the design of a ramp or a pair of ramps to measure the tractor's center of gravity height was presented to students. The design should meet several requirements:

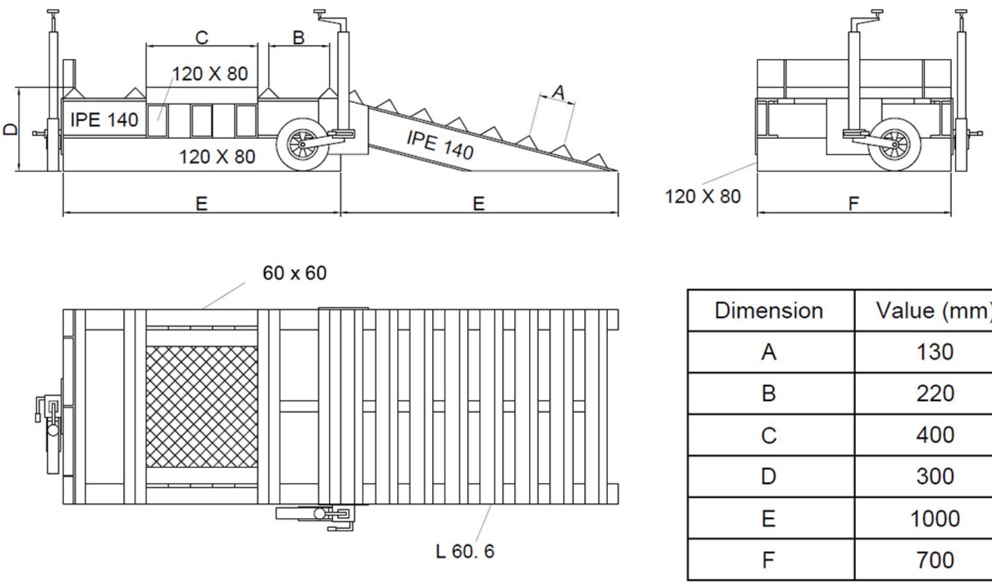
1. The ramp should have adequate dimensions to enable the tractor's front axle to go up on this ramp, keeping the rear axle at soil level. This requirement was very important because the ramp should be able to work with vehicles of different dimensions and weights, from sub-compact and compact tractors to utility and agricultural tractors: these tractors normally vary between 11 kW and 310 kW, while they measure between 1.4 m and 3.4 m in wheelbase and between 1 m or even less to 3 m in track width. Furthermore, ramp design in width had to consider that tractors can be mounted with different tires.
2. The ramp should be movable within an agricultural building, and transportable to different sites on a standard car trailer.
3. The ramp should be steep enough to achieve a front axle height that made it possible to measure the tractor's center of gravity height, but the slope should be gentle enough to enable safe operation.
4. The ramp should be designed to embed weighing scales, which were already available at the university facilities. Their dimensions were provided to the students.

Third-year students (Agricultural Machinery course) were selected to carry out this task, considering that they would use the ramp during the following academic year in the Quality Systems and Work Safety course. The students had to deliver self-videos of 5 minutes maximum in length to show the project carried out, along with a brief document that described the design proposed; creating and watching videos seems to be a useful active learning approach [23]. This task had to be performed individually. Furthermore, the task was planned as a competitive project-based homework, and students were ranked by grade. Only the first three students would get extra marks: the first one would get 1 extra point, the second 0.5 points, and the third 0.25 points. Grades were assigned by both the professor, who evaluated the brief document (50% of total), and the mean value given by the rest of the classmates, who evaluated the self-video (50% of total).

2.2 Second stage: ramp-to-build design and use

After completion of the first stage, the professor designed and calculated the final ramp to be built based on previous students' work and considering the above requirements (Figure 1). Then, an outside company built the pair of ramps (Figure 2), and later they were used in a practical classroom activity in the Quality Systems and Work Safety course; in this activity, students had to determine a tractor's center of gravity coordinates in relation to the contact point between the rear wheels and ground (Figure 3). To carry out this practical exercise, ramps were used along with two weighing scales of 8,000 kg capacity each (Dini Argeo, Modena, Italy). Students had to take measurements and later analyze these data as homework to deliver a brief report that detailed the calculation of the coordinates of the center of gravity. This report was reviewed by the professor, and it counted as 5% of the final grade for the course.

The ramps were conceived to be applied to tractors with a wide range of weight, wheelbase, track width, and tire width, but not to lawn and garden tractors, which have too short wheelbase to keep the rear axle at soil level when the front wheels reach the weighing scales (Figure 1).



Dimension	Value (mm)
A	130
B	220
C	400
D	300
E	1000
F	700

Fig. 1. Final design of the ramps

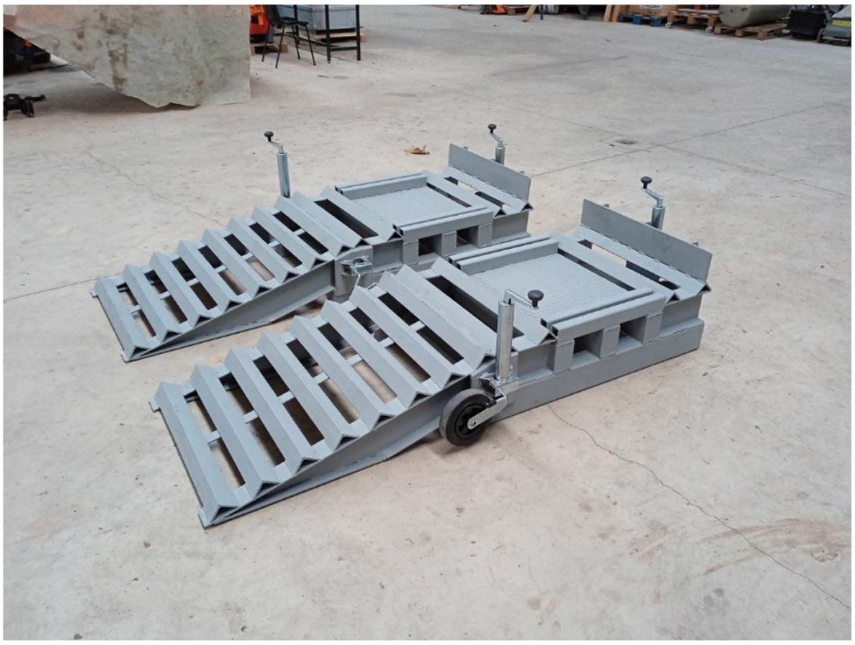


Fig. 2. Ramps on the floor without embedded scales ready to support a tractor

Fig. 3. Tractor weighing process: (left) the tractor on a flat surface to determine the center of gravity location between the two axles; (right) the tractor on the ramps to determine the height of the center of gravity

3 RESULTS

3.1 Design proposals by students

The first results were the designs delivered by the students. Five students participated in this stage of the project. Students' results met previously established requirements, and all of them were functional. However, these designs were assessed to ensure ramp functionality under real conditions (Table 2).

Table 2. Evaluation of the functionality of the students' proposals

Proposal No.	Functionality	Comments
Student 1	Yes	None
Student 2	Yes, but further details were needed	Ramps would need homologation to travel on public roads, and the ramp's height-to-length ratio should be assessed
Student 3	Yes, but further details were needed	Ramp height and weight should be assessed
Student 4	Yes, but corrections were required	The ramp design should be optimized to reduce weight
Student 5	Yes, but corrections were required	The ramp design should be optimized to reduce weight

This task allowed third-year students to be involved in a real design project, whose outcome would be used in their following learning process during their 4th year.

Students graded their classmates' proposals after viewing the self-videos, which were accessible to them through the Virtual Classroom. The professor also graded these videos, but their grades were not used to determine the final score of the students. It is important to remark that grades given by students were significantly correlated ($p \leq 0.01$) with those given by the teacher, but the latter showed greater differences between the highest and lowest grades than the former (Table 3). Furthermore, grades of the brief technical documents also followed the same trend. Final task grades presented such narrow differences that it was necessary to include a second decimal to decide the students' classification (Table 4).

Table 3. Results of the peer-review process of self-videos by students and grades given by the professor (from 0 to 10)

Proposal No.	Grades by Students During the Peer-Review Process					Mean Value by Students	Grade by Professor
	1	2	3	4	5		
1	–	9.5	9.5	9.2	9	9.3	9
2	9	–	8.75	8.8	9.2	8.9	8.5
3	9	9	–	8.4	8.3	8.7	8
4	8.5	9.5	8.5	–	8	8.6	7.5
5	8.5	9	8.25	7.4	–	8.3	7

Table 4. Grades of the project-based task given by students to their classmates' videos (peer review), given by the professor to the reports, and the final task grading in the subject (from 0 to 10)

Proposal No.	Peer Review by Students	Brief Document Grade	Final Task Grade
1	9.3	9.5	9.40
2	8.9	8.5	8.72
3	8.7	8	8.34
4	8.6	8	8.31
5	8.3	8	8.14

3.2 Ramp use

Students of the Quality Systems and Work Safety course participated in a practical classroom activity related to tractor stability. This exercise provided significantly different grades when comparing two years ($p \leq 0.05$) according to Student's t-test (Table 5). As can be seen, the success rate increased from 76.9% in 2020–2021, when ramps were not available yet, to 86.4% in 2021–2022, when ramps were available. However, the final exam grades did not show any significant difference between the three past years ($p > 0.05$) according to Student's t-test (Table 6). The academic year 2019–2020 was not included in Table 5 because those students did not perform the tractor stability exercise, as the weighing scales were available only since the 2020–2021 academic year, and the ramps only since 2021–2022.

Table 5. Practical classroom activity about tractor stability in the Quality Systems and Work Safety course. Grades are indicated on a scale of 0 to 10

Year	2020–2021	2021–2022
Total number of students	13	22
Students who delivered the exercise report	11	19
Students who passed the exercise	10	19
Mean grade	7.6	9.0
Standard deviation	2.1	0.7
Maximum grade	10	10
Minimum grade	3	7
Significance	*	*

Notes: *Indicates significant differences between mean grades of each year; $p \leq 0.05$, according to student's t-test.

Table 6. Final exam results for the work safety part in the Quality Systems and Work Safety course on a scale of 0 to 10

Year	2019–2020	2020–2021	2021–2022
Total number of students	16	13	22
Students who participated in the final exam	13	10	19
Students who passed the final exam	12	7	18
Mean grade	7.1	6.1	6.3
Standard deviation	2.0	1.7	1.9
Maximum grade	9.5	9.3	8.7
Minimum grade	3	4	1.6
Significance	NS	NS	NS

Notes: NS indicates no significant differences between mean grades of each year; $p \leq 0.05$, according to student's t-test.

4 DISCUSSION

The first project stage consisted of designing a pair of ramps that any tractor could go up to measure each tractor's axle weight. Although tractor tilt could be performed using supporting cranes without a tractor driver [24], the ramp design option was selected to allow students to link this task with the calculation of steel structures, which is taught in another 3rd-year course. During the second phase of the project, the students used real ramps to measure the weight of each tractor axle to calculate the tractor's center of gravity, pitch angle, and rollover angle. Therefore, this teaching-innovation project involved students in two stages of the educational process: (1) conceiving and designing an educational material, and (2) using this material to perform a practical classroom activity.

There were few students in the Agricultural Machinery course (first stage), but they delivered projects of high quality that met most of the previously established requirements. All projects obtained high grades in both the peer-review process by other classmates and in the assessment by the professor. Previous studies report limited student capacity to judge the quality aspects of evaluated works [25], but in this research, the peer-review grades correlated with teacher's scores ($p \leq 0.01$). Further improvements to the peer-review process could be implemented; for example, the inclusion of gamification [26] or the assessment of the satisfaction of students with the peer-review method [27]. The project-based task during the first stage helped to improve Agricultural Machinery course grades from 6.9 ± 1.2 in 2019–2020 to 8.4 ± 0.6 in 2020–2021 (mean ± standard deviation). This improvement could be due to increased student motivation, which usually rises when active teaching methods are applied [13]. Some studies have highlighted that project-based tasks are likely to improve attitudes and habits but are unlikely to provide better grades [28], although combining active-learning activities with drawing prompts seems to help students to engage in conceptual problem-solving as professionals do [29]. Furthermore, the gap between the maximum/minimum final exam grades narrowed from 8.8/5.5 in 2019–2020 to 9.1/7.5 in 2020–2021. The reason could be that a greater number of learning activities allowed students to develop their preferred skills; for example, some students developed outstanding design projects but later obtained average grades in the exam, and vice versa. Thus, this result marks the importance of selecting different task categories and their corresponding evaluation systems to cover—and develop—a wide range of students' skills [30].

Concerning the development of the competencies linked to the two subjects involved (Table 1), the activities of stage 1 of the project facilitated both the development and the assessment of various of them: "analysis and synthesis" of the problem to be solved, "organization and planning" of the tasks to be developed, "problem-solving" applied to this design activity, and "application of theoretical knowledge" (on agricultural tractors, their dimensions, weights, tires, etc.) to practice. "Decision-making" and "critical reasoning" were also implicitly applied during the tasks undertaken by the students. During stage 2, "problem-solving" was directly associated with the practical activity performed by the students, who also had to apply some degree of "analysis and synthesis" and "critical reasoning". Therefore, it is clear that active-teaching activities, such as the project presented here, can enhance the development of outcomes and their grading. The improvement in the mean grades of the first course and the increment in the grades of the practical exercise of the second course, as detailed above, are indeed evidence of the positive effects of this project in the development of competencies.

During stage 2, students used the ramps in a practical exercise to determine the center of gravity coordinates along with the rollover and pitch angles of an agricultural tractor. As shown in Table 5, the grades for this activity significantly improved in 2021–2022 compared with those in the previous year ($p \le 0.05$), in which the tractor could be weighted only in a flat area without ramps, and thus students could not calculate the height of the center of gravity. For instance, the differences between the maximum and the minimum grades in the practical exercise were reduced from 7 to 3 points. However, the differences in the final exam were 5.3 and 7.1 in 2020–2021 and 2021–2022, respectively (Table 6). It can be deduced that this teaching-innovation project did not have a significant influence on the mean grade of the final exam.

It is important to highlight that, to improve subject grading, the professor should inform students accurately about the evaluation process [31]. In addition, the heterogeneity of students should be considered, because prior learning achievements and motivation influence the level of project complexity that can be faced by each student and the corresponding outcomes [32].

Teaching-innovation projects aimed at introducing project-based learning at the degree level can help to reach some of the European Higher Education requirements through active teaching and new learning methods [33]. The results obtained in this study indicate that active-learning methodologies helped students to pass the practical exercise related to tractor stability, but it is not clear if this kind of learning activity could improve their grades on the final exam. Further work seems to be needed to assess the influence of active teaching activities on agricultural engineering students' motivation, learning, and grading.

In the coming academic years, the teaching material developed in this study will continue to be applied to teach rollover risks in the agricultural engineering program. In addition, this tool could also be used in specific postgraduate programs for agricultural graduates who want to work in farm advisory services and education roles, increasing students' practical and theoretical knowledge about rollover risks.

Extension programs could also benefit from the practical experience gained during this study, which will serve to improve courses in farm occupational health and safety. This pilot experience, which included feedback from agricultural engineering students, could be integrated into the process to develop intervention protocols for promoting safe farming practices, which can follow different paths [34]. Moreover, the pair of ramps designed and built in this study could be applied to the determination of the center of gravity of specific tractors used by farmers and the corresponding rollover risk assessment, which could be part of educational activities aimed at farmers' peer-learning groups to promote occupational health and safety practices.

The two-phase project-based learning strategy designed and implemented in the present study has demonstrated its utility and could be useful for educators all around the world. Involving students in the design, development, and management of teaching tools could improve the effectiveness of agricultural education. The engagement of students, their motivation, and the improvement of practical outcomes achieved through this learning activity have implications for farm safety promotion initiatives.

5 CONCLUSION

Tractor stability is an important issue to teach in Agricultural Engineering degree programs due to the high rate of deaths related to tractor overturning. A two-stage teaching-innovation project was prepared and applied to two subjects of agricultural engineering to improve students' competencies in tractor stability.

A pair of steel ramps were designed and used during this project. This teaching material was aimed at determining the tractor's center of gravity height, pitch, and rollover static angles. The ramps design process (first stage) was planned as a project-based task in which agricultural engineering students also peer-reviewed and graded their classmates' projects. In this sense, it was found that peer-review grades significantly correlated with professor grades. Furthermore, this active-teaching methodology based on a real design project improved the mean grades for the course and reduced the gap between the maximum and minimum final exam grades. Ramps usage in a different course (second stage) facilitated the development of a practical classroom activity involving the calculation of parameters related to tractor stability; the consequence was an increment in the grades of this practical exercise.

The educational approach presented in this study could help increase the effectiveness of safety promotion programs at both university and agricultural extension levels.

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