Rosana Satorre Cuerda (Ed.)

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Editorial

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40. Unveiling the physics problem strategies of engineering and architecture students

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ABSTRACT

It is very common for students of technical degrees to think that solving physics problems consists predominantly of applying a series of formulae and substituting data. In other words, they do not need to understand the physical meaning of an equation. Some experimental studies focusing on basic kinematics have revealed certain shortcomings in the resolution strategies related to this topic. The aim of this work is to extend the experience to other physics themes and to identify whether objective assessment of the engineering or architecture student's reasoning significantly improves the learning of the matter in a dual teaching context. An illustrative example of how the evaluation rubric is applied to a problem proposed to students has been shown. To discourage copying or plagiarism in problem solving, learners have signed a declaration of honesty stating that they have not received any external help in doing the work. According to the students' feedback, the learning initiative has been highly rated and improvements to the rubric have been suggested. The presence of several errors in the resolution submitted by the students has shown a dispersion of marks that makes it necessary to reconsider the rubric for the next academic year. In spite of this, the fewer mistakes, the lower deviation in the marks.

KEY WORDS: physics, engineering, strategies, problem-solving

1. INTRODUCTION

Generally speaking, engineering and architecture students do not explain any step in the process of solving physics problems. Because of this, when they reach a solution, it is very frequent that they do not interpret the physical meaning of the result they get. Some research carried out in the framework of a simple kinematics exercise has shown evidence that the most widely applied strategy is to substitute data into a formula (Rodes-Roca et al., 2020; Zuza et al., 2016). For this reason, it has been proposed that the resolution of physics problems should include a brief explanation of the process carried out to reach the solution obtained. The analysis of the students' answers will provide the level of learning and understanding of the applied concepts and laws of physics. A questionnaire will provide the pupils' feedback on the experience and their perception of their learning.

Any engineer developing a project must demonstrate the ability to think about how it would be implemented, how experimental data would be presented and analysed for decision making. To acquire these skills, it is essential to approach physics problems solving from an inquiry-based, open-ended perspective (Gil & Martínez-Torregrosa, 1983). Such methodologies have shown evidence of improved learning and proper interpretation of the concepts and laws involved in physics problems. Among them it is worth highlighting proposals involving paper and pencil problem-solving research (Gil et al., 1990; Martínez-Losada et al., 1999); problem-solving by developing guided research (Guisasola et al., 2011); or design teaching-learning sequences (Guisasola et al., 2021; Savall-Alemany et al., 2019).

The objectives to be achieved in this work are: to design exercises in which students must reflect on what would be the first phase for their resolution, to introduce the need to briefly explain each step of the process carried out, to analyse the evolution of the students' learning based on the submission of the problems proposed both online and in person, and to obtain the students' perception of the experience by answering a questionnaire. The starting hypothesis is that if students manage to explain what they are doing and why they are applying a concept or law of physics to solve the exercise, they will improve their knowledge of physics.

2. METHOD

The methodology used for this study is based on formative evaluation in a dual teaching context. Firstly, a sample exercise is provided with the aim of finding out how well the proposed teaching experience is understood as well as the use of the rubric in the assessment of the assignment submitted (Rodes-Roca et al. 2020). Secondly, a feedback to the student is established for each assignment. Finally, the consistency of the rubric is analysed by the network through the blind correction of three exercises, one good, another one acceptable and another one insufficient.

2.1. Description of the context and participants

This study has been developed by a university teaching research group from the Department of Physics, Systems Engineering and Sign Theory of the University of Alicante during the 2020-21 academic year. Taking into account the conclusions obtained by Rodes-Roca et al. (2020), this project is based on research into the resolution of physics problems in engineering and architecture degrees taught at the Polytechnic University College. The participants in the educational action have taken the subjects Applied Physics 1 (second semester of first year, 18 students, 11 females) and 2 (first semester of second year, 26 students, 13 females) of the degree in Fundamentals of Architecture and Fundamental Physics of Computer Science (first semester of first year, 21 students, 3 females) of the degree in Computer Engineering. The first two subjects were taught in English and the last one in Catalan/Valencian, respectively. The mobility of students has been restricted due to the pandemic situation in Spain, so the educational experience has been carried out both online and face-to-face.

2.2. Tools

The students were given a detailed explanation of the rubric to be used for the evaluation of the exercises and a practical demonstration of how the correction of the exercises would be carried out. The timetable for the test was then provided according to the programme established in the subject guide. A set of deliverables was planned through the UACloud platform together with a declaration of honesty from the student specifying that no external help had been received.

An *ad hoc*, anonymous and voluntary questionnaire was created to indicate the degree of agreement (Lickert scale) when the project was completed. An open-question at the end of the survey gave the students' impressions, opinions and suggestions regarding the rubric and the acquisition of problem-solving skills.

2.3. Procedure

The selection of subjects has allowed the design of exercises covering electromagnetism, fluid mechanics, thermodynamics and statics following a methodology similar to that reported in Rodes-Roca et al. (2020). The activities proposed for online submission have provided students with practices in solving problems according to the rubric. On the other hand, the quantitative and qualitative review of the tasks performed has shown some misconceptions as well as a lack of interpretation in the solutions obtained by the pupils.

The questionnaire was opened from the end of the first semester until the end of the academic year in order to gather as much participation as possible. The responses were transferred to a spreadsheet for subsequent statistical analysis. Finally, feedback from the students was also considered in terms of making the appropriate modifications to the project for implementation in future courses.

3. RESULTS

It is obvious, apparently, that if an exercise is well done or has serious mistakes, the grading is usually independent of the reviewer. However, when the errors are not extremely important, there are divergences that may be significant in the evaluation. For this reason, this section presents the results of the consistency of the rubric in addition to the monitoring of the project and the analysis of the responses to the survey.

3.1. Testing the consistency of the rubric

The educational research group has selected three exercises classified into three levels of resolution corresponding to a grading of excellent, acceptable or insufficient (see Table 1).

Table 1. General rubric for solving problems

How to achieve each mark	
Excellent (90%-100%)	You have given the correct answer and explained correctly every step you have done to solve the problem/question.
Good (70%-89%)	You have given the correct answer or made unimportant mistakes but one step is not explained correctly.
Acceptable (50%-69%)	You have given the correct answer or made unimportant mistakes but some steps are not explained correctly.
Insufficient (30%-49%)	You have given a wrong answer or made important mistakes but some steps are explained correctly.
Very basic (10%-29%)	You have given a wrong answer or made important mistakes but one step is explained correctly.
Wrong (0%-9%)	You have given a wrong answer and wrong explanations.

The results of the review carried out by several members of the network are summarised in Table 2.

Table 2. Results obtained by applying the rubric after blinded review.

	Student 1	Student 2	Student 3
Review 1 (assessed with a maximum of 50 points)	43	28	18
Review 2 (assessed with a maximum of 50 points)	39	22.9	20
Review 3 (assessed with a maximum of 50 points)	45	18	17.9

	Student 1	Student 2	Student 3
Average	42	23	18.6
Standard deviation	3	5	1.2
Relative deviation (%)	7.2	21.8	6.4
Review 1 (exercise 1: 10 points)	3	3	6
Review 2 (exercise 1: 10 points)	2	4.9	6.9
Review 3 (exercise 1: 10 points)	5	5	8
Average	3.3	4.3	7.0
Standard deviation	1.5	1.1	1.0
Relative deviation (%)	46	26.2	14.4
Review 1 (exercise 2: 10 points)	10	10	3
Review 2 (exercise 2: 10 points)	10	9	2
Review 3 (exercise 2: 10 points)	10	8	2
Average	10	9.0	2.3
Standard deviation	0	1.0	0.6
Relative deviation (%)	0	11.1	24.7
Review 1 (exercise 3: 30 points)	30	15	9
Review 2 (exercise 3: 30 points)	27	9	9
Review 3 (exercise 3: 30 points)	30	5	10
Average	29.0	10	9.3
Standard deviation	1.7	5	0.6
Relative deviation (%)	6.0	52	6.2

3.2. Learner participation

Although the groups were selected to be able to carry out the project in face-to-face mode in accordance with the restrictions derived from the pandemic, the reality imposed that it will be executed in dual teaching mode finally. Consequently, the participants solved the problems partly in online format and partly in person. Table 3 shows the trend of the students' assignments in both modalities, where the order of the numbers indicates the gender (female+male).

Table 3. Students who carried out the work and sent in their physics problem sets.

Subject	Online1	In person1	Online2	Online3	In person2	Online4	In person 3
FPSC (3+18)	2+18	2+15	1+14	2+16	1+16	2+12	
AP2 (13+13)	11+10	12+11	10+9	7+11	9+11	10+10	11+10
AP1 (11+7)	7+5	8+4*	7+0	7+1**	7+0		

Note: FPSC = Fundamental Physics of Computer Science; AP2(1) = Applied Physics 2 (1); *Online by Moodle; **In person.

It should be noted that the contents of the subjects are not common, so different physics topics have been analysed in a face-to-face class. Another significant difference is that while AP2 and AP1 they can use all kinds of materials (except electronic devices) in FPSC they are only allowed to look at a formulary. The purpose is to analyse whether, in the final phase of the semester, students have acquired the ability to explain how they have solved an exercise and whether they know how to interpret the solution obtained.

An exercise discussed here is designed to investigate students' reasoning about magnetic field created by electric currents in FPSC. The question presents two very long parallel rectilinear currents whose values are (2 I) A and (6 I) A, respectively. It is known that they have the same sense of circulation and that they are separated by a distance L. A computer engineer has to calculate the points at which the total magnetic field is zero. To reach the solution, learners have to calculate the magnetic field, identifying that in this context it is convenient to apply Ampere's law. In addition, they have to calculate it in the three regions of space that define the currents and locate the points that satisfy the condition requested in the exercise.

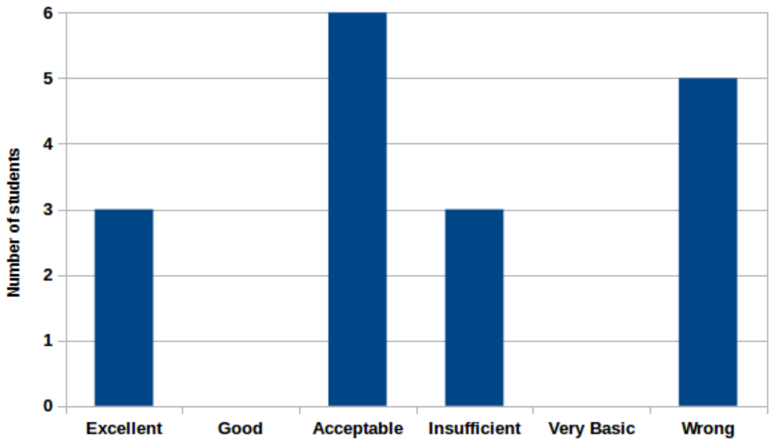

Figure 1. Students' results regarding acquisition of knowledge/skills about magnetic field and Ampere's law.

As can be inferred from Figure 1, about 18% of the participants (14% of the total enrolment) were able to draw a diagram of the situation, identified the three zones where a magnetic field acts, applied Ampere's law and got the correct answer explaining reasonably well the whole process done. About 35% of the students (28% of the total) interpreted the context of the exercise adequately, but tended to solve it only in the area between the wires or the reasoning was incomplete. Although they understood the purpose of the exercise (insufficient category), 18% of them (14% of the total) had significant mistakes for university students both conceptually to calculate the magnetic field and mathematically to clear some unknown. No response or meaningless arguments corresponded to the rest of the students.

Surprisingly, the tutoring attention requested throughout the educational experience was extremely scarce and limited in a very high percentage to issues arising from the pandemic.

3.3. Students' feedback

Only 16 out of 65 students answered the anonymous questionnaire so far. Two distinct parts of the survey can be considered: on the one hand, related to personal issues (gender, age, number of times studying the subject and attendance) and, on the other hand, related to the educational experience (problem solving and student perception). The answers to questions 5 to 8 were organised using a Likert scale with 4 options, the meaning of which is explained at the bottom in Table 4.

Table 4. Responses to the feedback questionnaire to evaluate the teaching experience.

	Gender	Age	Times	Attendance	Question 5	Question 6	Question 7	Question 8
Student 01	M	19	1	4	4	2	4	3
Student 02	F	21	1	4	3	3	3	3
Student 03	M	21	2	4	3	3	3	3
Student 04	M	20	3	4	2	1	1	1
Student 05	F	21	2	1	4	4	4	4
Student 06	M	33	1	4	3	3	3	3
Student 07	M	18	1	2	3	3	2	2
Student 08	M	18	1	4	3	3	4	3
Student 09	M	20	1	2	3	3	3	3
Student 10	M	19	1	4	1	2	3	2
Student 11	M	19	2	3	2	2	3	3
Student 12	M	18	1	2	3	2	4	3
Student 13	M	18	1	3	1	4	2	1
Student 14	F	20	1	3	3	1	4	3
Student 15	M	19	1	4	2	4	3	4
Student 16	M	21	1	4	3	3	3	2
Average		20		3.3	2.7	2.7	3.1	2.7
Standard deviation		4		1.0	0.9	0.9	0.9	0.9
Median		18	1	4	3	3	3	3
Mode		19.5	1	4	3	3	3	3

Note: Attendance code is 1 = [0-25]%; 2 = [25-50]%; 3 = [50-75]%; and 4 = [75-100]%. Question code is 1 = Strongly disagree; 2 = Disagree; 3 = Agree; and 4 = Strongly agree. Question 5: Physics problem-solving is a necessary skill for a professional career; Question 6: The rubric has helped me improve problem-solving strategies; Question 7: The assignments have helped me to acquire the ability to solve problems with initiative, decision-making, autonomy and creativity; Question 8: The rubric has helped me in my skill to know how to communicate and transmit the resolution process using the principles and laws of physics.

Regarding the students' perception of the rubric, about 62% indicated that it helped them to identify problem-solving strategies and almost 69% stated that they improved their skills in explaining and interpreting the solution of the exercises. However, it was also commented that the level of explanations to be given should be more detailed. Nearly 81% participants answered that autonomous learning through assignments enabled them to acquired initiative, decision-making and creativity in problem-solving. Concerning the importance of physics for their degree, almost 69% agreed. A few of them, however, were of the opinion that physics was not significantly related to the degree in Computer Engineering.

The analysis of items Q5-Q8 is shown in Table 5. The correlations between the questions and the total scale have a moderate or acceptable correlation, which allows us to affirm that they measure different nuances of the same construct (Alaminos & Castejón, 2006).

Table 5. Correlation matrix for the 4 items and with respect to the total scale.

Item	Total	Question 5	Question 6	Question 7	Question 8
Question 5	0.74	1.0000			
Question 6	0.49	0.0353	1.0000		
Question 7	0.79	0.5644	0.0258	1.0000	
Question 8	0.89	0.5628	0.2773	0.7432	1.0000

Cronbach's (1951) alpha coefficient of internal consistency has also been calculated, obtaining a value of $\alpha = 0.70$ (Alaminos & Castejón, 2006). Taking into account that the maximum value is 1, the reliability of the scale can be considered satisfactory.

4. DISCUSSION AND CONCLUSIONS

One of the most active fields of physics education research in university degree courses is the analysis of physics learning through problem solving (Guisasola et al., 2015). The difficulties of engineering and architecture students in dealing with physics problems in novel situations is a fact that has been evidenced in almost all branches of physics since the 1980s. For example, in kinematics (Rodes-Roca et al., 2020; Zuza et al., 2016), electromagnetism (Campos et al., 2020; Guisasola et al., 2011; this work) or the atomic spectrum (Savall-Alemany et al., 2019). According to the answers given in the questionnaire, this project has shown some evidence that formative assessment using a rubric helps students to understand and apply Ampere's law to calculate the magnetic field generated by parallel current wires. On the other hand, exercises are being designed with an algebraic character, i.e. without numerical data, and/or with a non-sequential question, i.e. some physical magnitude that is not explicitly requested has to be deduced beforehand.

This methodology has also been applied to an exercise on heat transmission for AP2 and another on mass geometry for AP1, but only one student completed the survey, so there has been no feedback on the perception of the architecture students to date.

Having said that, this study has some limitations such as a scarcely representative sample, low feedback, exercises from different branches of physics that make a direct comparison of the results difficult and high absenteeism, which in the case of AP1 reached over 60% in the last part of the semester. Although this is a historical problem in architecture degrees (Rodes-Roca et al., 2006), it is quite possible that covid-19 and dual teaching have considerably aggravated this issue. At the same time, it is necessary to extend this project with a control group to verify whether formative assessment in the experimental group represented an improvement in problem-solving. It was not possible to implement it due to the health context during the course.

In addition, it should be noted that students' mathematical reasoning in physical contexts has some shortcomings that need to be understood in order to improve physics problem-solving (Guisasola et al., 2015 and references therein). Although not expected, it is usually common to find errors related to operations with fractions and to the geometry of simple plane shapes, typically the circle.

In summary and in conclusion, students have realised that physics is not just a matter of mathematical equations but involves an understanding of concepts and laws to deal with problems in unfamiliar situations. Therefore, learning methodologies that introduce research strategies in problem-solving point to an improvement in learners' attitude towards these models (Campos et al., 2020; Gil & Martínez Torregrosa, 1983; Gil et al., 1990; Guisasola et al., 2011, 2015, 2021; Martínez-Losada et al., 1999; Savall-Alemany et al., 2019; Zuza et al., 2016, 2020; this work).

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6. ANNEX

Answers to the open-ended question (answers have not been edited).

Please justify your answers by indicating the aspects to be improved in the dual teaching carried out this academic year.

- Per a poder millorar la docència online, haurien de millorar els dispositius d'escriptura per a poder entendre millor els escrits. A més, la docència online no es el mateix que la docència presencial, ja que a casa, hi han moltes distraccions i no s'absorbeixen de la mateixa forma els coneixements que de forma presencial. Amb tot allò vuic dir que la docència online, no és la millor opció per a rebre les classes, sobretot per les distraccions i per la falta de dispositius d'escriptura digitals acceptables.
- It was hard but very helpful in terms of understanding how certain things work.
- Se podría probar a utilitzar Google Meet (u otra similar) en lugar de la herramienta de docencia dual de UACloud. En otras asignaturas la experiencia es mejor con esas herramientas.
- Faltaría a mi parecer una mayoría énfasis a un curso preparatorio previo de mayor calidad para los que no hayan cursado física en bachiller.
- Al principio no funcionaba usar la pizarra física de la clase, porque no se apreciaba bien lo que el profesor escribía, pero se cambió a la pizarra online y todo fue mucho mejor. Han sabido solucionar los problemas que iban surgiendo y nos han ayudado mucho.
- Tot correcte.
- El sistema está perfecto, algo para mejorar serían los incentivos, por lo demás se ha realizado la docencia a la perfección.
- No tinc molt que aportar ja que al asistir presencialment a totes les classes, no he experimentat canvis significatius respecte de qualsevol any normal.
- Jo personalmente em centraría mes en fer-mos participar als alumnes en les clases pràctiques ja que considere que realitzant exercicis es la millor manera d'aprendre. I centraria els esforços en realizar més exercisis pràctics.
- No crec que aquesta assignatura servisca per a la carrera.

- A vegades no s'entén l'explicació perque es fa tot al full del problema i queda un poc borrós.
- En el cas de la física considere que s'ha fet un bon treball a l'hora de la docència dual no considere que siga necessari cap canvi.
- Els lliuraments estan correctament corregits seguint la rúbrica. Però aquesta no m'ajuda en cap aspecte de l'assignatura, i a més l'assignatura em fa qüestionar la carrera que estic fent. Tal vegada si relacionaren més la física amb l'informàtica i feren entendre molt més per a què la està la física, doncs li donaria algo de sentit que aquesta estiga en la carrera, però de moment és una roca en el camí.
- En mi opinión el profesor ha sido muy flexible a favor de los alumnos tanto a la hora de la entrega de los trabajos como en la decisión de cada uno de si dar la clase online o presencial. Gracias a ello he podido organizarme mejor con la asignatura.
- Gràcies a la rúbrica m'ha ajudat a saber comunicar el proces de cada pas per a la resolució de problemes. S'ha seguit completament les instruccions de la rúbrica.
- Aún teniendo las rúbricas no queda claro el nivel de explicaciones que hay que dar para obtener una buena nota.