Impact analysis of error-controlled exercises training on learning

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Abstract - This article presents the experience of teaching innovation introduced in subjects taught at the E.T.S.I. Minas y Energía of the Universidad Politécnica de Madrid, based on training with exercises containing controlled errors. The results obtained with the use of this methodology and its impact on learning are analysed. Several training exercises have been prepared containing common errors made by students in three subjects: Chemistry, Business Management and Graphic Expression. The training exercises consist of short quick-answer questions with four possible answer options. For the analysis of the impact on learning, the results obtained by the students in the evaluation tests and the students' perception by means of a survey were taken into account. In the first two subjects, the evaluation exercises were error-free, while in Graphic Expression they were based on the detection of controlled errors. In the subjects of Chemistry and Business Management, error-controlled training has improved the marks obtained by the students. Moreover, in the case of Graphic Expression, the results show how the use of controlled errors improves the students' skewness.

Keywords: Learning improvement, distribution of results, error-controlled training.

1. INTRODUCTION

Constructivism is the set of conceptions that provides a solid basis for understanding that learning is not a phenomenon exclusive to schools and classrooms, but that it occurs permanently in people, in their environments of socialisation (Ordóñez, 2004). On the other hand, making mistakes is something that accompanies us throughout our lives. The effect that these mistakes have on each person can be different: we can fail to detect the mistake and trip over that "stone" on many occasions or, at the other extreme, we can learn quickly from that mistake and try not to make it again. In any case, what seems undeniable is that every mistake made is an opportunity for learning, in line with what has been proposed by several authors (Manrique and Puente, 1999; Briceño, 2009), so it seems logical to use tools focused on mistakes to enhance learning.

When a student studies for an evaluation test, it is common for doubts to arise that cannot be asked to the teacher at that moment, so having tools or resources that help them to solve them autonomously (Amez, et al.. 2019, Castells, et al 2019) is of great help. One way to optimise the time students spend on self-study is to carry out training with controlled errors introduced in the questions that reinforce learning, in the form of self-evaluation or partial tests. When errors to be detected are included in different types of questions, it is not only useful for students to "learn by heart" the subject contents for the day of the evaluation, but they are forced to reflect on what they know. Van Lehn (1999) argues in his CASCADE theory that errors can spark reflections that lead to deeper understanding (impasse-driven learning).

This conception of using errors as a tool for better learning is also supported by the reflections of other authors (Noris and Ennis, 1989; Moreira, 2005; Zunzarren, 2012) who highlight the importance of promoting a critical spirit and the conception that the person is formed as he/she corrects his/her errors (Principle of Learning by Error). Promoting the development of the critical spirit of the student improves to a certain extent their search for excellence, which can then be extended to his/her professional future.

On the other hand, Siegler (2002) assumes that the probability of choosing a correct answer can be improved by reducing the probability of an incorrect answer. That is, if students learn not only to look for the correct answer, but also to detect errors among the proposed alternatives, the chances of obtaining better results increase. In Siegler's study (2002), prompting students to explain correct and incorrect solutions led to greater flexibility of knowledge than if they only explained the correct solutions.

The proposed methodology makes use of errors commonly made by students by including them in a controlled way in questions designed both for training and, in some cases, for evaluation. If the student is able to detect these errors introduced in a controlled manner in the training exercises, he/she will become more aware of what he/she is learning.

One of the conditioning factors of this methodology is to limit the response time per question. Rapid response systems have been used in the classroom with good results, allowing interactive learning that facilitates discussion and analysis of the questions posed, as well as greater participation (Rivas, 2010).

2. CONTEXT

Several experiences have been carried out with exercises based on error detection in three subjects at the E.T.S.I. Minas y Energía (E.T.S.I.M.E) of the Universidad Politécnica de Madrid (UPM) consisting of training (preparation exercises) for the evaluation tests with exercises containing controlled errors. Analysing how the inclusion of this type of exercise influences learning may help this methodology to become a regular tool in other subjects. Work has been carried out in the subjects of Chemistry, Business Management and Graphic Expression, with multiple-choice questions with four possible options and a limited response time. The evaluation was carried out under two different approaches: evaluation with controlled errors (Graphic Expression) and without errors (Chemistry and Business Management). In addition, in the case of Graphic Expression, data from previous years in which training with errors was not used are presented, comparing the distribution of the results obtained.

The development of new methodologies that improve the learning experience for students is a continuous source of research by teachers. Learning should not be based only on the pure memorisation of the contents or methodologies taught by the teacher in class or the information available to them by other means. One of the traditional ways in which learning has improved, and not only in regulated studies, but in all areas of life, is the fact of making mistakes, being able to detect them and make progress in the learning of a given subject. To include controlled errors in activities or tests has an impact on has an impact on the student's critical spirit, making knowledge more firmly established.

The main purpose of this methodology is to facilitate the teaching process in order to improve the level of learning, encouraging through critical thinking a reflective attitude that accompanies the student in the different learning processes that he/she will face throughout his/her life. Moreover, the student has to face a series of reflections at a higher level than the simple memorisation of contents and, in this way, the contents learned remain over time. This improvement will be considered in the results obtained in the evaluation tests carried out after training with exercises containing controlled errors.

The methodology has been implemented in the three aforementioned subjects of the Engineering Degrees (Degree in Mining Technology Engineering - GITM and Degree in Energy Engineering - GIE) taught at the E.T.S.I. de Minas y Energía of the Universidad Politécnica de Madrid. For the three subjects, the errors introduced have been of calculation and comprehension. Extensive banks of questions containing controlled errors have been designed, and the students have had access to them in the form of a control test or self-evaluation (training), as an additional study tool in preparation for the exam. The system allows questions to be presented to students randomly, and the banks of questions are expanded each year, so that it is difficult for students to learn them by heart if the evaluation consists of error-controlled questions.

This methodology can be applied to any subject at university level, as error-controlled training can be carried out with both theoretical and practical content. One of the keys to the correct implementation of this methodology lies in the appropriate design of the questions containing controlled errors. For this, a key step is the compilation of the most frequent errors made by students.

3. DESCRIPTION

In the three proposed subjects, the study was carried out in two phases. A first "training" phase with exercises which may or may not contain controlled errors, and a second evaluation phase which, depending on the subject, may or may not contain controlled errors. As mentioned above, the errors included in the answers are common errors among students and the time they have to answer is limited.

The development of the different questions has followed a meticulous process of analysis and selection to optimise their impact on student learning. First, evaluation tests carried out in previous years were reviewed and an analysis was conducted based on the experience of the different lecturers of these subjects, compiling the most frequent errors in each one of them. Questions were designed, some of which contained controlled errors, and different training modes were scheduled with the students so that they could practise for the exam. A summary of the data used for this study and the type of analysis carried out (comparisons) is shown in Figure 1.

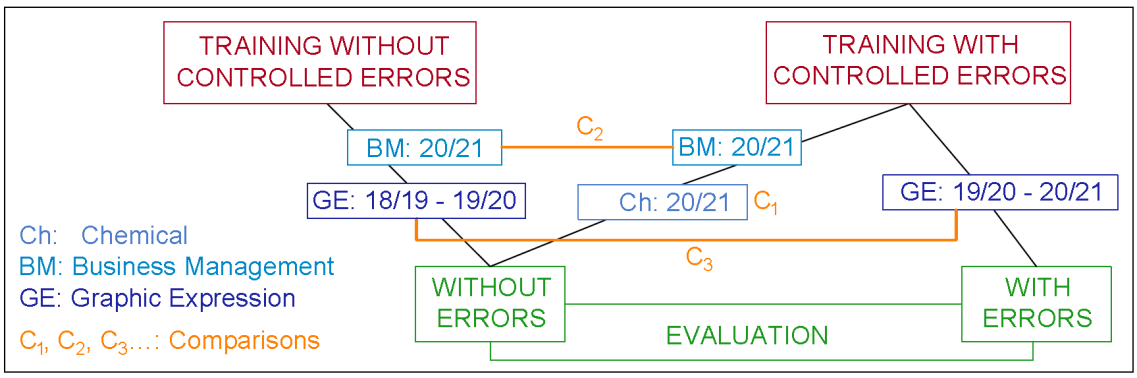

Figure 1. Summary scheme of error-controlled training study.

The types of training exercises and subsequent evaluation that have been performed in the different subjects proposed for this study are detailed below.

Chemistry: Voluntary online questionnaires with multiple-choice questions with 4 possible answers were proposed through the Moodle platform, consisting of exercises similar to those carried out in the laboratory practical exams (to check if there is an improvement in learning based on the mark obtained afterwards), according to one of the following typologies:

- Numerical problem solved with calculations up to the final result with a typical controlled error along the resolution that they must identify.
- Direct calculation problem with the answers developed, of which 3 options are procedures that are usually erroneously applied.
- Detection of the error between several statements, with concepts of a theoretical-practical nature in which they tend to fail repeatedly.

Figure 2 shows an example of one of the proposed problems with controlled errors.

Given the tests shown in the next table for the reaction of 2 M hydrochloric acid with magnesium at room temperature, and that the reaction rate, v, is $v = k\,[\text{hydrochloric acid}]^{x}$; complete the table and determine the order of reaction. (x)

Test	HCl 2M volume	Water Volume	Mg mass	[HCl]	HCl mass	Mg mass	Reaction time	Reaction rate	Reaction order
	mL	mL	mg	mol/L	mol	mol	s	mg Mg/s	(x)
1	50	0	12	2	0.1	4.94E-04	38	0.32	3
2	30	20	12	3	0.15	4.94E-04	111	0.11	

Figure 2. Example of an error-controlled problem related to the Chemical Kinetics laboratory.

Business Management: In this subject, a database of theoretical test-type questions was generated for training with controlled errors through the Moodle platform. For each attempt, the student was randomly presented with different questions from the database, having to give a quick answer to the four possible options presented. The student had to select the one that contained an error or indicate that all the options were correct with the last option. Figure 3 shows an example of one of the training questions offered to students in this subject. For the evaluation test, however, the questionnaire consisted of questions without errors, i.e. there were four answers, only one of which was correct, thus ensuring that the students learnt the subject and not that they learnt to do a particular type of test by repetition (training).

T7-EEA1. If we are comparing two alternatives for an investment project with similar conditions and risk, and we have obtained for option A, a payback (A)=3 years and for option B, a payback (B)=10 years, indicate which of the following statements contains an error:

□ It means that we recover the initial investment after 3 years for option A and after 10 years for option B.

□ Using payback as the only selection criterion we should choose option A (the one with the lowest payback).

□ We should not choose an investment project on the basis of payback alone.

□ All three answers above are correct.

Figure 3. Example of a question from the subject Business Management.

Graphic Expression: For this subject, the questions were adapted for each of the thematic blocks. In the 3D objects Visualisation block, the students were presented with the perspective of a piece as a statement and the 3 views of it. They were asked in which of the 3 views an edge was missing or was in excess, giving them a fourth option with the possibility that in none of them there was a mistake, having one minute to answer. In the Dimensioned Plans block, the student was shown a detail of an area of a solved exercise and was asked whether it was well solved or not, with 30 seconds to answer. In both blocks there were some previous calculation questions (minimum knowledge) in which they had two chances and had to get 100% correct in order to be able to do the previous questions. The response time was very limited in order to improve the relationship between correct answers and the student's level of knowledge. Figure 4 shows an example question from among those proposed in this subject.

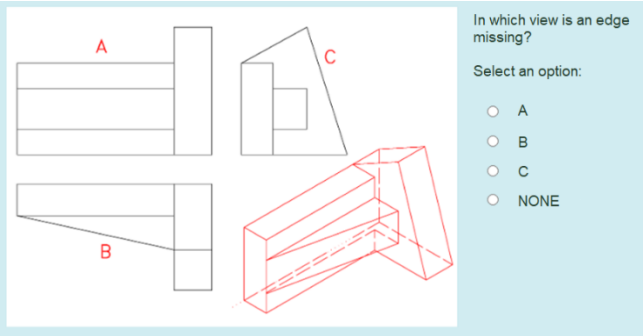

Figure 4. Sample question from the Visualisation block of Graphic Expression.

In the evaluation, the questionnaires were similar questions, so as not to give any learner the possibility of facing questions that they had already seen in the training. A very basic part of the design of the questionnaires was to organise them by "difficulty blocks" within each topic and to ensure that each learner received the same number of questions from each block.

As for the comparisons carried out (C1, C2 and C3 in Figure 1), in the subject of Chemistry the results obtained in three consecutive laboratory sessions were compared, in the subject of Business Management the results obtained by students with and without controlled error training in the same course were compared, and in the case of Graphic Expression the results obtained in different years with traditional exam and with controlled error exam, with and without training, were compared.

In addition, student satisfaction surveys were carried out on this methodology, in order to qualitatively assess the students' perception.

4. RESULTS

Considering the results of the different evaluation tests and the rate of use of the error-controlled training questionnaires by the students, the most relevant results obtained for each of the subjects considered for this study are presented below.

Chemistry: In this subject, training with error-controlled exercises was carried out in 3 different laboratory sessions called P1, P2 and P3. The ratio of students who performed at least one attempt out of the total number of students (107, 252 and 106 students respectively) in the subject were 20 %, 19 % and 8 %, respectively. For the first of these (P1), no significant differences in mean marks were obtained between the group who had trained and those who had not. However, for P2 (assuming a 90 % confidence level) and P3 (with a p-value < 0.01) the marks were statistically higher.

Therefore, a temporal evolution of improvement can be seen for those students who have continued to use this learning tool. However, as this is a voluntary activity, we should also consider the possibility that the most dedicated students are those who have chosen to use this educational resource and, therefore, even without the training, it would be a priori expected that these students obtain better results. Figure 5 shows the distribution of the marks obtained by the students who carried out the training with controlled errors (With trial) and those who did not (Without trial).

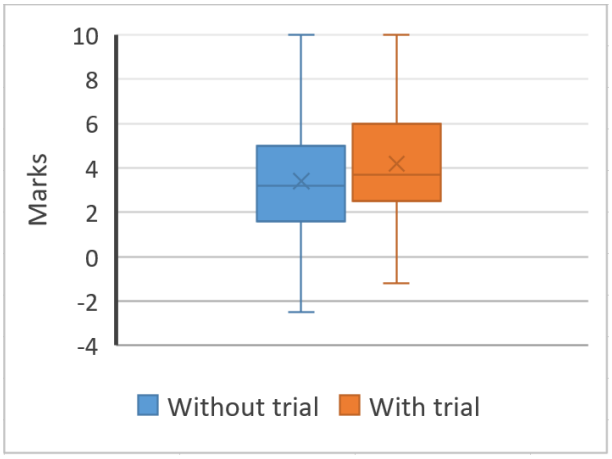

Figure 5. Comparison of marks for the second chemistry laboratory session.

Business Management: For this subject, the students had different trial questionnaires available which they could use in an unlimited way. Out of the total of 74 students, 59 students used the training tool with errors. The students were divided into three groups: those who did no trials (No trial), those who did between 1 and 4 trials (Little trial) and those who did 5 or more trials (Many trial). Of the total number of students who took the evaluation test, 20 % did not use the trial questionnaires (No trial), 42 % used them between 1 and 4 times, while the remaining 38 % practised 5 or more times.

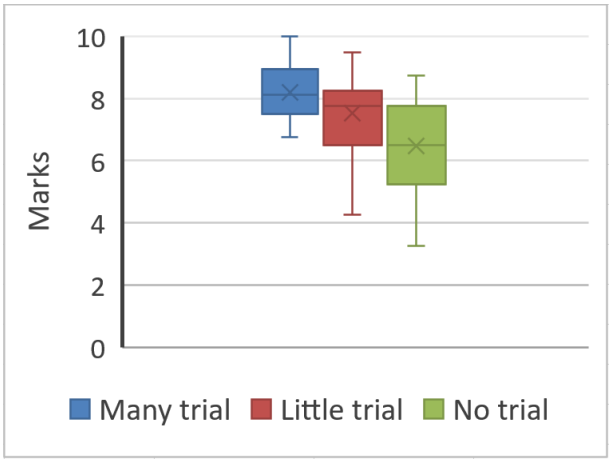

Figure 6. Comparison of marks in Business Management as a function of training.

Comparing the average mark between the three categories, it was found that there is a statistically significant difference at the 95 % confidence level. Therefore, not only are the marks of those who perform the tests higher, but also more training leads to an improvement in the final result. Figure 6 shows the distribution of the scores obtained by the students according to their level of training.

Graphic Expression: In this subject we had data from previous years, so we were able to compare the traditional evaluation with the evaluation containing controlled errors. In total, there was a sample of 425 students who took the traditional evaluation and 232 students who took the exam with controlled errors after having tried the same type of exercises. The histograms of the marks obtained are shown in the graphs

in Figure 7. It can be seen that, although the marks were higher in the tests without errors, the distribution of marks when controlled errors are included in the questions is better.

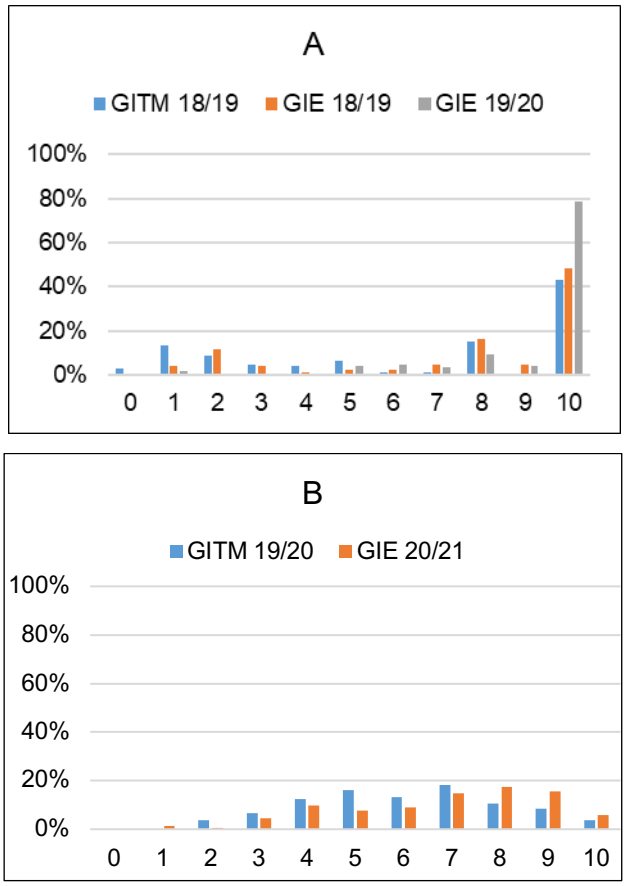

Figure 7. Histogram of grades obtained in Graphic Expression for two degrees (GIE and GITM) without the use of tests and evaluation tests with controlled errors (A) and with the use of tests and evaluation tests with errors (B).

5. CONCLUSIONS

Training with exercises with controlled errors has proved to be a tool that improves students' learning. On the one hand, we have the improvement in both the marks and the distribution of the results obtained by the students, and on the other, the good feedback it has received from the students, who state that it has helped them to consolidate their knowledge, as shown in the satisfaction surveys carried out by the students a posteriori. It should be noted that this type of new methodologies tend to be used more by students who attend classes more often, so this component should be taken into account when evaluating the results. In this respect, for future courses, we should try to implement it in such a way that all students feel sufficiently motivated to carry out the training prior to the evaluation.

The main advantage of this methodology, which considers errors as a learning strength, is the development of the student's critical spirit. This is something that they will learn and apply in all aspects of life, as it is not just a question of learning because we make errors, but because we are capable of locating errors in situations that is apparently correct.

Due to the good results obtained, even though it was developed during the Covid-19 pandemic, the methodology put into practice in this study will continue to be applied in future courses with extensions to the question databases. It should be noted at this point that, due to the difficulties encountered in the normal development of the course due to Covid-19, this methodology has become one more tool at the service of the students to reinforce learning and maintain it at optimum levels despite the lack of presence in some phases of the course. As for the transferability of the methodology, new subjects can be added, as the methodology can be extrapolated with slight modifications in the types of questions depending on the subject.

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