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Self-regulation in Mathematics Courses for Engineering Based on Study and Research Paths

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Abstract

Several studies have shown that there is a positive correlation between self-regulation and the academic performance of students. Self-regulated learning is the set of processes that the learners deploy to achieve their personal goals and that have to do with the learning strategies they use, with the answers they offer when evaluating the effectiveness of learning and with the motivations they have. To this end, the Study and Research Paths (SRPs) strategy is proposed to encourage better self-regulation processes in the students of the Unidad Profesional Interdisciplinaria de Ingeniería Campus Guanajuato (UPIIG) of the Instituto Politécnico Nacional (IPN). This strategy was proposed by Yves Chevallard within the framework of the Anthropological Theory of the Didactic and the World Questioning Paradigm. Students of the courses of Numerical Methods and Numerical Analysis of the academic programs of engineering in: Aeronautics, Automotive Systems, Biotechnology and Pharmaceutical formed the study group. This research work presents the analysis of the results of the initial phase of the measurement of the evolution of the self-regulatory processes that students use in the development of engineering projects that need the application of numerical methods for the analysis of situations, the decision making and the development of new products.

Keywords: Study and research paths; Self-regulated learning.

1. Introduction

This is a report that presents results about a Numerical Methods course for engineering students based on the notion of Study and Research Paths and in which the World Questioning paradigm is fostered as formulated within the framework of the Anthropological Theory of the Didactic [1]. The study can be mainly qualitative with quantitative components. First, the way in which the course was developed before the implementation is described. With this, we can distinguish the problem that was intended to solve with this project. Then, the description of the course that was proposed is presented. To complement the description in a quantitative way, two tools were used. One was a translation into Spanish of the Survey of Epistemological Beliefs for Mathematics developed by 2. The self-regulated learning strategies section of the Motivated Strategies for Learning Questionnaire developed by 3 was also used. The most outstanding results of these surveys are presented. This first report is finished with a description of the works for the first part.

2. Objective and Achieved Goals

General

Study self-regulation behaviors of students and their transformations due to activities carried out in courses based on Study and Research Paths.

Specific

• Adapt a self-regulation characterization instrument for mathematics courses in engineering.
• Apply the instrument in the four different stages of course development based on Study and Research Paths.
• Study the effect of the Study and Research Paths (SRPs) on self-regulation behaviors in the Learning units of the Method.

Achieved goals

1. Adaptation of the characterization instrument of learning self-regulation.
a. The elaboration of the diagnosis of the current situation of the mathematics students was constructed to develop the theoretical reflection.
b. Which allowed to have a starting point in the study.
c. After the diagnosis, the diagnosis was adapted.
2. Design of the Scenario of Study and Research Paths.

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a. According to the results of the diagnosis for its application in the respective working groups.
3. Application of the instrument.
a. First, the instrument was piloted
b. Application to all students during classes of teachers of mathematics academy.
4. Evaluation and statistical analysis of the instrument.
a. At the end of this document the results and statistical analysis are presented.
b. RStudio was used since it is a free software, whose characteristics were adapted to the needs of the project and helped us given that resources were not allocated for this item.
5. Application of the Study and Research Paths strategy.
a. Meetings were held with the members of the work team to discuss the results found and proceed with the application of the strategies.
6. Measurement of the effect of the Study and Research Route strategy.
a. A questionnaire was made with questions that measure the self-regulation process of the students.
b. Forums in which the concerns of the students were expressed, as well as the progress that was achieved in the different projects proposed.
c. Incorporation of one logbook per student.
d. Incorporation of the teacher's logbook.
7. Generation of strategies proposals to improve the processes of self-regulation of learning.
a. Forums for the interaction and participation of students.
b. He used logbooks to keep track of the various situations that occur during the project, as well as having an analysis and reflection to arrive at the best conclusion of the proposed project.
c. Elaborate measuring instruments to know the why of the desertion of students? and thus be able to take them to the same motivation as the rest of the classmates.
d. Personal attention to the work teams to encourage motivation and avoid the feeling of disinterest of the teacher over the student.
8. Writing the final report

3. Material and Method

3.1. Experimental Part

Numerical methods before the proposal: the elements of the Numerical Methods course before the implementation of the didactic proposal were:

Topics:
Introduction to Scilab and calculation of errors
Differentiation
Solution of linear and non-linear, independent and simultaneous equations
Interpolation with functions of one variable
Optimization of functions of one and several variables
Linear and nonlinear adjustment using least squares
Integration
Ordinary differential equations
Partial differential equations

Students studied the topics through the teacher's presentation or videos provided by the course space in Moodle Pty Ltd [2], administered by the school. The ordinary evaluation consisted of three partials. In each, the following percentages were available:

Tasks, 40%
Exam, 60%

A very important component of the evaluation was the validation factor, which gave the exam more importance. If the grades of the tasks (T) and of the exam (E) were taken between 0 and 100, the validation factor was

$$v = \min\left(1, \frac{E}{50}\right),$$

and the average between 0 and 10 was calculated as

$$P = \frac{0.60E + 0.40vT}{10}.$$

The qualification of partial C, finally, was obtained through

$$C = \begin{cases} \text{is rounded down,} & \text{if } P<6 \\ \text{it is rounded,} & \text{if } P\geq 6 \end{cases}$$

This factor was agreed by the Mathematics Academy because there was no certainty that the students were honest in carrying out their tasks. Thus, the supervised test validated that the students had performed the tasks by themselves. A very (perhaps the most) common scenario is for students to have 100 marks on tasks and 50 on the exam. The average, in that case, would be P = 7.0, with a partial grade of C = 7, which is greater than 6, the minimum approving.

The tasks were carried out on the WeBWorK platform [3]. Generally they consisted of problems in which the student was asked to use some method of the subjects indicated above. Ideally, the students themselves should

program their codes so that they are displaying the skills expected to be developed in the course. However, it was usual for them to get the codes made in previous semesters by other students and use them to introduce the answers generated by them.

The problems of the exam had to be similar to those of the task. There was a problem, whether or not students could introduce their codes to the test? When the students could not enter their codes, it was verified that the tasks had not been done in a way that was useful to pass the exam. In the case that they could introduce codes, the exam became a search for useful codes for some exam problems. So, they only had to find half of the exam codes to pass. There were, therefore, very low requirements to pass the course and, with it, difficulties for a lasting learning for its application in future courses, no longer said in the field of the application of engineering.

The courses in which this course is taught are: Engineering in Aeronautics, Engineering in Biotechnology, Pharmaceutical Engineering and Engineering in Automotive Systems.

3.2. Statement of the Problem

The evaluation determines the student's actions and therefore the characteristics of their own learning [4]. In the course description given above, it can be seen that the skills students had to use to pass the course were, mainly, two: Try to anticipate what kind of problems could arise in the exam and carry the necessary codes. Use memorization for some problems that did not require any particular code. This had the following effects: High reprobation occurs. This problem occurs to a greater extent in Automotive Systems. In Biotechnology and Pharmaceuticals it is smaller, but it is still a lot. In Aeronautics the problem is minor, but still high.

The knowledge acquired in the course is not significant. Students remember names of some methods or techniques. However, when they are in the context of application, they usually believe the methods are not relevant. That is, knowledge is not applied. Applications are presented only in simplistic exercises. The problem of segmentation of the knowledge also exists. Although there have been efforts to integrate the "Learning Unit" (that is the name given by the institution to the courses), few students manage to see the relationships between different topics.

3.3. Study and Research Paths (SRPs)

The SRPs were proposed within the framework of the World Questioning Paradigm [1] to design a course to address the problem. The initial point of an SRP is a generating question C_0 that the students try to answer with the help of the teachers to obtain an acceptable answer $R^{\heartsuit}$. In this way, we have a general structure that can be represented as follows.

$$C_0 \xrightarrow{Path} R^{\heartsuit}$$

It has been shown that, in the school context, the path may be with less or greater teacher intervention [5]. Thus, one can see the study of a particular subject in a traditional class as a specific type of path. On the other side of the spectrum, to take another example, there exists the problem-based learning technique (ABPs) and, in general, a whole family of didactic strategies based on inquiry-based learning [6, 7]. The areas of research of Problem Solving [8], Education in Realistic Mathematics [9] and the Theory of Didactic Situations [10] are also related to didactic strategies of inquiry type [11].

The general scheme of the course design consists in proposing to the students a generating question C_0, the students would try to solve C_0 in teams, the teacher would try that the students were as independent as possible in the course, intervening only when it was very necessary, students would submit a chosen answer $R^{\heartsuit}$ in a formal report.

3.4. Initial Considerations of the Course

For the course, it is proposed to use teams of 3 to 5 students. As a general question, we can consider the following:

C_0: How can you analyze the performance of a runner if you have your GPS records?

An example of this data is:

Table-1. Data of performance of a runner

Time	latitude (°)	longitude(°)	altitude(m)
23/11/2017 15:28:48.00	21.1054234	-101.635706	1807.2
23/11/2017 15:28:48.86	21.1054961	-101.635774	1807.0
23/11/2017 15:28:55.78	21.1055125	-101.636098	1807.4
23/11/2017 15:28:59.23	21.1055136	-101.636199	1807.6
23/11/2017 15:29:06.14	21.1053879	-101.636345	1807.6

As a first activity, it is proposed to find an answer to the next related question, which can be attempted through Internet research, taking advantage of the fact that some classes of the course are assigned in a computer classroom.

C_{00}: What is the distance between two points whose terrestrial coordinates are given?

There are several ways to solve this question. One of them is to find the points in Google Maps and use the contextual menu option to measure distances. There are other ways to answer that question, but to direct the course towards mathematical analysis you can request an answer to the following question.

C_{01}: How is the distance between two points whose terrestrial coordinates are given calculated mathematically?

3.5. Relationship With Traditional Topics of the Course

This could be considered as an a priori analysis in the field of didactic engineering [12]. The next natural question is:

C_{02}: What is the distance traveled given many points whose terrestrial coordinates are given (a larger table than the previous one)?

This already suggests the structure for programming, which is part of the first theme of the traditional course. So far, the teacher provided the questions. Then you can use a strategy such as ABPs in which students are asked to generate their own questions, study objectives and roles of the members of each group. It is also expected that from here there will be more marked differences in the work of the teams. Some questions that can be presented are:

C_i: How to calculate the speed of the runner?

The topics that can be presented here are finite differences, interpolation and numerical differentiation. You can also find a question related to acceleration and then the following question may arise:

C_j: At what time do you get the maximum speed or acceleration?

These types of issues involve the topic of optimization and, possibly, roots of equations. If you have the data of several races of a single runner you could use regression (adjustment via least squares) to predict the time in a race whose distance is not within the data.

The task of the teacher is to try to keep the interest of the students by introducing or letting things flow so that they are not too difficult, which would cause the frustration of the students, and that are not too easy, so they would not feel motivated. They would lead to new knowledge. At the end of the REI, students have to arrive at an acceptable answer according to the mathematical requirements that they impose (milieu). First it was thought that this route would be concluded approximately one week before the second departmental and three before the IPN Once K 2018 race, so that some predictions can be verified. However, after the first departmental the participating teachers and in collegial work concluded that the students' advance had been little and that the second departmental should be taken to continue working in the SRPs.

3.6. Percentages

In each partial, the following percentages will be considered: Logbook, 20% (includes self-evaluation and co-evaluation), Teacher's Log, 20%, Advance of the report, 10%, Report, 30% and Presentation, 20%. Extraordinary and ETS exams will be applied on a computer. Its content will be that of the Agenda indicated above.

3.6.1. Student's logbook

Individually, a professional sized notebook will be used. Observations on the activities that the students carry out on all school days or outside of it will be included. Teachers could indicate special contents for this blog.

3.6.2. Teacher's logbook

Each session, the teacher will evaluate some teams. It will be averaged over the days that qualification was obtained. A rubric is used to evaluate a session of the course, which will evaluate the following aspects: attitude, availability to actively learn, teamwork and relative progress.

3.6.3. Advance and Report

In the middle of the partial, an advance is delivered that will serve to obtain feedback to make the report. The report will be sent at the beginning of the week before the exams. Students were provided with a template in .docx format with the sections indicated in the following rubric, which was used to qualify this first work: Introduction, theoretical aspects, method, questions and answers, conclusions and references.

3.6.4. Presentation

Presentations will be made on the last day of the week before the exams and the exam day. Teachers will ask specific students questions about the content of their reports. All the students of the team will be assigned the same grade.

3.6.5. Assistance

If a student is missing, he will have zero in the teacher's logbook for that day, even if his team has not been evaluated in that area. There are fifteen minutes of tolerance to enter the classroom.

3.7. Participating Groups and Teachers

Table-2. College career, group and number of participating teachers

Group	Carrer	Teacher	Attached
S1	Automotive Systems	1	2
S2	Automotive Systems	1	2
S3	Automotive Systems	1	3
A1	Aeronautics	2	4
A2	Aeronautics	5	6
B1	Biotechnology	2	
B2	Biotechnology	7	
F1	Pharmaceutical	2	8

3.7.1. Objective of the Investigation

The course design presented in the previous section is, as the name implies, initial. In this sense, the first phase of the design research methodology was completed [13]. For the experimentation phase, the teachers will have to make adjustments in a collegiate way according to the observations that they themselves are making so that the students have a good learning performance. In this document a retrospective analysis is being made to the first partial. There will have to be other analyzes, but maybe only at the end of the semester. Thus, the main research objective is:

Describe how a course is developed in which teachers promote the highest degree of independence of students when carrying out their learning activities.

To achieve this goal, it is broken down into description elements that are specified below.

Investigation questions

The following questions do not only apply to the first partial, but to the entire semester of the course.

1. What are the epistemological beliefs regarding students' mathematics and how do they change, if at all, during the course?
2. Are students able to generate issues related to the generating question independently?
3. What are the characteristics of the questions generated by the students, unlike the ones proposed by the teacher?

3.7.2. Justification

As previously mentioned in the problem, students are not achieving learning that will be useful in the future. Students are usually overwhelmed by the number of topics. Although for some there are not many, some conceptual deficiencies of mathematics or programming can cause them low performance. Also, in case that with this project the desired results are not obtained, evidence will be generated that can be revised in future innovations to avoid having the same mistakes. In education, it is usual for some teachers to achieve good results with new ideas that they carry out, but which are lost because they do not document it. With the reports generated in this project it will be tried that the effort by the investigators and teachers involved have benefit beyond the current semester.

But in addition to the benefits to the institution that houses the project, there is an interest in generating knowledge. As far as the author knows, there have been no experiments in which a whole course is based on investigative activities within the research tradition within the framework of the Anthropological Theory of the Didactic. This project is directed towards this vacuum taking into account experiments that have already been carried out [14, 15].

3.7.3. Viability

The design of the course had the approval of the academy. The teachers also agreed and show enthusiasm. The fact that there are other participating teachers could help to rule out possible effects that the fact that the professor is a researcher in this project could have.

4. Results

Self-regulation

In this section the levels are given in the following way:

Table-3. Response range and its meaning

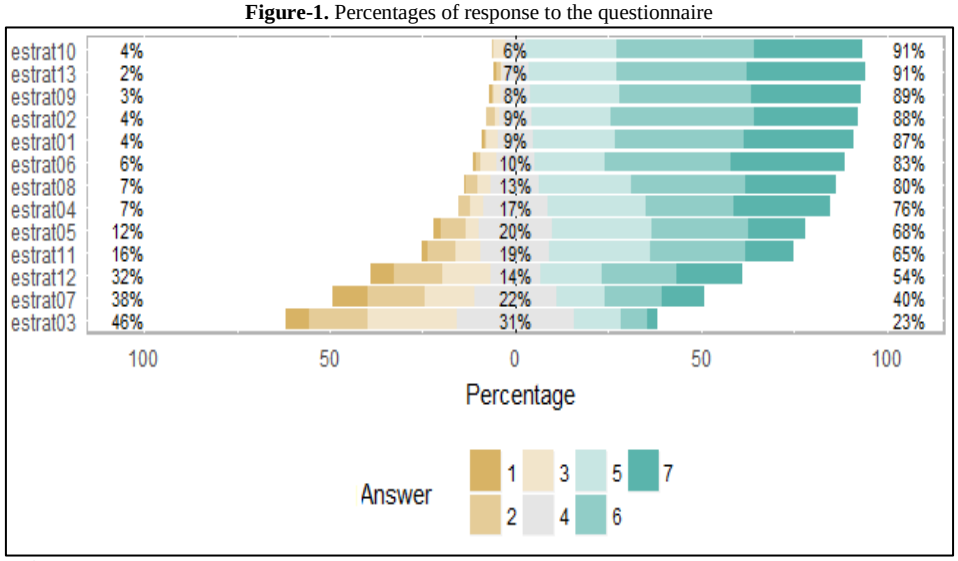
Number	Level
1	Never true for me
2	Almost never true for me
3	Few times true for me
4	Sometimes true for me
5	Usually true for me
6	Almost always true for me
7	Totally true for me

The Cronbach's alpha of this part is 0.7727795.
Use of Cognitive Strategies
Alpha of Cronbach: 0.7354254.
Questionnaire
The items and codes of the questionnaire are:

Table-4. Questionnaire and its code

Code	Item
estrat01	When I study for a math test, I try to integrate the class information and the book information.
estrat02	When I do the math assignments, I try to remember what the teacher said to answer correctly.
estrat03	It's hard for me to decide what the main ideas are when I read some math.
estrat04	When I study mathematics, I put the main ideas in my own words.
estrat05	I always try to understand what the teacher says in the math class, even if it does not make sense.
estrat06	When I study for a math test, I try to remember as much content as I can.
estrat07	When I study math, I copy my notes again to help me remember the material.
estrat08	When I'm studying for a math test, I keep repeating important content over and over again.
estrat09	I use what I learned in past tasks and from the book to solve my new math assignments.
estrat10	When I'm studying a subject of mathematics, I try to make everything together make sense.
estrat11	When I read math material, I repeat the concepts over and over again to help me remember.
estrat12	I frame the chapters of the math book to help me study.
estrat13	When I read math, I try to connect the things I'm reading with the ones I already know.

Figure-1. Percentages of response to the questionnaire

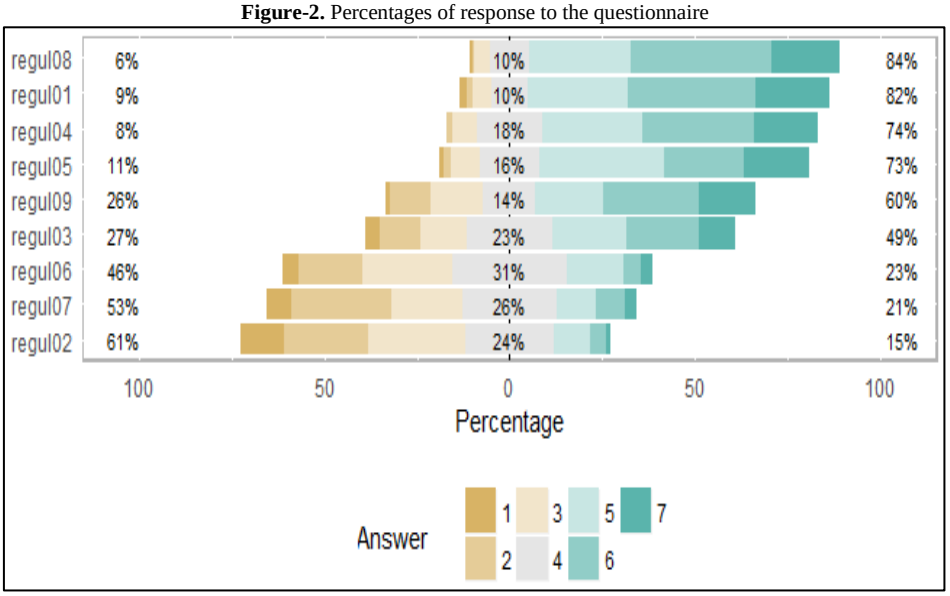


Self-regulation
Alpha of Cronbach: 0.4413976.

Table-5. Questionnaire and its code

Item	Question
regul01	I ask myself questions to be sure I know the material I am learning from math.
regul02	When the work of mathematics is very hard, or I stop studying or studying only the easy parts.
regul03	I work in practice exercises and I solve those at the end of the chapter in the math book, even if I do not have to.
regul04	Even when I'm studying arid and uninteresting topics, I keep working until I finish my math work.
regul05	Before I start studying mathematics, I think about what I need to do to learn.
regul06	I often realize that I have been reading for math class, but I do not know what it is about.
regul07	I realize that when the math teacher is talking, I'm thinking about other things and I'm not really listening.
regul08	When I'm reading some math, I stop from time to time to review what I've read.
regul09	I work hard to get a good grade, even if I do not like math class.

Figure-2. Percentages of response to the questionnaire



The questionnaire was answered by 165 students. The value of Cronbach's alpha of the complete questionnaire is 0.8118482. The following table shows the Cronbach's alpha values corresponding to removing each of the items. The negative sign in front of the item code indicates an increase in Cronbach's alpha when removing that item. The increase is not very noticeable in any of the cases.

Table-6. Code and it's Cronbach's alpha.

Code	Cronbach's Alpha
estrat01	0.7963
estrat02	0.7994
estrat03-	0.8191
estrat04	0.8023
estrat05	0.809
estrat06	0.7998
estrat07	0.8109
estrat08	0.8045
estrat09	0.7976
estrat10	0.7963
estrat11	0.8033
estrat12	0.8035
estrat13	0.7941
regul01	0.8042
regul02-	0.813
regul03	0.8057
regul04	0.8012
regul05	0.8054
regul06-	0.8127
regul07-	0.8138
regul08	0.7978
regul09	0.8085

The p-value of Bartlett's test is 1.5885566 × 〖10〗 ^(- 96). The KMO value of the survey is 0.7717626. Thus, with the former being very small and the latter greater than 0.70, we can continue to analyze principal and factorial components. For this work, we will perform confirmatory factor analysis because we have a theory of self-regulation with which we obtained the factors Strategies for learning, corresponding to the items with a prefix estrat; and Regulation of learning, those of prefix regul. With the package *lavaan* from R, the next output for that analysis is produced.

Table-7.

lhs	rhs	est	pvalue
Strategies	estrat01	1	None
Strategies	estrat02	0.9021	1.026e-08
Strategies	estrat03	-0.0728	0.67
Strategies	estrat04	0.844	1.023e-06
Strategies	estrat05	0.7339	8.488e-05
Strategies	estrat06	0.9489	3.425e-08
Strategies	estrat07	0.6613	0.004382
Strategies	estrat08	0.7736	6.808e-06
Strategies	estrat09	0.9051	4.733e-09
Strategies	estrat10	0.9232	7.251e-10
Strategies	estrat11	0.8636	6.94e-06
Strategies	estrat12	1.073	1.094e-05
Strategies	estrat13	1.039	8.287e-11
Regulation	regul01	1	None
Regulation	regul02	-0.4463	0.07942
Regulation	regul03	1.188	0.001076
Regulation	regul04	1.083	0.0003078
Regulation	regul05	1.046	0.0006743
Regulation	regul06	-0.4367	0.07978
Regulation	regul07	-0.4871	0.07715
Regulation	regul08	1.35	4.52e-05
Regulation	regul09	1.236	0.0009473

Viewing the p-values, observing problems in the variables estrat03, regul02, regul06 and regul07. Then, the new Estrat and Regul variables are created, adding the sum of the values of the corresponding values and measuring, respectively, the states of the study strategies and the norms of their study habits.

Figure-3. Score in study strategy

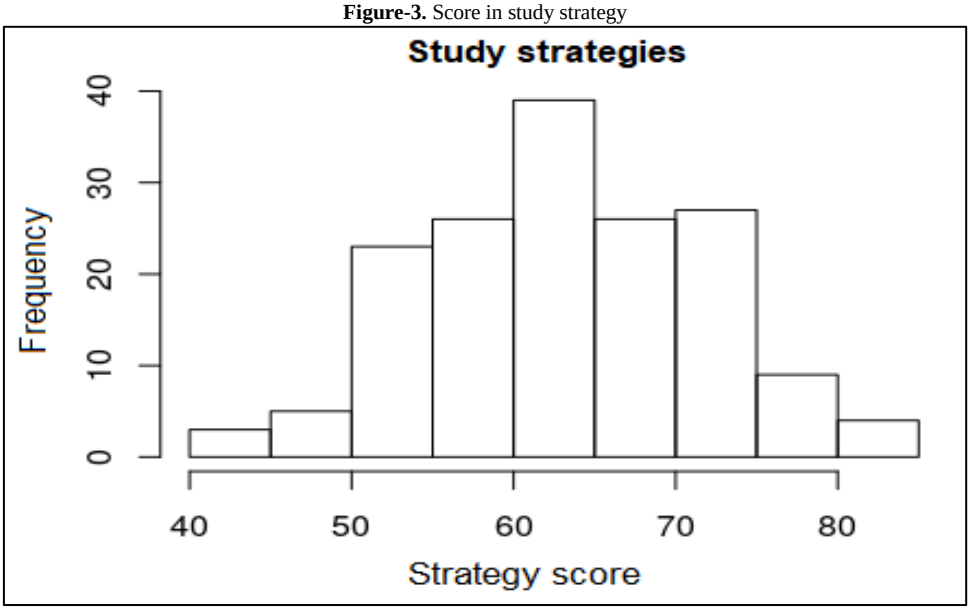
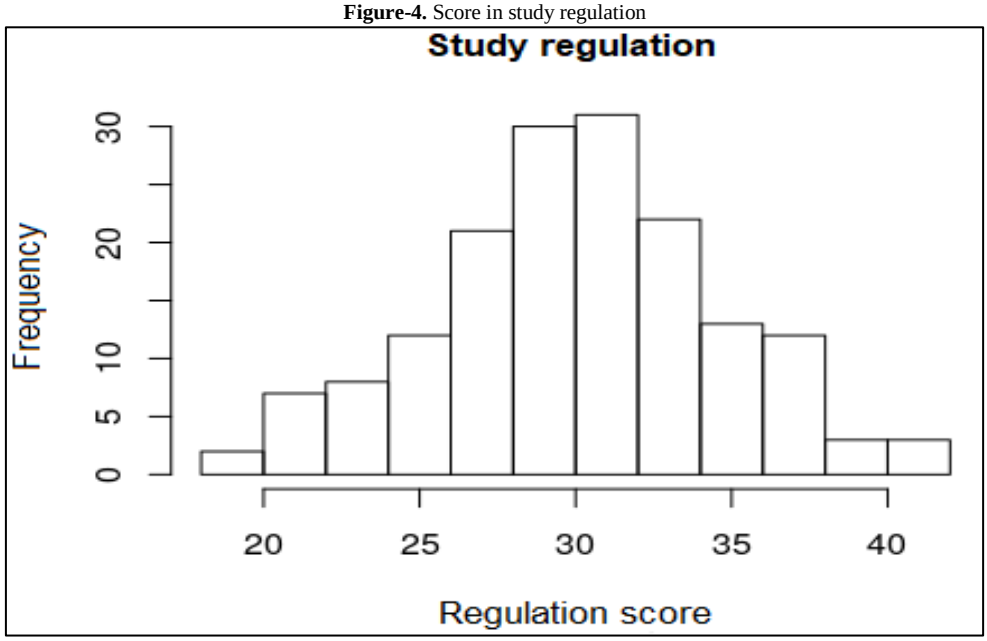


Figure-4. Score in study regulation



5. Conclusions and Impact of the Investigation

The Cronbach's alpha of the survey is not very high, but that does not necessarily indicate that it is a negative point. Being few questions, this indicates that there is no redundancy in them. An item elimination analysis was not performed to increase reliability alpha, as it was not considered necessary due to obtaining descriptive graphs such as those shown. In the graphs, it is observed that the students report that they do develop specific self-regulation strategies for mathematics. However, it is necessary to review the validity of the questionnaire in the specific context in which the Study and Research Paths that are reported in this work were launched. A variable related to this is that of previous knowledge of the students. The study of relationships like that is part of the work that is developed in the research to provide didactic proposals that benefit mathematics education in engineering.

The impact lies in the self-regulation strategies confirmed by the Research Paths, facilitating the student's identification of these values and concepts developed through the strategy.

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