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# Decision Making and Experiments in the Engineering Laboratory

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ABSTRACT: *In engineering topics, the laboratory exercises are probably the best field to promote the active participation of the student. There are several teaching strategies that can be performed in the laboratory. Practical work is frequently used as a means by which to acquire skills in the handling of apparatus, for the learning of specific experimental techniques, and as a way to illustrate or check experimental facts and scientific laws presented earlier by the teacher. This type of work is usually guided by means of very clear instruction sheets. However, we should not stop at this type of practical work. The work students do in the laboratory must be analogous to the behaviour of a real engineer in the exercise of his profession. So, they must be able to fix their objectives, test their conjectures, choose from among various paths, design and follow experimental procedures and analyse and report results, always within situations of a difficulty appropriate to their potential for development. This work contributes to the educational research of the engineering higher education. The so-called teaching by investigation strategy that promote the significant learning of engineering topics and organisational skills is applied. This strategy, described by eight relevant characteristics, is intended to improve the design and development of experiments. The methodology applied proposes the design of experiments that give students experience of: formulation of questions based on prior knowledge, proposal of probable solutions, testing of these solutions and testing and discussion of procedures and final solutions. The objectives are (i) that the students acquire a vision of the working methods in Technology through these activities and (ii) that these methods are consistent with the professional role of the engineer and current social demands. A case study of designing and conducting experiments to determine heat transfer in electronic equipment is described.*

## 1 INTRODUCTION

Many reviews of engineering and engineering education over the last two decades (ASEE, 1994; GRINTER, 1995; ABET, 1997; CAE, 1993; BATES et al., 1992) have identified a preponderance of technical and discipline-specific course content over non-technical and professional practice skills. However, employers value the possession of these professional skills, and the inclusion of these elements in undergraduate curricula is conducive to the development of lifelong learning habits in students. A list of desirable generic skills identified in the literature (RILEY & PICKERING, 1995; PALMER, 2000) includes, but is not limited to, communication, teamwork, creative thinking, initiative, and the practical meaning of the results of their work. Especially in engineering science subjects and in those of a technological nature, laboratories offer an unequalled opportunity for the students to actively participate in the construction of their own meaningful learning and to exercise the skills we have referred to.

The didactic approaches habitually used in laboratory can be classified in three main types (GIL, 1983): teaching by transmission, teaching by discovery and teaching by investigation. The first two types of teaching are normally applied in our laboratory practice. Practical work is frequently used as a mean by which to acquire skills in the handling of apparatus, for the learning of specific experimental techniques, and as a way to illustrate or check experimental facts and scientific laws presented earlier by the teacher. This type of work is usually 'guided' by means of very clear instruction sheets and we believe them to be necessary. Above all in the first stages of learning: the students must learn to measure and to measure well. The experiments also fulfil the aim of reinforcing the knowledge acquired in theory classes. However, if we are to be able to respond to the requirements mentioned above, then the work students do in the laboratory must be analogous to the behaviour of a real engineer in the exercise of his profession. Such that they can fix their objectives, test their conjectures, work in a team, choose from among various paths, design and follow experimental procedures and analyse and report results, always within situations of a difficulty appropriate to their potential for development. In this sense, the paradigm of teaching by investigation seems the most appropriate to achieve these educational objectives. Through practical work, the aim is to construct (not discover (GIL, 1983)) scientific knowledge from the interaction of our ideas with those of others and with experience. Teachers should act not only as transmitters of knowledge and skills, but as guides who aid the processes of complete learning.

This study proposes the application of the teaching by investigation methodology to laboratory work. This strategy promotes the significant learning of engineering topics and generic skills. The objectives to reach are (i) that the students acquire a vision of the working methods in Technology through these activities and (ii) that these methods are consistent with the professional role of engineer and current social demands. A case study of designing and conducting experiments to determine heat transfer in electronic equipment is described.

## 2 A STRATEGY TO IMPROVE LEARNING IN ENGINEERING LABORATORY

The teaching by investigation methodology consists in proposing laboratory work that gives students experience of:

a) formulation of questions based on prior knowledge
b) proposal of probable solutions
c) testing of these solutions
d) testing and discussion of procedures and final solutions

To successfully carry out this work it is necessary to define the general characteristics of laboratory practical if they are to be considered an investigative activity. We understand that, in addition to being experimental work, it must integrate other equally important processes of scientific activity, by which we are referring to some aspects whose presence is considered fundamental if one is to talk about the truly investigative nature of the practical session. These aspects, suggested in GIL & VALDES, 1996, which in no way constitute an algorithm to be followed linearly, are as follows:

1) Present *open problematic situations* of a suitable level of difficulty (corresponding to the *potential state of development* of students) such that they are capable of taking the correct decisions.
2) Encourage students to reflect on the importance and *possible interest of the situations* proposed, which gives meaning to their study (considering the possible implications for science, technology and society, etc) and avoid out of context, socially neutral study.
3) Foment *qualitative analysis*, meaningful analysis which helps one to understand and situate the situations proposed (in the light of the knowledge available, the interest of the problem, etc) and formulate operative questions about what is being sought.
4) Propose the *emission of hypotheses* as the central act of scientific research, susceptible of guiding the treatment of situations and making student's preconceptions functionally explicit. Likewise, give these hypotheses a basis and make them operative, deriving testable consequences, giving adequate attention to the control of variables, etc.
5) Recognise the importance of the *elaboration of designs* and of the planning of experiments by the students themselves. Encourage wherever possible the incorporation of current technology to experimental designs in order to favour a more correct vision of contemporary scientific-technical activity.
6) Encourage the *detailed analysis of results* (their physical interpretation, reliability, etc), in the light of available knowledge, of the hypotheses used and of the results of 'other researchers'. Pay particular attention, if it were necessary, to the *conflicts* between results and initial conceptions, thus functionally aiding conceptual changes.
7) Grant special importance to the elaboration of *scientific reports* that reflect the work carried out and which can be used as a basis to highlight the role of communication and discussion in scientific activity.

8) Foment the *collective dimension of scientific activity* organising research teams and aiding interaction between each team and the scientific community, represented in the classroom by the other teams, the body of knowledge already constructed (in text books), the teacher as expert, etc.

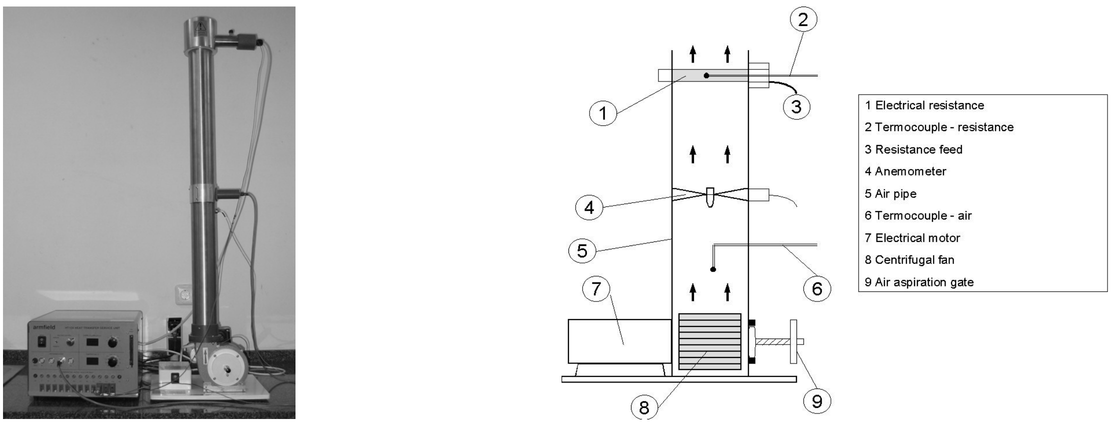
In reference to the learning and teaching styles described in FELDER & SILVERMAN, 1988, the teaching styles of most engineering professors are verbal, abstract (intuitive), deductive, passive and sequential. Meanwhile, many of the relevant aspects of the teaching by investigation method mentioned above address some of the learning styles that most of engineering students possess: visual, sensing, inductive and active. So, matching the teaching style with the learning style, a significant improvement of student learning might be expected. Additionally, some principles of good practices in undergraduate education (CHICKERING & GAMSOM, 1987), such as co-operation among students or active learning, are main characteristics of this strategy. Some other references (MOSKALSKI, 2003; FELDER & BRENT, 2003) highlight the relevance of the teamwork and the active learning in engineering education. Thus, the potential to improve the student significant learning with the application of this methodology is very great.

It must be pointed out that not all practical sessions can fulfil all these requirements, either because of the characteristics of the experimental equipment available, or because some of the aspects of the discipline are beyond the students' potential for development.

## 3 CASE STUDY

### Study background

An example of a laboratory experience on heat transfer by convection is presented. This experience is included in the subject Heat Transfer, which is taught within the first year of the degree in Electronic Engineering at the University of Burgos. The module comprises 20 h of heat transfer lectures and 10 h of laboratory experiences. The heat transfer by convection laboratory experience is developed in two sessions of 3 h each. There are two assessment tasks associated with this practical: an individual test administered at the end of each session, and the written reports that groups made up of four students have to present. The learning goals articulated for the subject are practical: students should be able to (1) recognise in practical situations the main role of the energy balance in evaluating heat transfer in electric/electronic equipment; (2) analyse the principal variables which influence heat transmission by forced convection. The methodology used to achieve these objectives will consist of the design of an experiment to study heat transmission in a small electrical element that gives off heat. The real equipment and its scheme are presented in Figure 1.




(a) (b)

Figure 1. The convection heat transfer device: (a) the real device; (b) a scheme

Previously to the laboratory session, the students have been given a set of instructions for the practical work prepared by the teacher. It contains the description of the objective of the practical work and the methodology required achieving it. Also, the criteria used for assessment, a brief introduction with antecedents to the scientific theme being studied and a description of the specific experimental objectives, which will require the active participation of the students and of the teacher in the role of moderator. The related concepts of the teaching by investigation method and this particular laboratory experience are described in Table 1.

TABLE 1. Relation between Teaching by Investigation method and the Laboratory Experience

| **Teaching by Investigation aspect** | **Sequential development of the heat transfer by convection laboratory experience** |
|---|---|
| *3 qualitative analysis*<br>*4 emission of hypotheses* | The **INTRODUCTION** is conducted through questions proposed by the teacher. First of all, it must be obtained, trough brainstorming, a wide list of electrical equipment used in industry, offices and houses. Afterwards, the students have to formulate answers to questions<br>Do they work alone? If they need to be plugged in, what is the electricity used for in the apparatus?<br>How do you know if they give off heat? Do they need to be cooled? If this is so, then how can they be cooled?<br>If you come to the conclusion that the apparatus uses or gives off energy, then does it gain or lose energy?<br>The teacher will propose analysis and discussion on these questions, in order to situate the scientific-technical context of the objective of the practical<br>In accordance with the antecedents and your previous knowledge, the students are asked to write a formula that reflects the behaviour of energy in a system (for example, an electrical device such as a television or a computer). Hoes does it behave when it is stabilised in time? The final formulation will be obtained by group discussion with the teacher as moderator. |
| *1 open problematic situations*<br>*2 possible interest of the situations*<br>*5 elaboration of designs*<br>*4 emission of hypotheses* | In accordance with this formulation the students are asked to **DESIGN an experimental bench** to measure the heat dissipation in the air of a small electrical or electronic element. They have to sketch the position of the constructive and measurement elements, and briefly explain their functioning. Groups made up of four students will do this work.<br>The students are placed as if they were recent graduates employed in the R&D department of a manufacturing company of electronic equipment. The results of their work will be valuable to improve the quality of electronic products.<br>The design will be handed in to the teacher and will be used to assess the practical. |
| *8 collective dimension of scientific activity* | Each group presents its design to the rest of the class trough **ORAL COMMUNICATION**. Teacher and students act as if they were the people in charge of this equipment in the manufacturing company. The class comments on the advantages and disadvantages of each design. |
| *3 qualitative analysis* | The teacher presents the **equipment** that is **really available** in the laboratory **to do the tests**. Its characteristics are compared with those of the students' designs, in order to check the hypotheses and previous ideas. The teacher describes its functioning: geometry, fluid used, variables which can be measured and modified. Through group discussion moderated by the teacher, the variables mentioned will be classified as dependent or control variables. (Finish of the first session) |
| *4 emission of hypotheses*<br>*5 elaboration of designs*<br>*1 open problematic situations* | Each team of four students is asked to plan an experiment to carry out the tests. The idea is to **DESIGN AN EXPERIMENT** to study the capacity of air to cool a small hot electrical element in the equipment described earlier. They must identify the objective function, the number of measurements to be taken, the forecast reduction of data and the final form in which the results will be presented (tables and graphics).<br>The design made will be handed in to the teacher and used to assess the practical. |
| *8 collective dimension of scientific activity* | By **ORAL COMMUNICATION,** each team presents to the teacher and classmates its experimental forecast, and they continue to act as though they were technicians in a company. Consensus is reached as to the most suitable experiment to perform. |
| *6 detailed analysis of results* | **The** chosen **experiment is carried out**. As a group, the results obtained are commented on and there is discussion as to whether the initial objective of the practical session has been achieved: to experimentally obtain the mathematical formulation of heat transmission by forced convection.<br>**FINAL CONCLUSIONS** will be obtained by interpreting the results. This section will be done through group discussion moderated by the teacher. (Finish of the second session) |
| *7 elaboration of scientific reports* | Each team will **WRITE UP A REPORT** with the results obtained. They will be used for the assessment. |

## Evaluation methodology

Fifty-one students were surveyed in the first semester of 2004. Student attitudes and perceptions to this sort of practical work were gauged in two ways. First of all, students were surveyed at the end of the teaching period through an anonymous questionnaire of 29 items. The attitude information was gathered by the presentation of statements to which students were invited to respond on five-point scales ranging from 'strongly agree' to 'strongly disagree'. Statistical significance of results were analysed by descriptive parameters as modal response (percentage and absolute value), mean value and standard deviation. The questionnaire was designed to discover students attitude to (i) the practical exercises of Heat Transfer, and (ii) the teaching style and engagement. As a second way of surveillance, observations of the behaviour of students were made during the teaching sessions. And third, the evaluation of the scientific designs and reports presented by the students.

## 4 RESULTS

The questionnaire has been divided into two parts. Tables 2 and 3 present the set of statements and statistical results focused towards objectives (i) and (ii), respectively. The numerals in the tables have been maintained correlatives to facilitate the discussion.

Table 2. Student's response (% (n)), mean values and standard deviation to 14 mapped statements presented an the questionnaires relating to the attitude towards the practical exercises of Heat Transfer

| Statement | 5 Strongly agree | 4 Agree | 3 Neutral | 2 Disagree | 1 Strongly disagree | Mean Value | Standard deviation |
|---|---|---|---|---|---|---|---|
| 1. The pace of laboratory sessions is appropriate | 4 (2) | 18 (9) | 36 (18) | 42 (21) | 0 (0) | 2.84 | 0.866 |
| 2. The laboratory environment is adequate to develop the practical sessions (lighting, tables, equipment, etc.) | 10 (5) | 49 (25) | 29 (15) | 10 (5) | 2 (1) | 3.55 | 0.879 |
| 3. The instruction guide of the practical is adequate | 6 (3) | 39 (20) | 45 (23) | 8 (4) | 2 (1) | 3.39 | 0.802 |
| 4. I have understand the objectives of the practical | 20 (10) | 46 (23) | 28 (14) | 6 (3) | 0 (0) | 3.80 | 0.833 |
| 5. The assessment criteria were clearly stated | 34 (17) | 32 (16) | 28 (14) | 6 (3) | 0 (0) | 3.94 | 0.935 |
| 6. The assessment criteria are corresponding with the task developed at the laboratory | 21 (11) | 39 (20) | 31 (16) | 6 (3) | 2 (1) | 3.73 | 0.940 |
| 7. I have taken many notes during the laboratory experiences | 2 (1) | 28 (14) | 38 (19) | 28 (15) | 4 (2) | 2.96 | 0.903 |
| 8. I have red carefully the instruction guide previously to my attendance at the laboratory | 4 (2) | 20 (10) | 24 (12) | 32 (16) | 20 (10) | 2.56 | 1.146 |
| 9. I have paid steady attention to the laboratory work because it is interesting | 8 (4) | 55 (28) | 23 (12) | 12 (6) | 2 (1) | 3.55 | 0.879 |
| 10. I have paid steady attention to the laboratory work because the assessment at the end of the session | 6 (3) | 42 (21) | 36 (18) | 14 (7) | 2 (1) | 3.36 | 0.875 |
| 11. I have paid steady attention to the laboratory work because the hints about examinations | 10 (5) | 29 (15) | 43 (22) | 16 (8) | 2 (1) | 3.29 | 0.923 |
| 12. I have paid attended to the laboratory work because pass the examinations is all that matters to me | 8 (4) | 10 (5) | 29 (15) | 43 (22) | 10 (5) | 2.63 | 1.058 |
| 13. The laboratory sessions are of interest | 12 (6) | 53 (27) | 21 (11) | 8 (4) | 6 (3) | 3.57 | 1.005 |
| 14. If this subject were optional I would choose it | 14 (7) | 31 (16) | 33 (17) | 12 (6) | 10 5) | 3.27 | 1.150 |

In relation with the results shown in Table 2, we can appreciate that students generally felt that the heat transfer laboratory experience was relevant. The understanding of the objectives and the previous knowledge of reasonable assessment criteria were the most appreciate items. About the pace of the sessions, some students write comments in the sense that they felt tired after three hours of hard work, and suggest having three sessions instead of two. The attention paid during the sessions responds mainly to the intrinsic interest of the topics (question 9, 55+8=63% of agreement modal response), unless the immediate assessment and future examinations also were relevant.

Table 3. Student's response (% (n)), mean values and standard deviation to 15 mapped statements presented an the questionnaires relating to the attitude towards the teaching style and engagement

| Statement | 5 Strongly agree | 4 Agree | 3 Neutral | 2 Disagree | 1 Strongly disagree | Mean Value | Standard deviation |
|---|---|---|---|---|---|---|---|
| 15. The open problematic situations presented (design of experiments, design of a bench) are interesting | 23 (12) | 57 (29) | 16 (8) | 4 (2) | 0 (0) | 4.00 | 0.748 |
| 16. The context of industry application of the situations presented is interesting | 20 (10) | 59 (30) | 22 (11) | 0 (0) | 0 (0) | 3.98 | 0.648 |
| 17. There is great opportunity to participate and ask questions during the practical sessions | 53 (27) | 41 (21) | 4 (2) | 0 (0) | 2 (1) | 4.43 | 0.755 |
| 18. It is easy to me to ask questions during the laboratory sessions | 24 (12) | 36 (18) | 28 (14) | 10 (5) | 2 (1) | 3.70 | 1.015 |
| 19. I have improved my qualitative analysis skill thanks to the way the sessions have been planned | 8 (4) | 47 (24) | 41 (21) | 4 (2) | 0 (0) | 3.59 | 0.698 |
| 20. I have been able to propose hypotheses based in my prior knowledge | 16 (8) | 64 (33) | 18 (9) | 2 (1) | 0 (0) | 3.94 | 0.645 |
| 21. I have been able to check the validity of my prior knowledge thanks to the way that the sessions have been planned | 12 (6) | 59 (30) | 29 (15) | 0 (0) | 0 (0) | 3.82 | 0.623 |
| 22. Having the opportunity of proposing my own ideas to design experiments has been very useful | 26 (13) | 58 (29) | 16 (8) | 0 (0) | 0 (0) | 4.10 | 0.647 |
| 23. I have enhanced my knowledge about how to design and plan experiments | 16 (8) | 55 (28) | 25 (13) | 4 (2) | 0 (0) | 3.78 | 0.856 |
| 24. The sessions planning has allowed me to achieve a detailed analysis of the results obtained in the experiments | 2 (1) | 49 (25) | 35 (18) | 12 (6) | 2 (1) | 3.37 | 0.799 |
| 25. The obligatory reports I have had to write have improved my learning | 8 (4) | 31 (16) | 41 (21) | 18 (9) | 2 (1) | 3.25 | 0.913 |
| 26. The reports required were adequate to the complexity of the task | 6 (3) | 44 (22) | 44 (22) | 4 (2) | 2(0) | 3.48 | 0.762 |
| 27. The teamwork is better way to learn than on my own | 39 (20) | 47 (24) | 12 (6) | 2 (1) | 0 (0) | 4.24 | 0.737 |
| 28. I have learned more with the oral presentation and group discussion than if it shouldn't have take place | 37 (19) | 45 (23) | 10 (5) | 8 (4) | 0 (0) | 4.12 | 0.887 |
| 29. I have listened carefully the statements and proposals of the others during the group discussion | 25 (13) | 63 (32) | 6 (3) | 6 (3) | 0 (0) | 4.08 | 0.744 |

All the statements presented in Table 3 refer to the eight aspects of the teaching by investigation mentioned above. Mean values of all items are comprised between 3.25 and 4.43, with small values of standard deviation. In all questions, the modal response is placed over the 'agree' response, except in question 17 that is 'strongly agree'.

## 5 DISCUSSION

The results obtained in Table 2 show that students give great importance to the knowledge of the learning objectives and assessment criteria. These constitute the most relevant reference for their attitude towards a specific topic. Agreement with the assessment criteria enhances this engagement. As a result, the general attitude of the students during the session was active towards the tasks proposed. Questions 15 (m.v. 4.00, s.d. 0.748) and 16 (m.v. 3.98, s.d. 0.648) show that this attitude enhances the student's interest towards the challenge of learning and lead to a high level of attention (questions 9 to 12).

Teamwork is recognised as a valuable characteristic of the sessions (question 27, m.v. 4.24, s.d. 0.737) and the students feel that improve their learning. Though, as observed by the teacher during the sessions, the role of each participant was not specified and a leader was not always chosen. Moreover, the teams found it difficult to organise their time adequately during the work sessions. We think this is a normal situation in first year degree students.

The proposal of design tasks has been demonstrated of great interest for student's learning (question 20, m.v. 3.94, s.d. 0.645; question 22, m.v. 4.10, s.d. 0.647, question 23, m.v. 3.78, s.d. 0.856), with modal responses of global agreement between 71% and 84%. The designs proposed by students during the sessions are an indicator of their creativity, which in another type of approach would not have been possible.

The analysis of results in the light of available knowledge, of the hypotheses used and of the results of other researchers (the rest of the classmates) has reached a good score but shows an opportunity to improve (question 19, m.v. 3.59, s.d. 0.698; question 24, m.v. 3.37, s.d. 0.799). The comments of some students in the questionnaire about the hardness of the task refer mainly to the last part of the session, when the final scientific conclusions are obtained from the analysis of experimental results. After three hours of work, the level of attention has decreased and the analysis ability has little opportunity to improve.

The student's perception of effective learning is due to the effort needed to write reports (question 25, m.v. 3.25, s.d. 0.913; question 26, m.v. 3.48, s.d. 0.762) as well as to the oral presentations and group discussions (question 28, m.v. 4.12, s.d. 0.887; question 29, m.v. 4.08, s.d. 0.744). During the sessions, it has been possible to observe that students' communication skills are very variable. Also, that they use different approaches to a single problem. Although the critical attitude of students towards others classmates in the oral presentations is variable, it has been recognised as a great value of the sessions (question 17, m.v. 4.43, s.d. 0.755; question 18, m.v. 3.70, s.d. 1.015, question 21, m.v. 3.82, s.d. 0.623)

## 6 CONCLUSIONS

The training of engineers has been undergoing a great deal of change for several decades. The preponderance of scientific contents and techniques in this training has given way to the inclusion of formative objectives in personal attitudes and skills that will be very important later in the engineer's professional career. This implies a move from teacher-centred training to student-centred training.

An example of laboratory practical work in Heat Transfer has been presented. The application of the approach of teaching by investigation has highlighted some remarkable aspects. The design and development of experiments is a typical engineering task and involves not only scientific or technical criteria but decision criteria within an interest context. This approach allows the students the achievement of activities directly related to engineer's professional work: design of equipment for an established purpose, design and conduction of experiments, communication and discussion of results and write up of reports. The percentage of students actively engaged with the laboratory exercises increases till 90% typically, which means a high level of active learning. The teachers must value carefully the grading of the difficulty of the task that the students have to perform in agreement with the course objectives. Teachers had to learn to guide sessions through questions, limiting the tendency to simply explain their knowledge, more usual in the traditional classroom situation. These sessions take longer than other types of practical work, although a better understanding on the part of students is achieved. Since resources are limited and the sessions require more time to carry them out, the teachers have to choose from between either run only a select subset of the experiments according to the suggested approach, or else significantly reduce the amount of subject matter to be covered in laboratory classes. Trough this case study of design and development of experiments, the most remarkable characteristics of the teaching by investigation strategy have been highlighted.

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