IMPORTANT PROBLEM FEATURES FOR THE PROMOTION OF CONCEPTUAL UNDERSTANDING IN INTRODUCTORY ELECTRONICS

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Abstract: This article describes an investigation in which a set of problems, specifically designed to develop conceptual understanding in introductory Electronics, were used as a teaching and learning strategy in an active learning setting. Some of the suggested problems have similarities with those presented by concept inventories, in that they are designed to address common students' misconceptions. The goal, however, is not to detect misconceptions, but rather to challenge students' conceptual reasoning. The investigation setting, integrated in the project-based learning environment established at the Higher Education Polytechnic School of Águeda (University of Aveiro, Portugal) since 2001, was designed as a source of abundant data that included field notes, students' written responses to the open problems and interviews. Qualitative analysis was used to identify important problem features that seem to prompt conceptual reasoning, and to evaluate the approach. Although the setting and the learning environment are described in some detail, to set the scene and provide context for the issues being discussed, this article concentrates on the problems and their important features in the promotion of conceptual understanding. Examples of the various formats of problems used in the investigation are provided to better illustrate the discussion. Results of the analysis indicate that the use of such problems does seem to have a positive impact in the conceptual reasoning of the students. However, students also report a generalized feeling of insecurity, for every new problem presented an emotional challenge, as well as a challenge to their assumptions. The analysis also indicates that it is important to seek a proper balance between the qualitative and quantitative components of the problems suggested to the students. As a conclusion, the article will offer a summary of the most important problem features in the promotion of conceptual understanding, as far as the results of this investigation are concerned.

Keywords: Conceptual understanding, Active learning, Problem features

1. INTRODUCTION

Conceptual understanding, as opposed to shallow, rote learning, has been the object of concern for a long time [1], given its importance in the way knowledge may be applied and created. Strategies and instruments to investigate misconceptions and assess conceptual understanding have been developed, such as the Force Concept Inventory [2]. This set the ground for the development of other inventories, devoted to different subject areas, namely the Signals and Systems Concept Inventory [3] and the Electronics Concept Inventory [4], which relate to the specific subject area addressed by this paper. Talk-aloud protocols [5,6] and clinical interviews [7] have also been used to identify misconceptions in an extremely rich way, allowing for the exposure of the students' reasoning processes and the tracking of the possible origin of the misconceptions. Teaching and learning strategies addressing the development of conceptual understanding have been tried and evaluated using some of the previously mentioned instruments, with special emphasis on the concept inventories, in pre/post-test structures. Discovery learning [8] and the use of interactive engagement methodologies, as defined by Hake [9], seem to have a positive impact on the development of conceptual understanding, as evidenced, for example, in the work by Hake.

In the Higher Education Polytechnic School of Águeda (ESTGA), the technology programs are organized in a project-based learning paradigm (PBL) [10]. Because it is a student-centred, active learning environment, conditions for the development of conceptual understanding seem to be present [11]. However, evaluation [12,13] of the introductory Electronics module shows students tend to use shallow, trial and error strategies to accomplish the required tasks, resulting in high failure rates in the supporting courses and poorer results in the project. As a result, a teaching and learning strategy designed to promote the development of conceptual understanding in introductory Electronics, based on exploratory open problems, presented to the students as challenges, after minimal instruction, has been proposed. Some of the suggested problems have similarities with those presented by the concept inventories, in that they are designed to address common students' misconceptions. The goal, however, is not to detect misconceptions, but rather to challenge students' conceptual reasoning. For the remainder of this paper, whenever the word "problem" is mentioned, it is meant to refer to the kind of conceptual driving challenges that motivate the investigation, and that will be further discussed in Section 3.

Two rounds of an experiment of the use of these problems have been conducted in the fall semesters of 2006/07 and 2007/08. The first stage of the investigation was described in [14]. Qualitative analysis has been carried out to identify the important features of the problems in promoting conceptual reasoning. One of the questions that guided this research, on which this paper will focus on, was:

- Which features of the proposed problems seem to have an impact in the grasp of concepts evidenced by the students?

The first part of the paper will set out to briefly describe the setting in which the experiment took place. The problems presented to the students will then be discussed. The paper will go on to concentrate on the analysis methodology and the results thereby obtained, in what concerns the important problem features to promote conceptual understanding.

2. THE SETTING FOR INVESTIGATION

For reasons that are beyond the scope of this paper, in 2001 ESTGA moved towards a PBL paradigm in its three-year technology programs [15,16]. The programs are now organized around one-semester long thematic modules that encompass a project and supporting courses. All courses are taught in four-hour blocks that can be organized differently according to the learning needs at any stage of the process, thus enhancing flexibility.

Integrated in the Electrical Engineering degree offered at ESTGA, the "Analogue Electronic Systems Module" is a third semester thematic module, in which students have their first contact with introductory Electronics. The module is made up of a thematic project and two supporting courses: "Semiconductors, Devices and Applications" and "Electronic Systems". It was in the context of this latter supporting course that the investigation described in this article took place.

"Electronic Systems" is a weekly four-hour block course, spanning the entire semester. Fundamental subjects related to electronic systems are addressed, in close articulation with the thematic project, meaning that there should be room for flexibility and reorganization of the delivery in response to students' needs, in the course of their project work. In brief, the subjects to be addressed are: Two-port Networks, General Amplifier Models, Linear and Non-Linear Applications of Operational Amplifiers, Elementary Signal Generation and Feedback Theory.

The proposed course organization was:

- Students were organized in groups of five members (about thirty students in each round).
- Minimal instruction was provided, either as introduction of new subject matters, or as general review overviews.
- In each four-hour session, three to four challenges were "thrown-out" to the students, either in the form of exploratory questions or the "conceptual triggering" problems that are the subject of the investigation. Students worked around these challenges, with the teacher acting as facilitator in the process.
- At the end of each session, two to three homework problems were assigned. At the beginning of the following session, a group would be randomly selected to present their solutions to the class. Another randomly selected group acted as a peer assessment group, driving the discussion. These activities were meant to promote out-of-class intra-group discussion and then in-class inter-group discussion.
- At the end of each important subject topic, students took a thirty-minute individual exam consisting of an open written problem. Five of these exams took place along the semester.

The setting just described is not original in its organization as an active learning environment, but it sets the scene for the issues being discussed in this paper.

3. THE PROBLEMS

As stated earlier in this paper, the type of problems used to challenge the students is the touchstone of this investigation. The idea is to use conceptual driving problems to create situations from which students cannot escape without having to deal with the desired conceptual framework, in a process of exploration that actually involves interactive engagement [9]. The main features of the problems proposed to the students for the teaching sessions, the group homework challenges and the assessment were:

- Open written problems, to allow for the analysis of the way students address the problems, and identify conceptual blockings;
- Incorporated qualitative rather than quantitative descriptors, and questions, designed to avoid concentration on the undesirable use of familiar algorithms in an unthinking way;
- Addressing common students' misconceptions, allowing for their discussion and demystification.

An example of a general challenge is shown in Figure 1, problem PA, in which students are prompted to deal with the "loading" effects of cascaded blocks. The fact that the amplifier blocks have somewhat non-ideal characteristics is also an important feature.

Accommodating the general features earlier described, and apart from the more common problem formats, three somewhat different formats have also been proposed:

- Multiple choice questions involving qualitative graphical analysis. Students are always required to fully justify their answer. Problem PB, in Figure 1, is an example of such a problem, in which students are prompted to deal with the DC gain of a practical integrator circuit.
- Reviewing a given solution to a problem. The solution may be completely correct, completely incorrect or may just have some mistakes. Students are again asked to justify their comments. In problem PC (Figure 1), students are challenged to address the concept of the virtual short-circuit across an operational amplifier's inputs, and then recognize a Schmitt-Trigger configuration.
- Work back through a problem from its provided solution, as shown in problem PD (Figure 1), where students have to interpret the consequences of amplifier negative-feedback to be able to draw the missing branch. In this problem, integration with previously addressed subject matters is also made explicit.

The analysis methodology for the experiment will be discussed in the next section.

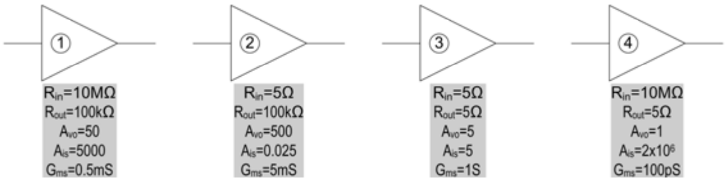
4. ANALYSIS METHODOLOGY

Due to the nature of this investigation, focused on the characteristics of the proposed problems that seem to have an impact on the students' conceptual reasoning, a deliberate choice for qualitative analysis techniques was made. The small number of students involved also contributed for that decision.

The whole setting, as described in Section 2, was designed as a source of abundant data for qualitative analysis, and comprised of:

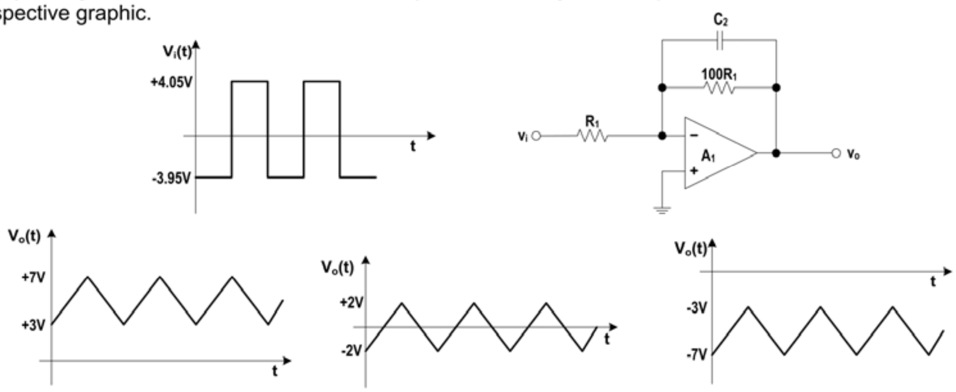
- Field notes on the students' in-class presentations and discussions.
- Self- and peer-assessment reflections on those presentations.
- Students' answers to the open-written assessment problems taken during the semester.

PA. An infra-red sensor exhibits a short-circuit output current range of ±50μA, and an internal resistance of 5Ω. The goal is to build an amplification system capable of driving another electronic system with an input resistance of 150MΩ, with voltages higher than 5V. Use a combination of the following available four blocks.



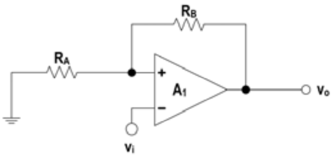
PA. An infra-red sensor exhibits a short-circuit output current range of ±50μA, and an internal resistance of 5Ω. The goal is

PB. The input signal of the circuit shown in the figure is the square-wave signal represented on the left. Which of the signals (I), (II) or (III) would you expect to observe at the output of the circuit? Please, explain your reasoning thouroughly. If the supply voltages of the OPAMP are ±5V, would your chosen signal be any different? If so, sketch the differences on the respective graphic.



PB. The input signal of the circuit shown in the figure is the square-wave signal represented on the left. Which of the signals

PC. A colleague of yours analysed the circuit shown in the figure, producing the set of expressions on the right as a result. Review his/her analysis, providing alterntive reasonings whenever you disagree with your colleague, and proper justifications for the steps with which you fully agree.



$$v^+ = v_i$$

$$i_A = \frac{v^+}{R_A} = \frac{v_i}{R_A}$$

$$v_{R_B} = R_B \cdot i_A$$

$$v_o = v^+ + v_{R_B} = v_i + R_B \cdot \frac{v_i}{R_A} = v_i\left(1 + \frac{R_B}{R_A}\right)$$

PC. A colleague of yours analysed the circuit shown in the figure, producing the set of expressions on the right as a result.

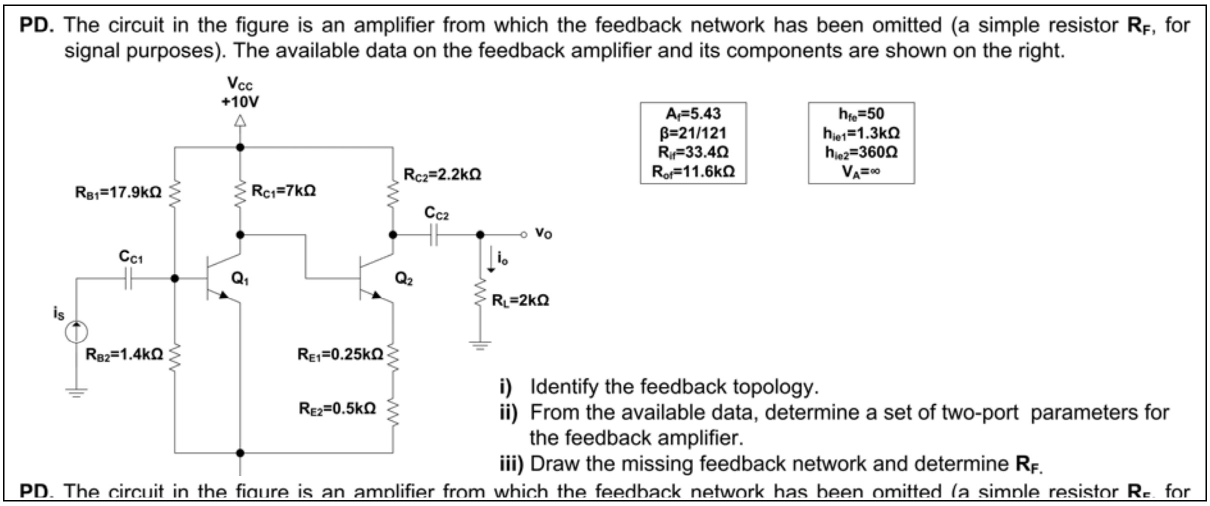


Figure 2. Examples of the problems used in the investigation.

In addition, at the end of the semester, after all assessment activities had been completed, a subset of the initially enrolled students was interviewed (twenty for the first round of the experiment, and sixteen for the second round). The interviews focused on the perceived learning experience.

Data from the previously described sources was analyzed employing Constant comparative method [17] in a systematic way. A simple set of codes was first established and applied to categorize excerpts of the data. An open coding approach was used, in which codes emerged from the data itself. The codes were then applied to the entire data set, allowing for refinements whenever necessary.

5. RESULTS

The results presented in this paper, since it is focused on the problems' characteristics, came essentially from the analysis of the students' answers to the problems, and the field notes. Nevertheless, whenever necessary, extracts from the interviews may be used to complement the discussion or provide context. In what regards the problem features, no significant differences were found between the first and the second rounds of the experiment. Therefore, no distinctions will be made in the remainder of this section.

5.1 Evolution of student's attitudes

One of the most important findings emerging from the analysis of the field notes relates to the evolution of the students' attitudes towards the setting and its activities. This moved from an initially passive *"Let's wait for the teacher to come around and tell us what to do"* attitude, to an active engagement posture in which the "coming around" of the facilitator was seen as an opportunity to discuss options which the students had already identified. A similar attitude change was observable in relation to the presentation of the homework challenges and the peer-assessment groups.

During the semester, a considerable improvement was also observed in the quality of the answers to the exam problems and in the results obtained. It also became apparent that individual progression in the capability to dwell with conceptual reasoning was quite heterogeneous, revealing who the driving students of each group were and, to some extent, the effect of group dynamics. Generally, however, a positive evolution was observed, in that there was an overall improvement in the quality of the approaches, in terms of analytical thoughtfulness and conceptual understanding. However, a great number of the students also reported, in the interviews, a generalized feeling of insecurity, for every new problem presented an emotional challenge. One of them stated: *"It is quite frightening, not having a familiar structure for problem-solving"*.

5.2 Important features of the problems

A significant finding was that open problems, described and answered in words and calculations, seem to be much more useful in engaging students than the multiple-choice format discussed in Section 3. When options are offered in that format, even when they incorporate common students' misconceptions, students tend to spend their time decoding those options, which may prompt valuable thinking, but sometimes distracts them from more important and basic discussions.
Problems that are of an entirely qualitative nature seem to be interpreted as *"too theoretical"*, as one student put it, and are not as successful in inducing discussion and student engagement. This feature may have been a characteristic of this particular group of students, who had been used to a project-based environment; but indications are that a balance should be sought between the qualitative and quantitative dimensions of the proposed problems.

The type of problems in which students are asked to review a given solution (PC, in Figure 1), seemed to prompt interesting and useful discussions, generating insight into the conceptual framework, with the further advantage of increasing students' awareness of the way they present their own resolved thinking. On the other hand, students sometimes showed a high level of suspicion, as if expecting that every detail of the problem resolution they had to review incorporated a *"trap"*. This may be another expression of the emotional insecurity earlier described.

Problems in which students were asked to work back from a set of given results (PD, in Figure 1), on the other hand, were very successful in promoting discussion and making students look at the problem from different perspectives. The requirement for different perspectives prompts for the use of high level capabilities and questions students' assumptions, which is at the core of conceptual reasoning. The analysis of the answers to the individual exam problems indicates that these type of problems prompt students to articulate their conceptual framework, even when they cannot reach a satisfactory solution to the problem. In corroboration of this indication, one student said, in his interview: *"It is amazing how, just by turning the perspective upside down, these problems question our assumptions and make us go back to the fundamentals."*

Whenever problems asked students to explore and gain further insight into some aspect of the subject matter and, at the same time, incorporated common student misconceptions in the demand, some degree of confusion was easily (but usefully) established, usually requiring the facilitator's intervention at some point. On the other hand, problems integrating aspects of previously addressed subject matter or material from other courses, seemed to have a very positive impact on the degree of discussion and the articulation of conceptual frameworks. Naturally, problems in which the articulation with the project work was obvious were highly engaging. Articulation with the other components of the thematic module should therefore be favoured in the choice of problems.

6. CONCLUSION

In this article, part of an investigation designed to evaluate the impact of using concept driven problems to promote the learning, concentrating on the important features of those problems, has been presented. The qualitative analysis, which involved content analysis of the students' solutions to the problems, field notes, and extracts of interviews conducted in the context of a larger investigation [14] indicates that:

- Students recognize the fact that the proposed problems forced them to dwell with the underlying conceptual framework;
- The element of emotional insecurity introduced by the fact that every problem, either explores some new concept, or its application, or questions students' assumptions, should be taken into consideration;
- Proper balance of the qualitative and quantitative components should be sought;
- While engaging with the graphical "multiple-choice" problems, students show a tendency to try decoding the options, which may distract them from developing their own line of reasoning;
- The "work back from a solution" kind of problems seem to prompt the explicit articulation of concepts, helping students to develop their own conceptual framework.

In conclusion, the strategy of using these problems as challenges to drive conceptual understanding (in an open written format), rather than just using them for pre/post testing of conceptual understanding, is valuable and should be further explored. The outcome of the strategy proposed in this article is best described by one student's remark, transcribed from his interview: *"It was just impossible to find a common method to address the problems, as we are used to doing in most other courses. We were forced to go back to the basics and discuss our way through, or…just quit".*

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