Applying the 4C-ID Model to the Design of a Digital Educational Resource for Teaching Electric Circuits: Effects on Student Achievement

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ABSTRACT
This paper reports the first results of an experimental research, carried out in a school with students of the basic education, where the instructional model 4C-ID was used for teaching and learning electric circuits.

We describe the principles and features of this model, its suitability for the teaching and learning of complex knowledge and skills, and yet their permeability to develop digital educational resources and learning environments.

We analyze the first results of this research and point out clues to future developments.

Categories and Subject Descriptors
H. [Information systems]: Models and principles – human information processing, software psychology.

General Terms
Performance, Design, Experimentation, Human Factors, Theory.

Keywords
Digital educational resources, Electric circuits, Instructional design & technology, 4C-ID model, Learning environments, Multimedia educational messages.

1. INTRODUCTION
In this paper we present the first results of a research based on the 4C-ID model (Four Components – Instructional Design Model), suitable for complex learning, developed by Merriënboer and colleagues in the early 90s [1]. There are other instructive models but not all have acquired the level of formulism of this one and not all are suitable to learn knowledge and complex skills, as it is most of the learning done at school and professional training.

Moreover, this model is very susceptible to the development of digital educational resources (DER) and multimedia learning environments (MLE) that are increasingly used in education and vocational training.

So, we will consider the design of a digital resource for teaching and learning electric circuits based on this model and the main results achieved with its application to students in the 9th year of schooling, following an experimental research design, held in May 2013.

The innovation of this research is the application of this model in the basic levels of education, since it has been used until now in university education and professional training.

2. THE MODEL BACKGROUND
As refers Anderson [2], a model is an application of a theory to a particular phenomenon. A theory is a precise deductive system, more general than a model. Often theories are grouped into frameworks. A framework is a general set of concepts for understanding a domain, but is not sufficiently organized to constitute a theory; from the same framework we can deduct various predictive theories.

The 4C-ID model was developed based on some general principles of Instructional Design & Technology (ID&T) [3], where we emphasize the influence of the ADDIE model and the work of Robert Gagné [4], [5], [6], and more recent theories, as the cognitive theory of multimedia learning, developed by Richard Mayer et collaborators [7], [8], [9] and the theory of cognitive load, established by John Sweller & colleagues [10], [11], [12]. All these theories can be integrated into the information processing framework, where memory (associated to other cognitive processes) is the basis and the result of the cognitive activity that occurs during learning. All these theories and models can be included in the cognitive framework. There are others two frameworks: the behaviorist and the constructivist frameworks, each of which has given rise to theories and instructional models [3], [13].

As emphasize Wilson, Jonassen, & Cole [14], ID as a discipline rests on the twin foundations of (i) a systems design model for managing the instructional development process [like de ADDIE model] and (ii) theories that specify what high-quality instruction should look like [15] [16].

2.1. The learning tasks
Like others ID models, the 4C-ID gives a great importance to the learning tasks [17]. They are de core of the instructional process, which consists of five steps: Analysis, Design, Development, Implementation and Evaluation – ADDIE [18]. However, the tasks in 4C-ID model are integral and real tasks that the learners
or professionals must performed. This is a major difference of this model when compared to other models that, in most cases, divide the overall learning tasks into subtasks of easier achievement. Most of the ID models use a bottom-up strategy, considering that much of the knowledge and skills are better learned by means of associative processes. It is the case of Programmed Learning by Skinner [19] [20]. Thinking from a simplistic way, it is as if they considered that the whole is merely the sum of the parts.

We know that it is not so [1], [12], [21]. The basic skills training and the development of automatisms are essential to the performance of many activities but these should be part of the task as a whole. We think that some of the transfer problems expressed by students come from the way they were taught [22], and one of these problems lies on the lack of prescription, training and practice (which is often one of the problems of the constructivist models) or the segmentation of tasks proposed by behavioral models [20]. We think that the cognitive approach or framework and its theories and models, mainly the 4C-ID model, combined the best of both worlds.

2.2 The Cognitive Theory of Multimedia Learning

Another source of influence of the 4C-ID model is the cognitive theory of multimedia learning developed by Richard Mayer, which posits that humans learn better from words and images than just words [9] [23] [24]. It is the multimedia principle. However, in order to have a meaningful learning it is necessary that multimedia messages are designed from the way the human mind works, i.e. how it handles this type of information. The theory is based on three assumptions and five cognitive processes, derived from the results of experimental research done in the field of cognitive psychology. The three assumptions are: “the human system information processing included double channels for the processing of visual/pictorial and auditory/verbal (the assumption of double channels) [25]; each one of the channels has a limited processing capacity (i.e., the assumption of limited capacity [of our working memory]) [25] [26]; and the active learning, which involves performing a coordinated set of cognitive processes during that learning (i.e., the assumption of the active processing)” (2009, p. 207) [9]. The five processes are: (i) choice of relevant words in the text or narrative presented, (ii) selection of the relevant images from the illustration showed, (iii) organization of the selected words into a coherent verbal representation, (iv) the organization of the selected images into a coherent pictorial representation, (v) and integration of the verbal and pictorial representations with the previous knowledge.

This theory also assumes that all human knowledge is stored in cognitive schemata, in long-term memory, which has an unlimited capacity. Learning consists of the construction of schemata, “including the formation of new schemata and the embellishment of existing schemata, or to the automation of schemata” (p. 75) [27].

The 4C-ID model proposes, in the development of learning tasks, multimedia educational messages which comply with these assumptions and processes.

Another theory that influenced the 4C-ID model is the cognitive load theory by Sweller [12].

2.3 The Cognitive Load Theory

This theory posits a set of principles that should guide the development of educational multimedia messages. These principles have been tested empirically, following an experimental design, with experimental and control groups, where one factor at a time were tested, i.e., the principle under investigation [12]. There are, until now, fourteen multimedia principles tested that way. For example: ‘The goal-free effect’, ‘The split-attention effect’, ‘The worked example and problem completion effects’, ‘The self-explanation effect’, ‘The modality effect’, ‘The element interactivity effect’, and so one.

Like the cognitive theory of multimedia learning, the cognitive load theory shares the same assumptions about the cognitive human functioning [10] [27], i.e., the ‘assumption of double channels’ and the ‘assumption of limited capacity of the working memory’. Cognitive load theory posits two main types of cognitive load that can be experienced by the cognitive human system during learning: Intrinsic and extraneous cognitive load and ways to reduce these two categories of cognitive load in the instructional materials and processes [12]. This theory has also developed methods for measuring the cognitive workload experienced by learners during the instructional process [12] [28].

3. THE 4C-ID MODEL

As mentioned by Merriënboer & Kester [27] “Well-designed educational programs take both human cognitive architecture and multimedia principles into account to ensure that learners will work in an environment that is goal-effective, efficient, and appealing” (p. 72). The 4C-ID model was conceived to answer to this kind of prescriptions.

The model can be described in terms of four interrelated blueprint components (Fig. 1):

![Figure 1. A schematic overview of the 4C/ID model and its main elements [37].](image-url)
3.1 General research on the Effectiveness of the 4C/ID Model

In two studies, Hoogveld, Paas and Jochems [29][30] research the effectiveness of the 4C/ID model as an instructional system design (ISD) approach to designing competence-based education. In the first study, two groups of teachers were compared: one group was trained to use the 4C/ID model to design instruction and the other was trained to optimize its design approach. After the training phase, the design quality of their educational products was measured by experts, and it was found that teachers trained to use the 4C/ID model developed qualitatively better designs than the other teachers. The second study researched whether teams or individuals benefited more from a 4C/ID approach to designing competence-based education. It was found that low achievers benefited more from the 4C/ID model when they were working in teams, but high achievers worked as well in teams as individually.

Nadolski, Kirschner and van Merrienboer [31] focused on segmenting complex whole learning tasks in the law domain into phases. They varied the number of phases (one, four and nine) of the whole task to determine the optimal balance between the advantages of the whole-task practice and disadvantages of cognitive overload caused by whole tasks that are too complex for learners. They found that learners who carried out the learning tasks in the four phases were most effective during practice as measured by the coherence and content of their learning products. Learners who carried out the learning tasks in one or four phases were more efficient during practice as measured by combination of learning products quality and invested mental effort. No effects were found on the transfer test performance. These authors confirm these results in a follow-up study in 2006 [32], in which learners who received learning tasks that consisted of four phases outperformed learners who received tasks consisting of eight phases. These results indicate that the whole learning tasks should only be segmented if this is the only possible way to diminish their complexity.

Lim and Reiser [33] compared the effects of the 4C/ID whole-task training and part-task training on the acquisition and transfer of a complex cognitive skill for novices and advanced learners. They found that both novices and advanced learners achieved better whole-task performance and better transfer performance if they received the 4C/ID whole-task training.

In others studies Sarfo and Elen [34] compared three groups who had to learn how to design a single building plan based on local conditions. The control group was taught according to an approach that was applied in technical schools in Ghana; the experimental groups were taught according to the 4C/ID approach, either with or without technology-enhanced learning. The groups performed equally well on a pre-test and both showed learning gains on the post-test, both experimental groups outperformed the control group on the post-test.

**Figure 2. The structure of the learning environment.**

4. THE EMPIRICAL STUDY

In this section we will describe the structure of the learning environment used in the context of teaching some concepts of electrical circuits with 14 years old students (mean = 14.31, SD = 0.54), of the 9th grade, from a private school in Lisbon. This training system was implemented in two lessons of 90 minutes each, with one students in each computer.

This application was developed with the Adobe Flash CS3 Professional and is divided into three learning classes, each consisting of a set of learning tasks: 1) learning class 1 is focused on the concepts of electrical current and potential difference. Before start the learning tasks students should observe a video (supportive information) with an explanation of the concepts of electric current direction and potential difference. After students must follow a set of three learning tasks (T1, T2 and T3) corresponding to a solved example (T1), a partially solved exercise (T2) and a whole task to solve without help (T3); 2) learning class 2 is centred in the ability to design an electrical circuit schema. In this learning class the supportive information focuses on symbology used for the construction of electric circuit diagrams. Then the students have to perform a sequence of six learning tasks (T1 … T6) in which they must identify symbols of electronic components. The first three tasks correspond to solved and partially solved examples and exercises; the last three tasks must be solved without help; 3) learning class 3 is related to the concepts of serial and parallel association of lamps. In this learning class the supporting information focuses on the main features of an association in series and in parallel. Learning tasks are organized in worked examples (T1 - T3), partially solved examples (T4 - T6) and practical exercises (T7 - T16).

Performance tasks consist of items of completion and multiple choices. For each performance task there is a system of feedback (corrective and cognitive) requiring students to read the conceptual justifications for all options. The structure of the learning environment is presented in the Fig. 2.
decrease, and the students must performed the last task autonomously without support. The items types that make up the various tasks are: completion, multiple choice and drag and drop.

As an example, we give a brief description of the structure of the class learning 2. The main objective of this learning class is allowing students to learn the symbology of the components that are necessary for a simple electrical circuit representation.

The learning class 2 starts with a task (task 1) that corresponds to a solved example in which the students are asked to click with the mouse over the names of the five components of an electrical circuit (lamp, power supply, switch closed, open switch and electric motor) while the respective symbol shows up. In task 2 (partially solved example) the same symbols are given, however the application only show the names of the first two, making the student opt between three sequences that correspond to the names of the remaining components. In task 3, students have to complete the task 1 without assistance. The remaining tasks correspond to practical exercises in which students must identify the names or symbols of the five components of a simple electrical circuit in a circuit schema. During resolution of all tasks students have always the possibility to access to the supportive information. Whatever the choice made by the student, the application always gives feedback on the selected answer. Thus, the student cannot pass to the next task without reading information contained in the feedback.

4.1 Methodology

4.1.1 Participants
The study of the efficiency of the learning environment design with the 4C/ID principles was done through the ability of the students to reproduce the knowledge acquired during the learning tasks about electric circuits and the ability to transfer this knowledge to similar tasks. The distribution of classes by teachers was taken as follows: teacher A teaches one class in the experimental group and the teachers B and C teach one class in the experimental group and one class in the control group each.

Two groups were constituted:
- An experimental group, with three intact classes (n = 81), in which the contents were taught solely based on digital learning environment in which students performed learning tasks, under the supervision of three teachers;
- A control group, composed by two intact classes (n = 50) were recorded, in which the contents were taught with a conventional expository strategy centred on the teacher, performing learning tasks previously selected from the manual adopted in school, under the supervision of two teachers.

Each class was randomly assigned.

4.1.2 Independent variable
For both groups, learners received an overview of the lessons from their teachers, which includes 1) purpose of the lessons, 2) conceptual overview of concepts related to the theme. Learners in each group, however, received two different instructional approaches to the theme “Electrical Circuits”:

a) In the experimental group the theme "electric circuits" was approached with the sole source application designed on the model 4C/ID;

b) In the control group, the same topic was addressed using a conventional teaching methodology.

4.1.3 Dependent variables
Data was collected from the following sources:
(a) Student scores on the two achievement tests;
(b) Student ratings of perceived cognitive load on the two achievement tests.

4.1.4 Performance
Two tests for assessing the efficiency of the learning environment were designed:
- A knowledge multiple-choice test that consists of 14 items that resembles the work done on the different learning class tasks (each correct answer is 1 point and each wrong answer is 0 points), which was applied to the two groups (experimental and control);
- A transfer multiple-choice test, consisting of 14 items, which appealed to the application of acquired knowledge to new tasks (each correct answer is 1 point and each wrong answer is 0 points), which was applied to the two groups (experimental and control).

4.1.5 Cognitive load
Perceived cognitive load was measured using a single self-rating scale developed by Paas and van Merriënboer [35]. Studies have shown that this scale is sensitive to relatively small differences in cognitive load and that it is valid, reliable, and unobtrusive. The participants (both experimental and control groups) were asked to use a nine-point Likert scale to identify the amount of mental effort they invested to perform the assigned tasks. The cognitive load measures ranged from 1 (very low mental effort) to 9 (very high mental effort). The rating-scale was administered after the learner completed each of the two achievement tests.

4.1.6 Instructional efficiency
Cognitive load theorists have developed a formula for determining “instructional efficiency”. This is a relative measure that uses (most often) two variables, standardized measures of learner effort (often self-reported on a Likert scale, either during the training phase or the testing phase) and performance. The difference between these two values results in either a positive or negative number, ranging from -1 to +1. Often, this quantity is divided by the root of 2 so that it might be plotted.

\[ E = \frac{Z_{\text{performance}} - Z_{\text{mental effort}}}{\sqrt{2}} \]

\(Z_{\text{performance}}\) is the performance z score, and \(Z_{\text{mental effort}}\) is the effort rating scale z score. Using this formula:
- if performance and rating z scores are equal, the efficiency is 0 (E = 0);
- if the performance z score is higher than the effort rating z score, the instructional efficiency is positive (E > 0);
- if the performance z score is lower than the effort rating z score, the instructional efficiency is negative (E < 0).

These z scores can be displayed and represented in a graph where z performance as the ordinate and z mental effort is the abscissa. Shifts to the upper left of the co-ordinate system indicate an
increase in efficiency (higher performance in relation to less invested mental effort) and shifts to the lower right indicate a decrease in efficiency (lower performance in relation to more invested mental effort). This approach to measure instructional efficiency was adopted in this research.

4.2 Results

4.2.1 Performance
Performance was measured on the two tests. For the first test (reproduction test), learners of the experimental group had a mean score of 12.19 (SD = 1.58), whereas the control group had a mean score of 11.41 (SD = 2.13). For the second test (transfer test), experimental group had a mean score of 11.18 (SD = 1.88), whereas control group had a mean score of 8.77 (SD = 2.64).

4.2.2 Cognitive load
The measures of mental effort were made during the reproduction and transfer tests. The average values obtained for these measurements are shown in table 1.

Table 1. Mental effort mean scores and standard deviations.

<table>
<thead>
<tr>
<th></th>
<th>Reproduction test</th>
<th>Transfer test</th>
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<tbody>
<tr>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Experimental group</td>
<td>2.77</td>
<td>0.73</td>
</tr>
<tr>
<td>Control group</td>
<td>2.92</td>
<td>1.21</td>
</tr>
</tbody>
</table>

4.2.3 Instructional efficiency
Table 2 represents the results obtained for the instructional efficiency for the experimental group and the control group, on the reproduction and transfer tests, respectively. See also Fig. 3 and Fig. 4.

Table 2. Instructional efficiency mean scores and standard deviations.

<table>
<thead>
<tr>
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<th>Reproduction test</th>
<th>Transfer test</th>
</tr>
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<tbody>
<tr>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Experimental group</td>
<td>1.95</td>
<td>1.36</td>
</tr>
<tr>
<td>Control group</td>
<td>0.028</td>
<td>1.09</td>
</tr>
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</table>

5. GENERAL DISCUSSION AND CONCLUSION

This study aimed to explore the effectiveness of a 4C/ID learning environment (with ICT) in terms of reproduction and transfer of learning.

The results of the experiment support the hypothesis that a 4C/ID learning environment contributed more positively to learning concepts related to theme “Electric Circuits” compared to a learning environment based on a conventional method. The results indicate that, relative to the control group, the experimental group was more capable to do learning transfer in the context of the Electric Circuits theme.

This result is consistent with the findings [36] [37] that a 4C/ID learning environment facilitates complex learning or, in other words, demonstrates the effectiveness of 4C/ID-model, and increases its generalizability.
The result contributes to an understanding of the effectiveness of the 4C/ID model in regard to the acquisition of integrated sets of knowledge and skills. More specifically, in this study, what promoted better performance of the experimental groups can be explained by referring to some essential ingredients in 4C/ID learning environments that were absent in the regular method of teaching. The active ingredients included the learning tasks, the instructional strategies (such as guided discovery, modeling examples and cognitive feedback) and the gradual withdrawal of support.

Learners in the experimental group were better able than the control group learners to transfer the skills they learned to a new situation, in this case with some concepts related to electric circuits. This result may be due to the fact that the 4C/ID instructional approach put an emphasis on promoting learners’ schema construction for non-recurrent aspects of a complex skill, that is, those constituent skills that are performed differently from one problem situation to another. For example, the experimental group was placed to select the appropriate electric circuit according to predefined objective (e.g., series or parallel). This skill was assessed on the transfer test, and learners in the 4C/ID approach performed the skill significantly better than did learners in the conventional approach.

The superior transfer performance of the experimental group may also be due to the fact that the 4C/ID approach varied the contexts in which the various tasks had to be performed, one of the most critical aspects for enhancing transfer of learning. In the present study learners in the 4C/ID condition were presented with problems scenarios in which they had to apply what they learned to different context. Perhaps as a result of solving these various whole-task problems, learners were able to develop rich schemata that facilitated transfer of the skills they were taught. This notion is supported by previous research, where variability in the types of practice problems learners received, was identified as a likely reason for their superior transfer test performance.

In recent years, much has been written about the potential value of employing 4C/ID instructional approach, but little research has been conducted in this area. The present study provides support for the notion that this model may facilitate skill acquisition and transfer. However, a great deal of additional research is necessary in order to determine whether these promising findings hold true across a wide range of cognitive skills and learners. We believe that researchers, who build upon the present study, following the suggestions we have offered, will help provide a richer picture of the benefits of the 4C/ID.

The research results presented in this article correspond to a preliminary treatment of all data collected and processed. In the next phase we will make a treatment of inferential statistics and estimate the effect size of the results obtained by the subjects of the two groups. Another aspect that we still treat relates to the analysis of qualitative data we collected (interviews with teachers and students and classroom observation) that will give us information about students’ learning process, in particular about the types of mental schemes acquired by the students.

6. REFERENCES


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