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IS A CONCEPT MAPPING WITH ERRORS USEFUL FOR EVALUATING LEARNING OUTCOMES? A STUDY ON DECLARATIVE KNOWLEDGE AND READING STRATEGIES USING EYE-TRACKING

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Abstract. Concept maps (Cmaps) can be used as an assessment tool because they highlight the structure of declarative knowledge of students in specific contents. In this paper, we propose to use a Cmap about concept mapping and learning theories with conceptual errors as assessment tool and explore the effects of declarative knowledge (DK) and reading strategies (RS) in this process. Eye-tracking measurements were made during the Cmap reading with 29 graduated students. Fixation count, observation count, fixation length and observation length for Areas of Interest (AOI), defined according to both conceptual errors and content, were recorded during the reading of Cmap with errors (experimental group, EG) or without errors (control group, CG). The results indicated (1) a marginally significant effect of RS, indicating that all students (CG and EG) explored the Cmap approximately in the same way and (2) a main effect of DK, wherein the students with High DK pointed more conceptual errors in EG and less in CG with greater precision compared to Low DK.
Keywords: Assessment, Concept map, Declarative Knowledge, Eye-tracking, Reading Strategies.

1 Introduction

Learning involves much more than the ability to recall information, facts, and names. It requires engagement in a personal process of meaning making (Novak, 2010). The process of knowledge acquisition implies an intentional action in order to create meaning between the existing declarative knowledge and the novel information. Meaningful learning occurs when the learner is able to apply the new modified information in their cognitive structure in different contexts in which learning occurred, even after a long period (Ausubel, 2000). To foster meaningful learning and minimize common-sense ideas about complex issues, teachers should recognize the importance of instruction and assessment planning. Among several strategies adopted to evaluate students' learning outcomes, concept maps (Cmaps) appear as an interesting alternative (Henno & Reiska, 2008; Kinchin, Hay & Adams, 2000; Schmid & Telaro, 1990). Cmaps are useful graphical organizers for identifying explicit conceptual relationships through propositions (initial concept + linking phrase + final concept). Concepts are embedded into a propositional network that allows processing information using text (semantic content) and images (visuospatial organization). For this reason, Cmaps may be useful for organizing instructional materials (Salmerón et al., 2009).

The proposition is the basic unit of meaning in Cmap, and it may be conceptually correct or incorrect (Novak, 2002). For example, the proposition *Non-learning − is the opposite of → Meaningful Learning* presents a misconception. Non-learning is characterized by a previous structure knowledge that remains unchanged, where the learner only repeats what he/she knew before (Hay, 2007). The opposite of non-learning is the occurrence of a learning situation, *i.e.*, where changes of knowledge structure occur. However, the degree of integration between the new concepts and parts of theirs declarative knowledge might lead to rote (concepts superficially integrated) or meaningful learning (concepts deeply integrated).

Assuming that knowledge of a specific content (*e.g.,* Ausubel Assimilation Theory) is organized around central concepts and that meaningful learning requires a highly integrated structure between these concepts, the Cmap appears to be a potential tool for explaining and assessing students' knowledge (Ruiz-Primo & Shavelson, 1996). In general, Cmaps show the structure of declarative knowledge (facts, definitions, descriptions, concepts) and provide the feedback from the teaching-learning process to both teacher and learner (Shavelson, Ruiz-Primo & Wiley, 2005). Although Cmaps are being used as an assessment tool, the most common tasks usually revolve around the preparation of Cmap by the student. In this paper, we propose the use of concept mapping with conceptual errors as assessment tool and explore the effects of declarative knowledge (DK) and reading strategies (RS) in this process. We hypothesized that not only the DK, but also the RS will interfere with the appointment of conceptual errors during the Cmap reading.

2 Method

2.1 Participants and Materials

Fourteen graduate students enrolled in the *EDM5103 Collaborative Learning and Concept Mapping: Fundamentals, challenges and perspectives* course offered at the University of São Paulo took part in this study (mean age = 30.1, *SD* = 6.0). The content was divided into 3 parts (Figure 1), and each class had 2 hours of theoretical discussions plus 1 hour of practical Cmap activity. The data collection occurred during classes 7-8 about 1 month after the Test 1 (class 5) and involved the identification of conceptual errors in a Cmap about 'concept mapping and meaningful learning' (topic of the Part I). Table 1 shows the selected readings and the main discussions covered during classes 1-5.

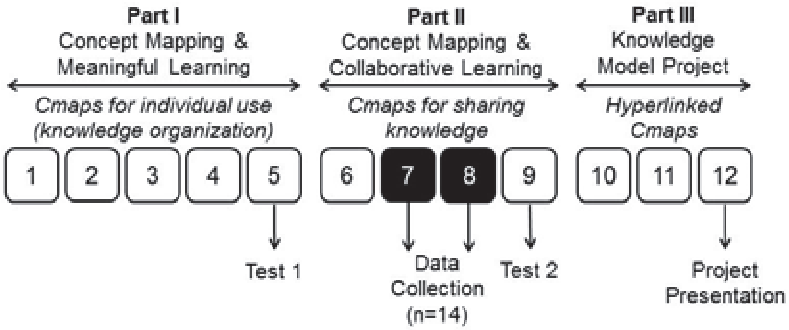

Figure 1. General organization of the EDM5103 Collaborative Learning and Concept Mapping course.

Table 1. Selected readings and main content considered in this study (Part I of the EDM5103 course).

Class	Preparatory Readings	Summary of contents
1	Kinchin, Lygo-Baker & Hay (2008)	• Scholarship of teaching • Concept mapping to visualize knowledge structures • Types of knowledge structures: spoke, chain, and net • Learning as a changing process • Pedagogic resonance as mediation supported by Cmaps
2	Novak (2010), Chapters 2 & 3	• Ausubel's Assimilation Theory • Rote and Meaningful learning: processes and requirements • Novak's Theory of Education • Five elements in educational events • Empowerment as a key element of the human constructivist view of teaching and learning
3	Hay (2007)	• Learning assessment • Deep/surface learning compared to meaningful/rote learning • Knowledge structures changing throughout the learning process • Threshold concepts as learning obstacles
4	Novak (2002)	• Conceptual errors during the meaningful learning • Limited or Inappropriate Propositional Hierarchies (LIPH's) • Situated learning • Concept maps as a metacognitive tool • Self-regulation of learning as an empowering road to lifelong learning
5	-	Test one: Cmap elaboration (individual activity)

2.1.1 Declarative knowledge test

Declarative knowledge was assessed by a 31-statement questionnaire about the course content presented in Table 1. The items were measured on a 4-point Likert scale ranging from completely agree (4) to completely disagree (1). The zero value ('I do not know the answer') was included to prevent random responses. The questionnaire was validated (Cronbach's alpha = .702). Some examples of statements used in the questionnaire are presented below.

- *Concept maps allow differentiating superficial learning from deep learning. (Correct)*
- *The choice of meaningful learning must be made by the student. (Correct)*
- *Situated learning is desirable and is related to meaningful learning. (Wrong)*

- *Radial structures of knowledge reflect clarity of purpose and strategic thinking aimed at a goal. (Wrong)*

2.1.2 Digital Cmaps

The researchers prepared two digital Cmaps containing 45 concepts about ‘concept mapping and meaningful learning’. One version has no conceptual errors (Cmap I, Figure 2) and the other contains some specific modifications to include 12 conceptual errors (Cmap II, see the errors in Table 2). These changes were made considering the students’ knowledge of the topic, which was assessed by Test 1 (class 5). The initial concept (‘Novak’) was highlighted, and the propositions were numbered to offer a navigation aid to the students.

Table 2. Digital concept map features used as reading material. The Cmap were divided into 8 main topics with different level of difficulty. To prepare the Cmap II (with errors), we change 12 propositions of Cmap I (Figure 2).

Main topic (identification)	Level of difficulty	Propositions number	Propositions with conceptual error (Cmap II)
Novak (NO)	Easy	1-6, 16-20, 34	3: Educational Situations − are equally understood by → Learner/Teacher 6: Situated learning − is desirable → in Educational Situations 16: Teacher − is the only one responsible for raising the → Previous Knowledge
Knowledge structure (KS)	Intermediate	7-11, 14-15	14: Teacher − will never present → Spoke Structure
Threshold concepts (TC)	Difficult	12-13	-
Ausubel (AU)	Easy	21-29, 33	22: Rote Learning (superficial) − is synonym of → Non-learning 23: Non-learning − is the opposite of → Meaningful Learning (deep) 25: Rote Learning (superficial)/ Meaningful Learning (deep) − explain the learning as a *continnum* between the → Ausubel Theory 26: Rote Learning (superficial) − must be avoided in → Education 29: Previous Knowledge/Novel Information − are retained in → Short-term Memory
LIPHs (LI)	Intermediate	30-32	30: Meaningful Learning (deep) − implies in learning without → Misconceptions 31: Meaningful Learning (deep) − always change → LIPHs
Concept mapping (CM)	Easy	35-39	-
Pedagogic resonance (PR)	Difficult	40-41	-
Metacognition (MT)	Difficult	42-45	42: Metacognition − is synonym of → Metalearning

2.1.3 Eye-tracking measurements

A VT2-Mini eye-tracking portable device (EyeTech, USA) and MangoldVision software (Mangold, Germany) were used to record the eye movements. Fixation count (FC), observation count (OC), fixation length (FL) and observation length (OL) was measured when students read the digital Cmap. These variables are recorded for specific ‘Areas of Interest’ (AOI) predefined by the researcher (Figure 3). In the case of this study, we defined two kinds of AOI:

- By content: 8 areas (main topics in Table 2);
- By error: 12 areas (propositions with conceptual errors in Table 2).

Eye movements reflect cognitive processes, especially visual attention during the reading (Rayner, 1977). For example, if the learner stays focused on one AOI they will probably present high FL and low OC.

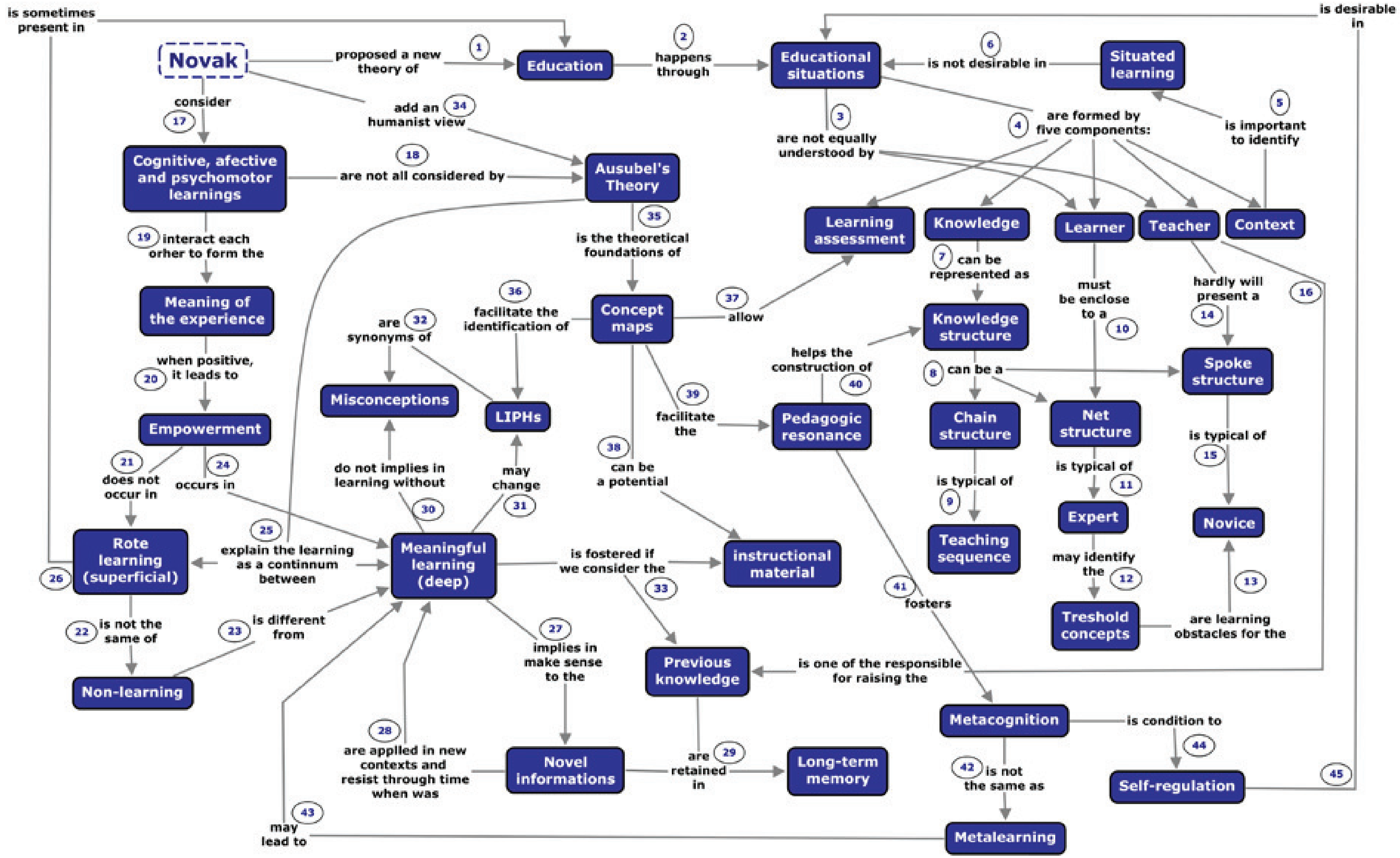

Figure 2. Cmap I (with no errors) used with the control group. Twelve propositions (see Table 2) are changed in order to add conceptual errors (Cmap II used with experimental group). All participants received the following instructions on the computer screen: "You will read a Cmap about classes 1-4 that may have conceptual errors. Please read this Cmap and identify all errors you may find using the number of the proposition".

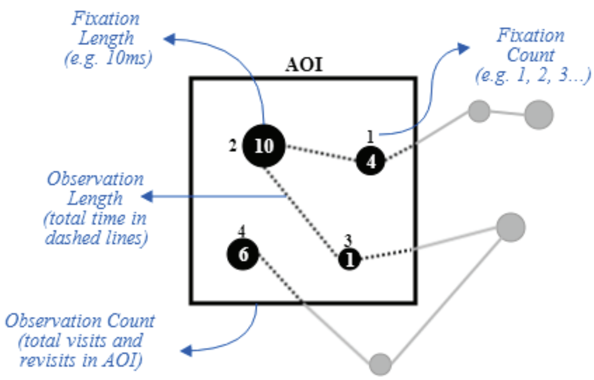

Figure 3. Eye-tracking measurements, recorded for each AOI, when students read the Cmaps I and II.

2.2 Experimental design and Procedures

The declarative domain knowledge test was conducted in class 5. A 2x2 experimental design was conducted considering the following variables: declarative knowledge (High, HDK and Low, LDK) and Cmap correctness (no errors - Cmap I/Control Group - CG and with errors - Cmap II/Experimental Group - EG). The data collection was carried out in the following order: eye movement recognition and calibration, participant identification (name and age), Cmap reading and identification of conceptual errors (eye-tracking recording). There was no time limit to complete tasks. All participants consented with the research. The specific instructions during the task are provided in the caption of Figure 2.

2.3 Data Analysis

The overall score on the questionnaire was standardized on a 0-10 scale, and the mean values were calculated for each student. The questionnaire was analyzed to (i) detect the main conceptual difficulties about the course contents (Table 1) and (ii) classify students according to their level of declarative knowledge (DK). Hierarchical Cluster Analysis (HCA) was used for (i) and Student's t-test was used for (ii).

Cmap I and II propositions were classified according to their conceptual level of difficulty (Table 2). Students received the following scores when they found a conceptual error in the Cmap: +1 (easy content), +2 (intermediate content), and +3 (difficult content). Students scored negative points when they found a conceptual error that did not exist: -3 (easy content), -2 (intermediate content), and -1 (difficult content). The sum produced a final score for each student.

Due to the small sample size, Kolgomorov-Smirnov normality test with Lilliefors correction was conducted for all eye tracking metrics. Parametric Student *t*-test or non-parametric U-Mann-Whitney pairwise comparison was conducted between HDK and LDK, EG and CG considering the ratio of eye-tracking measurements (i.e. count or length in a specific AOI divided by the total count or length in all Cmap). All statistical analyses were conducted using SPSS 22.0 (IBM, USA).

3 Results

3.1 Student's declarative knowledge

Ward's method HCA grouped students according to their answers to the questionnaire into four clusters (A-D, 66% of similarity). Table 3 summarizes the main features that characterize each cluster and reveals the patterns found by HCA.

Table 3. Main features of each cluster (A-D) considering student level of understanding (score) and topic involved.

Cluster	Prevalent student score	Topic of the clustered statements	AOI in the Cmaps I-II
A	0 (Don't answer)	MT	MT
B	2 (Many conceptual errors)	PR, TC	PR, TC
C	3 (Few conceptual errors)	KS, LI	KS, LI
D	4 (Full understanding)	AU, NO, CM	AU, NO, CM

The questionnaire score analysis confirmed a statistically significant difference between HDK (n=8, *M*=6.7, *SD*=.6) and LDK (n=6, *M*=4.2, *SD*=1.1), $t(13)=5.23$.

3.2 Eye-tracking measurements and reading strategies

The presence of conceptual errors during the Cmap reading revealed some differences between students in CG (Cmap I, no errors) and EG (Cmap II, with errors). The count (FC and OC) for proposition 3 (*educational situation – are equally understood by → learner/teacher*) were statistically higher for students in EG (t_{FC3} = 2.04, p<.025 and t_{OC3} = 1.78, p<.05). The presence of misconception in proposition 6 (*situated learning – is desirable in → educational situations*), also indicated a higher FC and OL for EG group (t_{FC6} = 3.01, p<.001 and t_{OC6} = 3.36, p<.001). Considering the AOI predefined by content, the EG group also demonstrated higher OC for 'Novak' AOI ($t_{OC\text{-}NO}$ = 2.37, p<.025) and OL for 'LIPHs' AOI ($t_{OL\text{-}LI}$ = 3.12, p<.001). On the other hand, the CG presented higher FC and OL for 'Ausubel' and 'Threshold concepts' AOIs, respectively ($t_{FC\text{-}AU}$ = -2.42, p<.025 and $t_{OL\text{-}TC}$ = -3.42, p<.001). There was no statistical differences between EG and CG for the other AOIs.

The declarative knowledge (DK) also interfered with how the students read the Cmap. HDK students had higher FC in proposition 14 (*teacher – never will present a → spoke structure*) and low OL for proposition 16 (*teacher – is the only responsible for raise the → previous knowledge*) in comparison to LDK (t_{FC14} = 2.28 p<.025 and t_{OL16} = -2.04, p<.001). LDK presented higher values for FC in 'Concept Map' AOI ($t_{FC\text{-}CM}$ = -1.98, p<.05) and for total length of reading at the three difficult areas: 'Metacognition', 'Pedagogic resonance' and 'Threshold concepts' ($t_{TL\text{-}MT}$ = -1.98 p<.05, $t_{TL\text{-}RP}$ = -2.68, p<.001, $t_{TL\text{-}TC}$ = -2.17, p<.025). The results revealed no statistical differences between EG and CG for the other AOIs, considering conceptual errors and content.

3.3 Conceptual errors identification

Figure 4 summarizes the scores for each student who participated in this study. HDK students (black bars) in experimental condition had positive and greater scores (Cmap II, with errors), indicating that they found the most errors we added to this Cmap. On the other hand, LDK students (grey bars) not only scored lower, but some of them also obtained negative scores (see participants #5 and #7). They did not found the errors that we added to the Cmap, and they indicated propositions with correct conceptual meanings as errors. The same pattern was observed for control condition (Cmap I, no errors). In this case, all the scores must be negative, once an error appointment is always a misjudgment. While LDK students had higher negative scores, HDK students had negative scores that did not exceed -6.

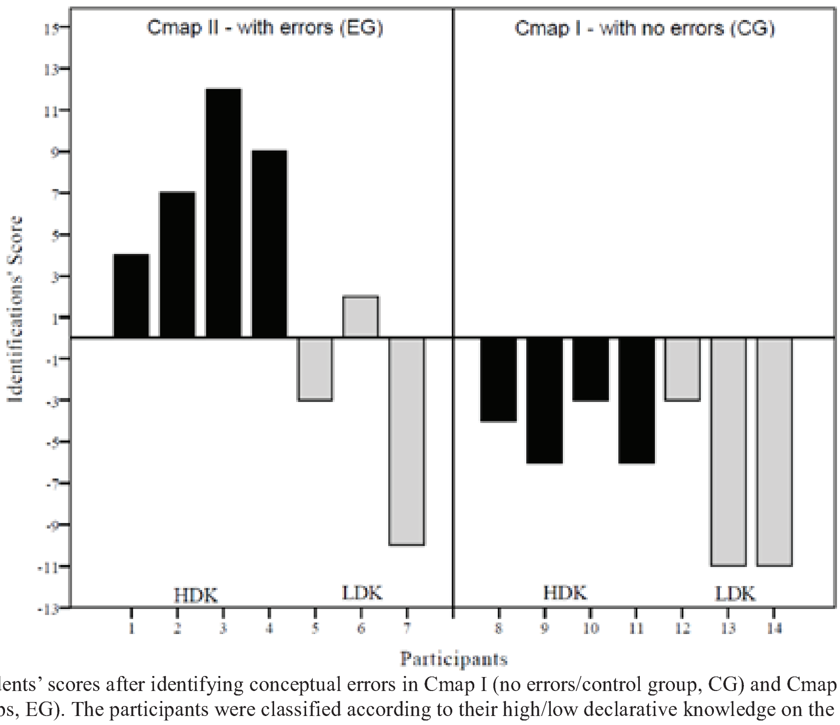

Figure 4. Students' scores after identifying conceptual errors in Cmap I (no errors/control group, CG) and Cmap II (with errors, experimental groups, EG). The participants were classified according to their high/low declarative knowledge on the topic (HDK/LDK).

4 Discussion

In this study, we proposed the use of Cmap with conceptual errors as evaluation tool. The contents of the proposed Cmap were classified according to their level of difficulty. Conceptual errors were added to it by considering easy, intermediate and difficult pieces of content. The learning evaluation using the error identification in Cmap was compared with the multiple-choice questionnaire that was used to measure the declarative knowledge of the students. No literature has been done on this kind of evaluation; however, applying pre-test, like the declarative knowledge questionnaire, is very common, especially in Social Sciences.

HCA showed the same pattern of results for both evaluations (Cmaps and questionnaire). The similarity among the questionnaire statements revealed: (1) the same pattern that was intentionally added as conceptual errors in Cmap and (2) the level of difficulty classified for Cmap contents. These results highlight the importance of a well-planned instructional design when proposing Cmap with conceptual errors as assessment tool. The level of complexity imposed by the content could not be too overwhelming for the students; otherwise, the cognitive demand imposed by searching and identifying conceptual errors would not have been achieved.

4.1 Effects of adding errors and declarative knowledge in students reading strategies

The possibility of reading a Cmap in different ways and the need to establish the reading sequence generates an additional cognitive demand that may compromise learning outcomes. In order to explore the effect of reading strategies (RS) during information seeking task we recorded the eye movements in AOI by content and conceptual errors. The main result revealed a slight difference between the experimental conditions. For most of the AOI, the addition of conceptual errors somehow affected the students interaction with the Cmap.

After adding errors in propositions 3 (*educational situation – are equally understood by → learner/teacher*) and 6 (*situated learning – is desirable in → educational situations*), students spent more time on these AOIs. Both propositions referred to 'educational situations,' and they were considered as easy issues. Apparently, the presence or absence of error stimulates different RS in Cmap contents. While EG focused and looked more often for areas related to 'Novak' and 'LIPHs', the CG paid attention to different contents, such as 'Ausubel' and 'Threshold Concepts'. One possible explanation for this pattern is that 'Novak' and 'LIPHs' together had the most errors present in the Cmap read by EG (five). If we removed these errors and provided all corrected propositions, 'Ausubel' and 'Threshold Concepts' areas would be the easiest and troublesome contents, respectively, increasing the attention of CG. This result indicated the magnitude of being aware of possible errors during the Cmap elaboration.

Declarative domain knowledge (DK) supplies cognitive resources to process the non-linearity of information seeking task. As result, the students with HDK should have diverse RS for the same experimental conditions compared to LDK. However, for most of the AOI, the level of DK did not affect how the learners read the Cmap. The level of DK lead to a different information processing only of propositions 14 and 16. Both were added as conceptual errors in EG, and they were related to 'teacher'. Proposition 16 (*teacher – is the only responsible for raising the → previous knowledge*) is trivial and very simple, which made HDK students spend less time processing it compared to LDK. On the other hand, proposition 14 (*teacher – never will present a → spoke structure*) is nearby to a sophisticated error, which took the HDK students longer to look for it. Besides that, the students with LDK look more often for a central area 'Cmap', and spent twice of the time fixed on the three most difficult Cmap AOIs (with or without error). This indicates that despite it being a difficult content to process, LDK required a greater cognitive effort into it.

4.2 The use of Cmap with conceptual errors as evaluation tool

The main results show that HDK students perform better on conceptual errors appointments not only when presented with Cmap with errors (EG) but also without them (CG). In the case of EG, positive global scores indicate that HDK learners pointed correctly the errors presented in most of the areas. A close look at this data shows that most students with HDK had minor false negative appointments (*i.e.,* proposition that are correct but pointed as wrong). In contrast, the LDK not only missed the wrong propositions, but also scored higher on false negative appointments. The results were close to zero or negative scores for these learners.

In the case of CG (only correct propositions), we expected scores near/below zero once all the appointments were penalized. The more negative values, the more wrong appointments the students would have done. The obvious explanations for that is the lack of content understanding. A close look at this data revealed that HDK students often have doubts not only about difficult issues, such as metacognition and pedagogic resonance, but also about propositions that appear to be not totally understood for this group. For example, all HDK students pointed an error in proposition 35, justifying that Novak's Educational Theory rather than Ausubel's Learning Theory is the theoretical foundation of Cmaps. Despite being an easy task, we believe that this kind of confusion is only possible when you fully understand both theories and perceive that in several points, they are similar. On the other hand, the LDK had high negative values, indicating that the Cmap errors appointment supports the questionnaire results.

Apparently, there is potentiality in presenting Cmap with or without conceptual errors as an evaluation tool. We found greater gap between the levels of DK when the students had to seek wrong propositions that were there (Cmap II with errors). It seemed that not founding an error (because they do not exist; Cmap I with no errors) was somewhat discouraging. In some cases, especially among HDK in CG, the students continuously searched for an error even when they did not found one. They completed the task when they found a proposition about which they have doubts, although it was not necessarily wrong. For this reason, we believe that presenting a well-thought Cmap with conceptual errors intentionally is much more effective in assessing the learners' declarative knowledge.

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