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Neighbourhood Analysis to Foster Meaningful Learning Using Concept Mapping in Science Education[✧]

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ABSTRACT: One critical aspect that hinders the systematic use of concept mapping in everyday classrooms is the difficulty of providing high-quality feedback to students so as to keep improving and revising their concept maps (Cmaps). The development of an innovative way to analyse, at a glance, students' Cmaps is presented to allow a diagnostic assessment of student conceptual learning. This paper proposes Neighbourhood Analysis (NeAn) as an innovative way to foster meaningful learning through the identification of Limited or Inappropriate Propositional Hierarchies (LIPHs) in Cmaps. The instructional strategy that underlies NeAn involves the selection of a compulsory concept (CC), which must be a threshold concept addressing the Cmap's focal question. The goal is to estimate students' understanding of the subject, in order to detect the presence (or absence) of LIPHs. We analysed 69 Cmaps from a higher education setting and found that 175 propositions were related to the CC. This subset of all propositions was enough for instructors to provide specific high-quality feedback to their students, even under normal teaching conditions. NeAn is a straightforward way to identify LIPHs allowing instructors to make diagnostic assessments of students' conceptual outcomes during the learning process, and to track the effects of their instructional options. NeAn can be meaningfully applied for assessing science students at secondary level and above, with special potential applicability across science subjects.

KEY WORDS: climate change, concept mapping, diagnostic assessment, meaningful learning, misconceptions

INTRODUCTION

Concept mapping is a well-known technique used to graphically represent aspects of individuals' mental models (Novak, 2010). Concept maps (Cmaps) are formed by embedding a set of concepts into a propositional network. Each proposition is formed using two concepts, which are linked by an arrow to indicate the reading direction (initial concept – linking phrase → final concept). A clear explanation of the relationship between

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these concepts must be added above or below the arrow to let the reader identify the precise understanding of the concepts held by the map-maker. The inclusion of linking phrases to clarify conceptual relationships makes Cmaps more powerful than other graphical techniques used to represent knowledge and information (Davies, 2011). Additionally, because our short-term memory can process textual and graphical information simultaneously (Paivio, 1990; Sweller, Ayres & Kalyuga, 2011), Cmaps are accessible even to first-time users. The process of making learning visible using Cmaps is therefore valuable in guiding the instructional process and assessing student conceptual outcomes (Kinchin, Hay & Adams, 2000; Hay, 2007; Hay, Kinchin & Lygo-Baker, 2008; Hay, Wells & Kinchin, 2008; Ingeç, 2009; Jaber & BouJaoude, 2012). Cmaps also makes visible the pedagogic resonance, i.e. the degree of mismatch between teacher's expert knowledge and students' learning. Therefore, students' Cmaps are suitable for collaborative discussions and reflections within the specific context of a course, providing an interesting documentation of the teaching-learning process (Kinchin, Lygo-Baker & Hay, 2008).

Since 1990, when the Journal of Research in Science Teaching published a special issue on concept mapping (see, Novak, 1990; Wallace & Mintzes, 1990;Wandersee, 1990), several reports in the literature have confirmed the usefulness of concept mapping in science education (Markham, Mintzes & Jones, 1994; Markow & Lonning, 1998; Rye & Rubba, 1998; Laight, 2004; Van Zele, Lenaerts & Wieme, 2004; Vassilis, Marida & Vassiliki, 2007; Oliver, 2009; Conradty & Bogner, 2010; Gerstner & Bogner, 2010; Schaal, Bogner & Raimund, 2010; Correia, 2012). Assessment and the development of score systems for Cmaps have deserved special attention due to the critical role of the feedback provided by the instructor to keep students continuously revising and improving their own Cmaps (Ruiz-Primo & Shavelson, 1996; Rice, Ryan & Samson, 1998; McClure, Sonak & Suen, 1999; Ruiz-Primo et al., 2001). However, a fast procedure to allow the diagnostic assessment of students' conceptual knowledge from their Cmaps is still necessary to take full advantage of concept mapping, mainly under normal teaching conditions. We believe there is a methodological gap that has not been addressed adequately to develop new strategies to use Cmaps in classrooms. As pointed out by Mayer (2010), there is an emergent science of instruction that can help us to devise innovative teaching strategies from a research-based theory. This paper is an attempt to fill this gap and to leverage the current experiences with Cmaps for students and instructors from an informed perspective about concept mapping, instruction and learning processes. In our opinion, this methodological gap complements the teaching ecology discussed by Kinchin (2001), which can be understood as a set of conditions to favour the effective use of Cmaps in the classroom.

New concepts are integrated into our cognitive structures to greater or lesser degrees depending on the cognitive effort that we expend in seeking meaningful relationships between concepts. Methods for relating new concepts and propositions to our existing cognitive structures fall along a continuum between the two extremes of meaningful learning and rote learning (Ausubel, 2000; Mayer, 2002). The former only occurs when conceptual relationships are established in a non-arbitrary and non-literal way, which requires more effort in order to relate prior knowledge to new information. On the other hand, rote learning occurs when these relationships are established in an arbitrary and literal way, skipping the intentional use of prior knowledge to make sense of the new information (Ausubel, 2000; Novak, 2010). There are 3 critical conditions to support meaningful learning:

- the identification of students' prior knowledge,
- the selection of instructional materials that are potentially meaningful to the students, and
- the students' option to learn meaningfully.

Meaningful learning depends on the idiosyncrasies of each person (*e.g.,* prior knowledge, experiences, self-efficacy, values, and control beliefs), the instructional strategies used, and learners' intrinsic desire to make meaning (Pintrich, Marx & Boyle, 1993; Ausubel, 2000; Novak, 2010). Moreover, meaningful learning does not imply the absence of conceptual mistakes. Rather, the literature refers to examples of such mistakes using misconceptions, alternative conceptions, naive notions, and pre-scientific notions. Novak (2002) has proposed the term Limited or Inappropriate Propositional Structures (LIPHs) to refer to these kinds of conceptual errors. The identification of LIPHs in Cmaps is straightforward, as the lack of semantic clarity of some propositions indicates the presence of mistakes. Frequently, poorly chosen linking phrases limit the accuracy of messages embedded in the propositional network. Novak (2002) suggests LIPHs as suitable starting point for professors to foster meaningful learning and intentionally plan further instructional activities.

LIPHs can be the result of meaningful learning and changing them is therefore a difficult task, in which students gradually revise the relevant structures of their own knowledge and build up new propositions over time. For instance, they must create new meanings from the comments made by the instructor in order to revise the Cmap under evaluation. If students choose to use rote rather than meaningful learning to overcome their LIPHs, the knowledge involved will not be easily applied in different contexts. This knowledge usefulness will be limited in time and restricted to the context used during the learning process (Novak, 2002). One educational challenge posed by this approach is convincing students to choose meaningful rather than rote learning. High-quality instructor feedback during the learning process is critical in order to keep students committed to learning meaningfully throughout the course and to develop their self-regulative capacities (White & Frederiksen, 1998). For all these reasons, we believe that there is a need in the literature for a procedure that allows for rapid identification of LIPHs using student Cmaps.

NEIGHBOURHOOD ANALYSIS

Neighbourhood Analysis (NeAn) is an innovative way to identify LIPHs in Cmaps. The instructional strategy that underlies NeAn involves the selection of a compulsory concept (CC) to be used by the students during the construction of their Cmaps. The CC is selected by the instructor, as is the focal question to be addressed by the map-makers. Some criteria to make an appropriate choice of CC are:

- the selection of a threshold concept, which may be transformative, integrative, irreversible, troublesome and/or that result in a troublesome knowledge as proposed by Meyer & Land (2005),
- the in-depth discussion of the concept during the didactic activities, and
- the usefulness of the concept to address the focal question appropriately.

The CC also becomes a privileged starting point for evaluating the Cmaps' propositional networks, because all other concepts can be classified into neighbour concepts (NC) or supplementary (SC) concepts. The former forms a proposition with the CC whereas the latter is not directly linked to CC (Figure 1). Therefore, NeAn allows us to classify Cmaps' concepts before reading the propositional network. Instructors can use NeAn to make a diagnostic assessment of student learning at a glance, considering only the semantic content of the propositions involving the CC.

Concept mapping is usually more cognitively demanding for students than most traditional exams, which are based on recalling information as presented during instruction. This traditional, prevalent approach considers the students to be passive receivers of content presented by professors, capable of recording the information without mistakes. Rote learning is the most preferred option in this situation because the learning expectations involve only the memorization of facts (Kember, 1996; Kinchin, Lygo-Baker & Hay, 2008). Alternatively, the construction of

Cmaps considers students to be meaning makers who actively transform received information according to their prior knowledge (Novak, 2002; Novak, 2010).

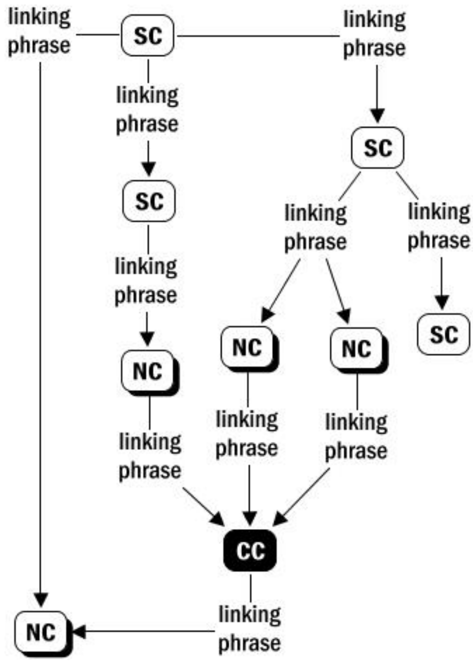


Figure 1. Classification of the Cmaps concepts according to their relationship with the CC (black box): NCs (shadowed white boxes) are directly linked to the CC, whereas SCs (white boxes) do not form a proposition with the CC.

We believe that inclusion of threshold concepts may make the creation of Cmaps even more difficult, because these concepts are not chosen by the map-makers themselves. As a consequence, map-makers need to find appropriate neighbour concepts (NCs) and linking phrases to express how the threshold concept can be inserted into the propositional network. This task may be more difficult than establishing propositions only using concepts selected by the Cmap's author. It is possible that the threshold concept may not be familiar to some students, in which case the appearance of LIPHs is more probable. On the other hand, when the map-makers can choose all concepts themselves (i.e., in the absence of a CC), the appearance of LIPHs is less probable because the map-makers feel more comfortable and use only concepts with which they are familiar, thereby avoiding the risk of exposing their own conceptual gaps. In this case, it is more difficult for instructors to identify LIPHs and to plan further activities to foster meaningful learning. In other words, propositions that involve the threshold concept can help to externalise naive messages or conceptual mistakes. In both cases, the identification of LIPHs is straightforward during the Cmap evaluation, and it can be done at a glance. Therefore, the CC facilitates the appearance of LIPHs, as well as diagnostic assessment, which instructors can carry out by comparing Cmaps obtained under the same instructional conditions. Figure 2 summarises the key ideas involved in the use of Neighbourhood Analysis (NeAn) as an innovative way to follow up on the learning process, using LIPHs as an important piece of information for students and instructors.

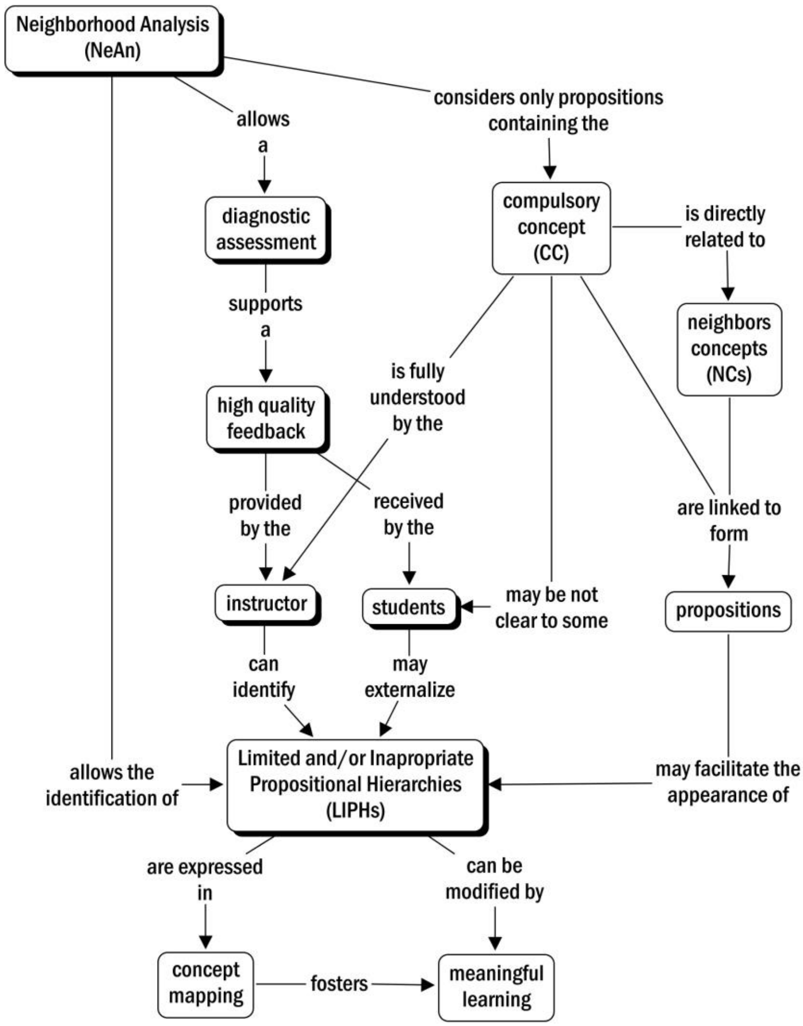


Figure 2. Concept map to address the following focal question: How can NeAn foster meaningful learning by using concept maps? Shadowed boxes indicate the potential instructional use of NeAn, whereas non-shadowed boxes indicate the strategy that underlies NeAn.

AIMS OF THIS STUDY

This paper proposes NeAn of Cmaps as an innovative way to identify LIPHs, in order to foster meaningful learning in science education. Empirical results are presented to show the usefulness of NeAn in making diagnostic assessments of student conceptual outcomes in a higher education setting.

RESEARCH METHODS

Data Collection

The empirical data included Cmaps (n=69) collected during the Natural Science Course, which is offered for all first-year undergraduate students at School of Arts, Sciences and Humanities, University of São Paulo (SASH/USP). The main goal of this course is to provide a broad overview of the impact of scientific and technological development on our society (Correia et al., 2010; Laherto, 2010).

The data were collected during 2010 and all Cmaps were made individually during the second exam for the Natural Science Course (E2), which occurred during the tenth class session (Figure 3). A training period to increase the students' proficiency as map-makers was offered during classes 1-4, following procedures described in the literature (Aguiar, Cicuto & Correia, 2014).

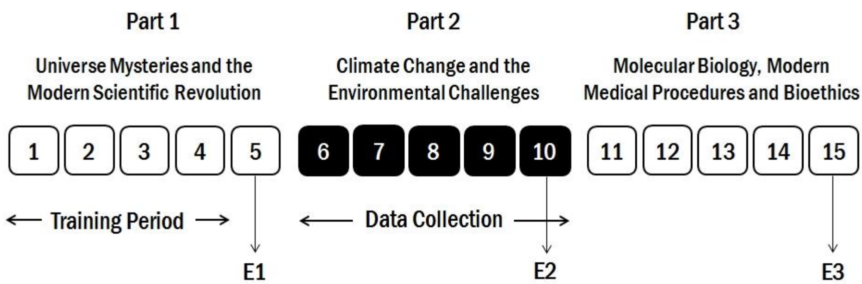


Figure 3. Overview of the Natural Science Course, highlighting the activities related to the training period on concept mapping (classes 1-4) and to the data collection (classes 6-10).

Three instructional strategies were used during the training activities: half-structured Cmaps (HSCmaps), expanded collaborative learning (ECL), and propositional clarity tables (PCTs). The HSCmap was inspired by the cyclical Cmap and experiments on dynamic thinking described in the literature (Safayeni, Derbentseva & Cañas, 2005; Derbentseva, Safayeni & Cañas, 2007). The HSCmap required summarising capabilities because it restricted the number of concepts used during Cmap construction. However, since the HSCmap did not define the map's structure, the map-maker was free to build propositions without restrictions.

Expanded collaborative learning (ECL) is characterised by student peer review of material that they produce collaboratively (Author, omitted reference). Since students inhabit a relatively consistent zone of proximal development, peer review offers an opportunity for them to share knowledge with each other; this experience is distinct from their interactions with the instructor, who is not in the same zone of proximal development (Novak, 2010; Vygotsky, 1978). Peer review enhances collaborative activities developed for small groups of students, and for this reason, we expect ECL to distinctly shift the nature of the learning experience and outcomes. The use of ECL can increase student awareness of personal achievements and failures in the Cmap training session. Moreover, ECL is an assessment exercise that may offer a safe avenue to self-evaluation, which allows map-makers to continuously revise their own Cmaps.

The propositional clarity table (PCT) was designed to reinforce the Cmap structure and is based on semantic units (Aguiar, Cicuto & Correia, 2014). The PCT asks the map-maker to go beyond reading and checking the Cmap as a whole; rather, he/she is asked to pay close attention to each proposition in the map. A four-column table is prepared, wherein each row contains one proposition from the Cmap. The first three columns ask students to describe the elementary components of the propositions (initial concept, linking phrase and final concept), while the last column asks students to rank the clarity of each proposition (Is it clear? Yes/No).

Climate change was the subject discussed during classes 6-10 (Figure 3). Didactic activities highlighted the role of dispersion as a key concept in understanding atmospheric dynamics and spatial aspects related to climate change. The literature suggests that there is a lack of understanding of how local actions are related to global environmental problems (Fenger, 2009; Ungar, 2000). Assigned readings (Mendes, 2003), news from online mass media, and satellite images were selected as instructional materials to be used in the classroom (Table 1).

Two videos from animated satellite images were showed to the students during class 9. The first one presented the Geostationary Operational Environmental Satellite and was produced by the National Oceanic and Atmospheric Administration. It showed the satellite capabilities in tracking oceanic and atmospheric dynamics, measuring temperature, humidity and other physico-chemical parameters. The most interesting part was the images showing the pollution (dust) emitted in California spreading throughout the Pacific Ocean. The second video was produced by the National Weather Service (Met Office, UK) to demonstrate how fast the ash emitted by the Eyjafjallajökull volcano in

Iceland reached the north of Europe. The intensity of the emission was sufficient to close many important European airports for several days during April, 2010. This event received detailed coverage by mass media and occurred during the Natural Science Course. Despite being an unexpected video, it was meaningful to the students because it was relevant to the broader issue under discussion, through its confirmation that the atmosphere is not static: particles and gases can move from one place to another, conferring a dynamic nature to the processes that occur above the Earth's surface. The use of both videos allowed students to visualise atmospheric dynamics while the professor talked about the images briefly. This approach is based on the cognitive theory of multimedia learning (Mayer, 2005).

Table 1. Learning activities on climate change developed during the Natural Science Course (NCS) during classes 6-10.

Class	Instructional Material	Classroom Activities
6	Text "Environment: Science and Technology" (Mendes, 2003)	Lecture classes on and discuss about the text Analysis of the relationships between science, technology and global environmental problems
7	Text "Environment: Energy" (Mendes, 2003)	Lecture classes on and discuss about the text Analysis of current standard of energy consumption and increased demand for fossil fuels Integration of the concepts of classes 6 and 7 through the discussion of climate change
8	News available on the Internet about climate change, selected by students	Activity in small groups of students Identification of sections of the news that indicate relationships between science / technology, science / society and technology / society Discussion about how climate change is presented in the media
9	Satellite images that represent the atmospheric dynamics	View videos that show the dynamic nature of atmospheric processes. Discussion about the relationship between local actions and global effects due to the dispersion of gaseous pollutants in the atmosphere.
10	Cmap prepared for consultation during the exam (E2)	Preparation of individual Cmap, with the compulsory concept (dispersion)

The second exam (E2) involved the construction of a nine-concept half-structured concept map (HSCmap) to address the following focal question: "How are scientific and technological developments related to climate change?" (Figure 4). The students were required to use "dispersion" as a compulsory concept (CC) to set up the propositional networks of their Cmaps.

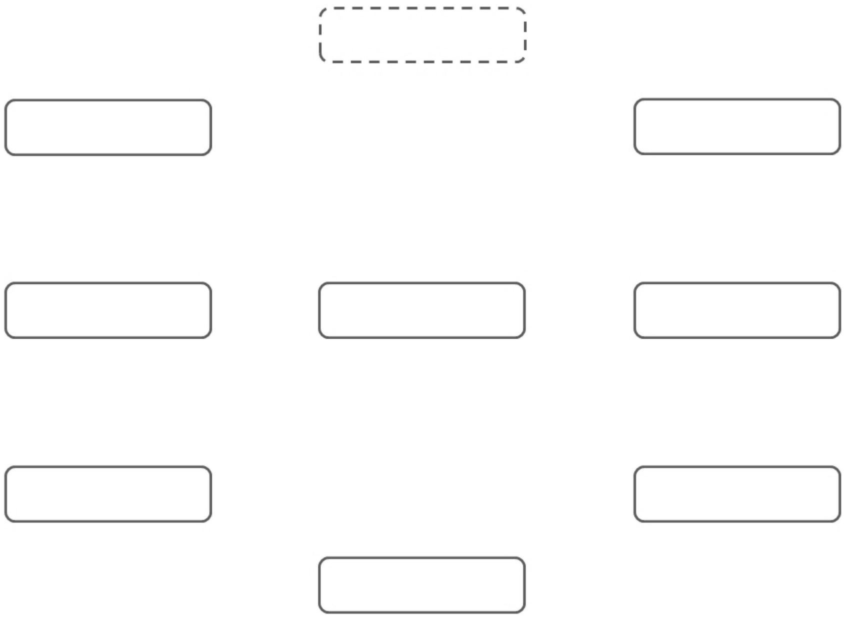


Figure 4. Nine-concept HSCmap used during the second exam (E2) of the Natural Science Course. The dashed box highlights the root concept of the HSCmap and student knows that this is the starting point for readers.

Data Analysis

Categorisation of propositions containing the CC

The 69 Cmaps produced by the students contained 985 propositions. However, Neighbourhood Analysis (NeAn) uses the compulsory concept (CC) as a privileged starting point to select propositions for analysis. Therefore, only the propositions containing "dispersion" (n=175, or 18% of the total) were used for the data analysis.

Four categories of analysis were utilised to classify the propositions according to their messages: limited (L), inappropriate (I), relevant (R) and very relevant (VR). The category limited (L) was assigned to propositions that could not be understood because of the lack of semantic clarity. The map-maker was not able to make her/himself clear, mainly due to poor choice of the linking phrase (e.g., dispersion – of → air masses). The inappropriate category (I) was assigned to propositions that expressed a mistake involving dispersion (CC), according to current scientific knowledge (e.g., dispersion – causes → warming of the Earth).

The category R was used to classify propositions showing a relevant connection between the NC(s) and the CC. However, these propositions did not mention the relationship between dispersion and the global aspects of climate change (e.g., dispersion – is a concept coming from → science; atmospheric phenomena – require understanding the concept of → dispersion). Lastly, the category VR was chosen only for propositions that mentioned dispersion to refer to some spatial aspect related to atmospheric dynamics. VR propositions established clear and valid statements about the global aspects of climate change using the CC (e.g., local action – requires understanding the concept of → dispersion; global effects – require understanding the concept of → dispersion).

Score system for the overall Cmap analysis

On the basis of the categories assigned for each proposition, the Cmaps were analysed using the score system presented in Table 2. The very relevant (VR) propositions received the highest score (+2), whereas the inappropriate (I) propositions received the lowest (-2). Propositions classified as relevant (R) and limited (L) were scored with +1 and -1, respectively.

Table 2. Score system for propositions containing dispersion (CC) based on four categories.

Category	Score	Example
Very relevant (VR)	+2	global effects - requires understanding the concept of → dispersion
Relevant (R)	+1	dispersion - is a concept coming from → science
Limited (L)	-1	dispersion - of → air masses
Inappropriate (I)	-2	dispersion - causes → warming of the earth

Each Cmap was scored by considering its weighted averages, according to the equation (1),

$$\text{weighted averages} = [(N_{VR} \text{ x } 2) + (N_R \text{ x } 1) - (N_L \text{ x } 1) - (N_I \text{ x } 2)] / (N_{VR} + N_R + N_L + N_I) \qquad (1)$$

where N_{VR}, N_R, N_L and N_I are the number of propositions categorised as very relevant (VR), relevant (R), limited (L) and inappropriate (I), respectively. The weighted averages values for all Cmaps (n=69) were used to compare the Cmaps in order to find patterns and identify LIPHs.

RESULTS AND DISCUSSION

NeAn first step: categorisation of the propositions containing the CC

The subset of propositions (n=175) involving dispersion (CC) was carefully considered during the NeAn. Semantic clarity and understanding were the parameters taken into account to categorise each proposition. Inappropriate (I) and limited (L) propositions were easily detected during the categorisation. As a result, limited and inappropriate propositional hierarchies (LIPHs) were more evident to the instructor. Table 3 presents the frequency of each category, according to the number of propositions between CC and its neighbour concepts (NCs).

Table 3. Categorization of propositions (n=175) containing dispersion (CC) as initial or final concept.

Category	Score	Number of Propositions							
		1	**2**	**3**	**4**	**5**	**6**	**9**	**Total**
Number of Cmaps	-	7	33	17	4	4	1	1	67[a]
Very relevant (VR)	+2	2	25	13	6	6	-	-	52 (30%)
Relevant (R)	+1	3	23	25	8	7	-	-	66 (38%)
Limited (L)	-1	-	7	2	-	4	3	7	23 (13%)
Inapprop. (I)	-2	2	11	11	2	3	3	2	34 (19%)
Total	-	7 4%	66 38%	51 29%	16 9%	20 11%	6 3%	9 5%	175 100%

[a]In spite of declaring the use of dispersion was compulsory, two Cmaps did not presented it. Therefore, the presented results were calculated from 67 instead of 69 Cmaps.

The use of the CC challenged the students to address the focal question (How are scientific and technological developments related to climate change?), while including dispersion as part of their answers. An understanding of the role of this physical phenomenon in linking local actions and global consequences was necessary in order to avoid LIPHs. This understanding is particularly important because dispersion and transportation of pollutants through the atmosphere are not appropriately considered in most discussions about climate changes in mass media (Bostrom et al., 1994; Fischhoff, 2007; Lowe et al., 2006). Therefore, the propositions established to or from dispersion may indicate the level of student understanding about why local actions may result in global problems.

The data from Table 3 show that almost 70% of the propositions were present in Cmaps containing 2 or 3 propositions. One might expect that an increase in the number of propositions would indicate a deeper understanding of dispersion (the CC), as there are many links with other concepts. However, only 2 students used more than 6 propositions, and all of them were categorised as limited (L) and inappropriate (I). It is probable that these students did not know how to use dispersion to address the focal question and instead closely followed the exam instructions, making as many propositions to/from the CC as possible. It seems plausible to assume that rote learning was responsible for the high number of NCs and the low quality of the propositions (Ausubel, 2000; Mayer, 2002). This possibility demonstrates that instructors can use this method as a straightforward indicator to track students who are choosing to use rote rather than meaningful learning. This information may be useful in planning precise interventions with specific groups of students, in order to influence them to choose a more meaningful approach to learning.

The majority of the propositions (68%) were assigned as VR or R and were prevalent in Cmaps containing only 2 or 3 propositions. The students who understood the role of dispersion used the CC very selectively to respond to the focal question, and connected the CC to other propositions only when it was necessary to enrich the network. This approach was utilised by skilled map-makers who could express the relationship between local actions and global consequences by using dispersion as part of their answer. This method is the opposite of rote learning and can also be used as an indicator of learning. The existence of few NCs with high quality propositions seems to be related to meaningful learning about the subject. In summary, a high number of NCs shows a lack of selectivity in using the CC appropriately and may be related to rote learning. On the other hand, a low number of NCs may indicate accuracy in using the CC to set up an appropriate Cmap to address the focal question, which may be related to meaningful learning (Cicuto & Correia, 2012). We believe the appropriate use of Cmaps in the classroom allows instructors to obtain valuable information about student understanding in order to make appropriate instructional choices and to foster meaningful rather than rote learning.

The low incidence of L propositions (13%) can be considered to be an indicator of student mapping proficiency, as the majority of propositions (87%) considered in this study were of high semantic clarity. Therefore, the training session applied during classes 1-4 (Figure 3) seems to have allowed first-time users to understand how to make good Cmaps. This prerequisite is critical in order to ensure a reliable evaluation of the Cmaps obtained in the everyday classroom. In our specific case, we can be sure that a proposition containing a concept error is due to a misunderstanding about the topic and is not related to the students' lack of ability to prepare a Cmap (Conradty & Bogner, 2010; Aguiar, Cicuto & Correia, 2014).

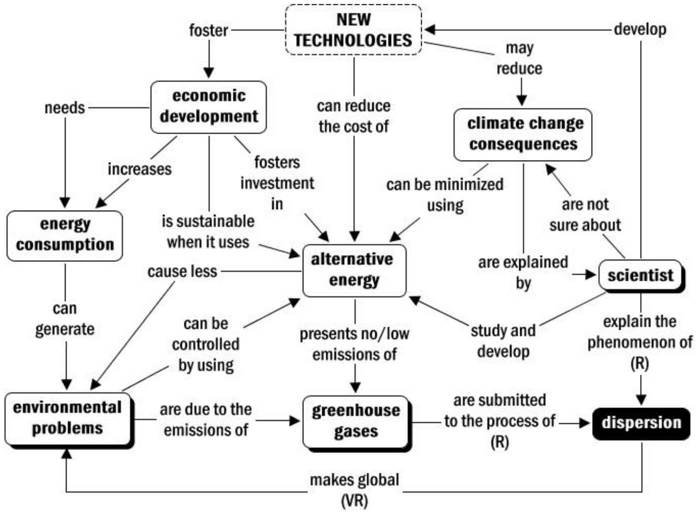
Figure 5 shows two illustrative Cmaps to highlight the differences between the patterns that emerged after categorising the propositions to/from the CC (dispersion). In this first step of the NeAn, the differences in quality between the propositions of students' Cmaps became clear. Figure 5a shows a rich Cmap with 3 NCs (shadowed white boxes) and 3 propositions linking them to the CC (black box). These propositions were categorised as very relevant (VR, e.g. dispersion – makes global → environmental problems) or relevant (R, e.g. greenhouse gases – are submitted to the process of → dispersion). On the other hand, Figure 5b shows a poor Cmap containing 7 NCs (shadowed white boxes) and 9 propositions linking them to dispersion. All of them were classified as limited (L, e.g. CO_2 – because of the → dispersion) or inappropriate (I, e.g. energy crisis – brings → dispersion). It is worth noting that the length of the linking phrase is another indicator of conceptual understanding. Typically, the linking phrases in Figure 5b are longer than in Figure 5a, because this student needs to use more words to express his own ideas and to connect the concepts. A clearer understanding of the topic allows the map-makers to be more concise in describing their thoughts.

NeAn second step: fast assessment of Cmaps from a classroom

A quick diagnostic assessment of learning using students' Cmaps can be achieved by using the second step of NeAn. The categorised propositions (n=175) were used to calculate a weighted average for each Cmap. The goal was to estimate the understanding level of all students at a glance, thereby informing the instructor about the presence (or absence) of LIPHs. The WAs were used to separate Cmaps into the same categories developed in the first step of the NeAn: inappropriate ($-2 \leq$ weighted averages < -1), limited ($-1 \leq$ weighted averages ≤ 0), relevant ($0 <$ weighted averages ≤ 1), and very relevant ($1 <$ weighted averages ≤ 2). The results shown in Figure 6 indicate that 60% of the Cmaps could be classified as relevant (R) and very relevant (VR), taking into account only the propositions using dispersion (CC). These Cmaps (n=41) have no (or few) LIPHs involving the CC and the subset VR category (n=25) represents the class benchmark.

Evaluating Cmaps is a complex task because the one-right-answer approach is not useful to deal with the multitude of ideas expressed by the propositional networks set up by students. Therefore, the identification of the best Cmaps in an everyday classroom can help professors to establish parameters to more precisely rank student Cmaps. This strategy seems more interesting than the use of the instructor's own Cmap as a model of desirable answers. The difference among the zones of proximal development among students (peers) is lower than the difference between students and the professor (high asymmetry). Considering the multitude of possible propositions stated by the students, it is fairer to compare only Cmaps produced by students (Correia & Infante-Malachias, 2009).

(a)



(b)

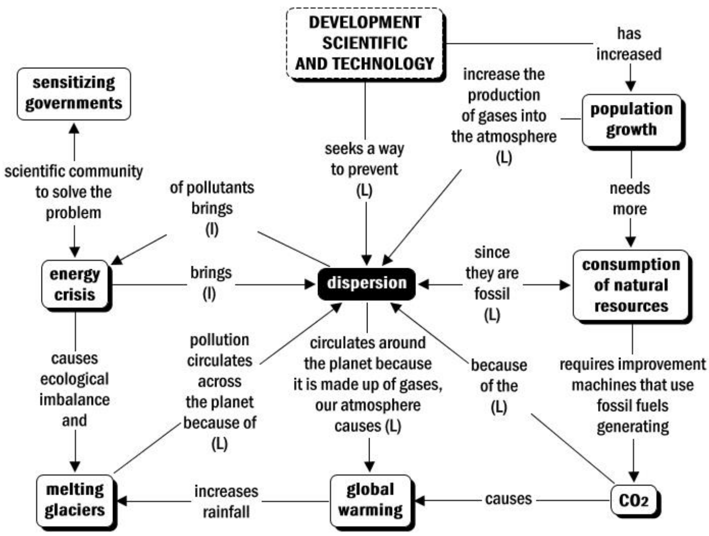


Figure 5. **Students' Cmaps to illustrate (a) the selective choice of NCs to make acceptable propositions, and (b) the pervasive use of NCs to make irrelevant propositions using dispersion. Focal question: How are scientific and technological developments related to climate change? Compulsory concept (CC), neighbour concepts (NC) and supplementary concepts (SC) are represented in black, white shadowed and white boxes, respectively. The dashed box highlights the root concept of the HSCmaps.**

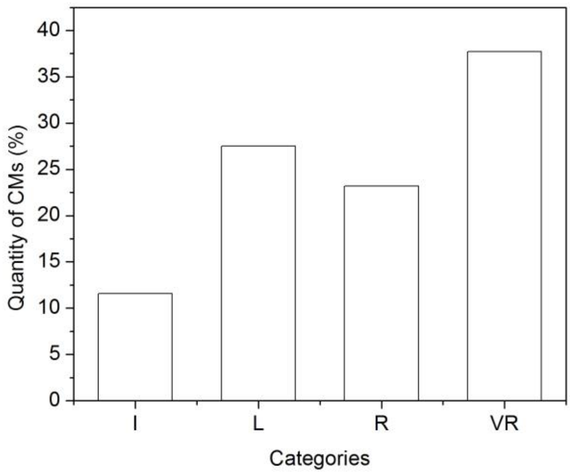


Figure 6. Frequency graph showing the Cmap distribution among the categories inappropriate (I), limited (L), relevant (R) and very relevant (VR).

LIPHs were found mainly in the Cmaps (n=18) classified as limited (L). A more detailed analysis reveals the mistakes in the concept relationships made to/from dispersion (the CC). The precise identification of the students' LIPHs helps the instructor to plan the next activities and thereby foster meaningful learning. These students probably need to revise some concepts involving climate change; specific recommendations can be made by the professor. Only 11% of all Cmaps (n=8) were classified as inappropriate (I), which reinforces the importance of the training session on concept mapping (Figure 3).

Figure 7 shows selected Cmaps to highlight the main features of the categories used to assess them using the NeAn and to identify LIPHs. The Cmap presented in Figure 7a contains only one neighbour concept (NC) related to dispersion (CC). Despite being very selective, this student made a mistake while expressing the relationship between greenhouse gases (NC) and dispersion (CC). The proposition that "greenhouse gases – are not submitted to the process of → dispersion" is the opposite of what is considered correct according to current scientific knowledge. This mistake reveals the existence of LIPHs, and the proposition is more inappropriate than limited. This lack of understanding about the role of dispersion (CC) in answering the focal question explains the appearance of this inappropriate (I) proposition.

The Cmap shown in Figure 7b has 2 NCs (CO2 and planet) linked to dispersion. The propositions elaborated by this student (CO2 – reducing the → dispersion, and dispersion – in the → planet) are not clear enough to allow a critical judgement about the messages they express. The concepts seem to be in the wrong place (*e.g.*, dispersion can reduce the concentration of CO_2), and "dispersion in the planet" could be considered as a concept, because there is no verb to clarify the relationship between these concepts. These propositions reveal the existence of LIPHs, and they are more limited than inappropriate (the opposite of the Cmap presented in Figure 7a).

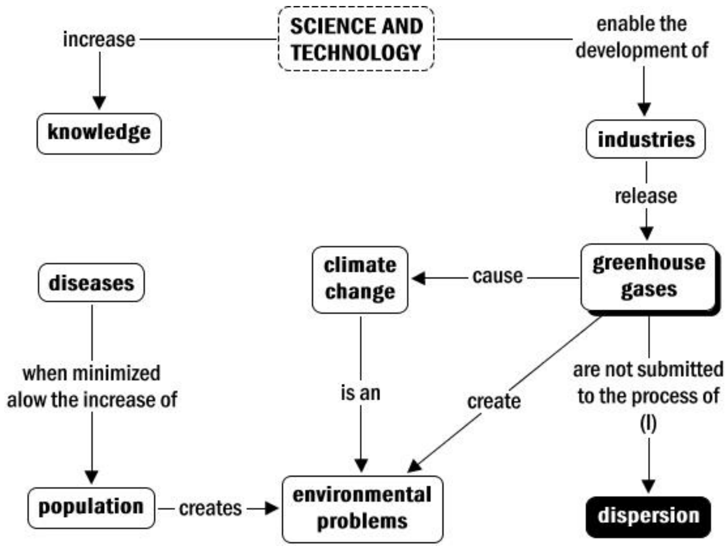
Figures 7c and 7d present Cmaps without LIPHs concerning the propositions involving the CC. However, the proposition in Figure 7c (greenhouse gases – are submitted to the process of → dispersion) does not address the possible implications of local actions for global environmental consequences. This topic, explored during the instructional period, is a critical aspect for differentiating relevant and very relevant Cmaps. Figure 7d presents a Cmap with 2 NCs and 2 propositions that make clear the student's understanding about the spatial dimension of the climate change (dispersion – globalises → climate change, and dispersion – socialises the → pollution). These statements appear because this student understands climate change beyond the naive description presented in the mass media. The role of atmosphere dynamics is taken into account to explain why we are facing environmental challenges that are more complex than those previous ones. Climate change requires a global commitment to discovering potential actions to mitigate its dangerous effects and to solve this problem during the 21st century. This Cmap reaches the instructor's expectations and indicates the effectiveness of discussions during classes 6-9. It needs to be stressed that 25 Cmaps (35%) considered in this study present this feature, indicating the positive effect of the instructional activities.

CONCLUSIONS

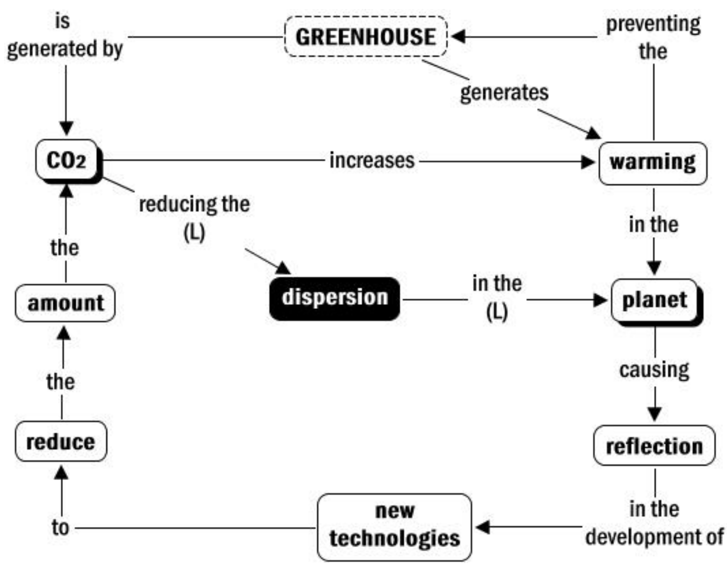
Neighbourhood Analysis (NeAn) is a straightforward way to identify Limited or Inappropriate Propositional Hierarchies (LIPHs) in Cmaps. The choice of the compulsory concept (CC) and the focal question allow instructors to find LIPHs through a fast diagnostic assessment of student conceptual outcomes. Only a subset of all propositions needs to be considered, thereby enabling a rapid evaluation of the Cmaps. Instructors can provide specific high-quality feedback to their students, even under normal teaching conditions. Cognitive conflicts can be dealt with through dialogue among students and the professor, who can address the specific misunderstandings of each student. NeAn used in conjunction with concept mapping helps the instructor to provide students with scaffolding during the course and to influence them to use meaningful, rather than rote, learning. In this context, students become aware of the utility of concept mapping as a way to learn how to learn, and their empowerment can be the most relevant achievement of this process, as suggested by

Novak (2002). We also believe that NeAn is a promising strategy to teachers tracking the effects of their instructional options.

(a)



(b)



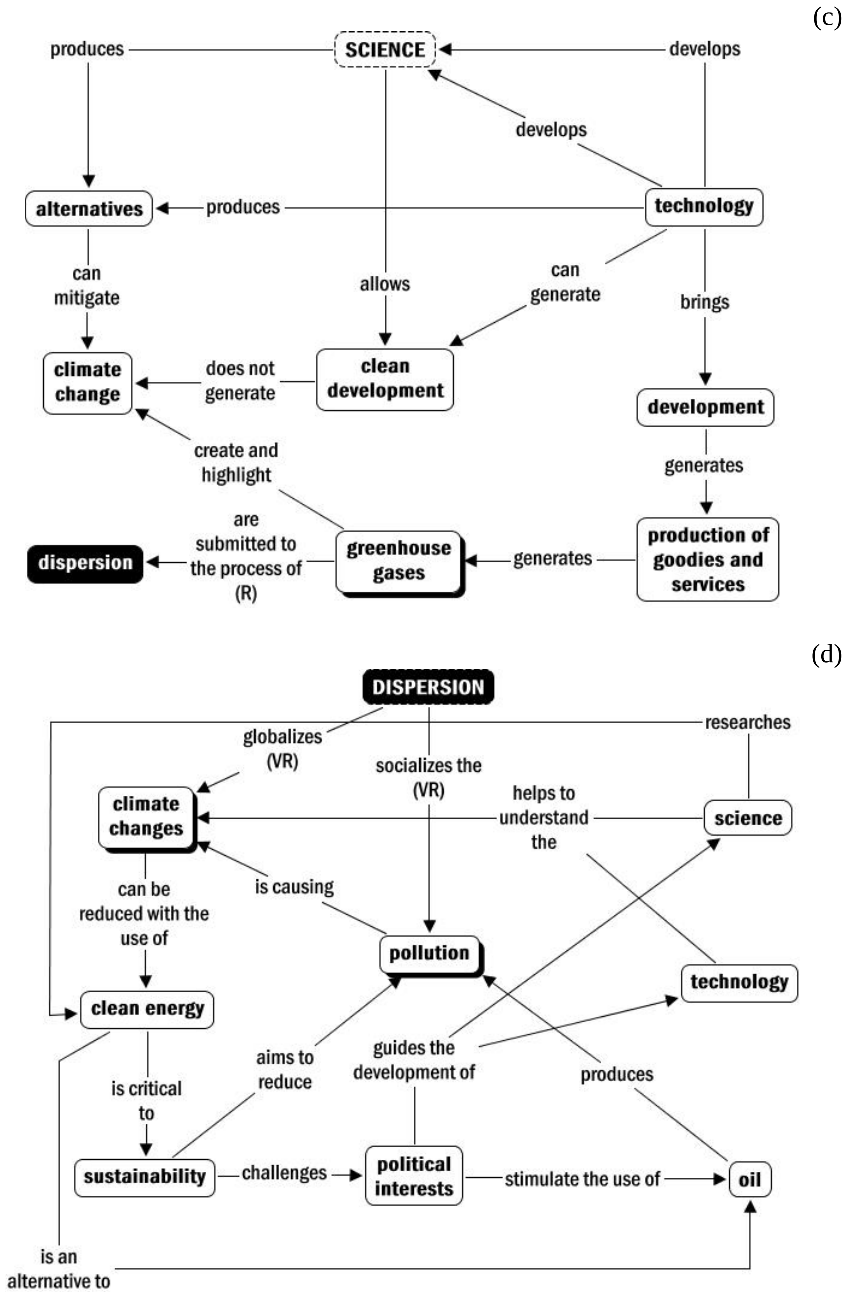


Figure 7. **Students' Cmaps to illustrate the main features of the categories used to analyse them: inappropriate (a), limited (b), relevant (c) and very relevant (d). Compulsory (CC), neighbor (NC) and supplementary (SC) concepts are represented in black, white shadowed and white boxes, respectively. The dashed box highlights the root concept of the HSCmaps.**

The results presented here demonstrate the possibility of identify patterns in student understanding of the role of dispersion (threshold concept) in explaining why local actions may have in global consequences. NeAn can be meaningfully applied for assessing science students at secondary level and above. The ideas presented in this article can be directly applied at the secondary level once students have been successfully introduced to the Cmap procedure. NeAn is very applicable for biology, chemistry or physics lessons and thus once the Cmap technique has been introduced to the students, assessment can take place in all science subjects in a similar manner and also, given the potential for interdisciplinary assessment, the NeAn idea can have potential applicability across science subjects.

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APPENDIX 1: LIST OF ACRONYMS

CC: Compulsory Concept

Cmaps: Concept Maps

ECL: Expanded Collaborative Learning

HSCmap: Half-Structured Concept Map

I: Irrelevant

L: Limited

LIPHs: Limited or Inappropriate Propositional Hierarchies

NC: Neighbour concept

NeAn: Neighbourhood Analysis

PCT: Propositional Clarity Table

R: Relevant

SC: Supplementary Concept

VR: Very Relevant