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BOTTOM-UP CONCEPT MAPS SUPPORTING GENERALIZATION

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Abstract. A preliminary study is critically reported to evaluate the feasibility of using concept mapping as an additional, flexible resource to strengthen the construction of superordinate concepts in a constructivist and mediative environment. One class of 24 fifteen-year-old students of the II-year chemistry course has been involved in a six-month study, divided into two phases.

1 Introduction

This paper reports a series of strategic actions aimed to develop - in a single class of food science and chemistry with 24 fifteen-year-old students (2nd year of Italian secondary school) - the mastery of superordinate concepts and to focus the attention on how these concepts can be applied, connected and developed to form dynamically connected systems. The specific class was chosen among the other possible candidates of same year because of its positive acceptance of educative relationship, absence of conflicts and vivacity of its atmosphere, likewise forecasting of intellectual vivacity. The second year, for studying the processes of conceptual change, was deliberately chosen by the author to proximally extend his previous research about conceptual development for 16 & 17 year olds (third and fourth year) (Tifi. 2014), whose finely tuned strategies were seemingly inapplicable with younger students of the first two years. The study was conducted starting in November 2015, after one month of training in concept mapping (Table 1).

2 Capturing the Synthesis of a Lesson

The initial aim of this action-research, was to compare the students' gain in drawing concept maps, versus writing short texts, as two alternative tools to facilitate the synthesis of any new topic that was introduced in the class. A few minutes after the topic was interactively presented, the students were answering a specific and overarching *focus question* in the two alternative modalities. During the answering phase, both the concept-mapper and text-writer students could view the same short list of relevant concepts and the same focus question on the whiteboard, as a guide to elaborate their personal synthetic answer, after it had been discussed, agreed and sometimes written. They were given around 10-15 minutes to arrange the text or the concept map. Depending on the lesson-time remaining, one or two of the elaborated documents were discussed and given more individual feedback, or used as stimuli for giving a feedback to the whole class.

Focus Question: How do substances in food undergo transformations in the nutrition process?
*"Nutrient substances are frequently transformed to perform their functions (**energetic**, **bioregulatory**, **plastic**). In carrying out the plastic function they become more complex, whereas in the **energetic catabolism** the substances become simpler. In a few cases, the food principles remain unchanged, just aggregating themselves with other substances" (S.F. October 19th)*

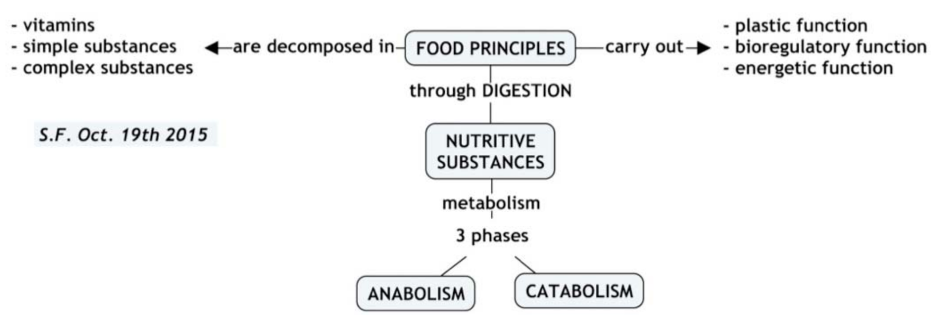

Figure 1. First synthesis, with both text and cmap, by S.F. Focus question: "How do substances in food undergo transformations in the nutrition process?" The cmap reports errors and concepts in linking phrases, while the text-answer was excellent.

The first activities, in October-November 2015 were initially exploited as for the necessary *training* in concept mapping, by following simple rules, often disregarded (as in Fig. 1), because the use of paper and pencil facilitated "free style" scheme construction, while the lack of online sharing slowed down the revision process.

RULES FOR CONSTRUCTING CONCEPT MAPS
1) concept words must be placed into boxes, whereas the linking words must be written into the connecting lines
2) Every connected triplet: [CONCEPT-1] ─ *linking words*→[CONCEPT-2], should result in a complete and meaningful phrase
3) Most important concepts ought to be placed upward and the subordinate ones downward, forming a "Christmas tree" shape
4) Concepts mustn't be repeated in the concept map

Table 1: Rules of concept mapping

To grasp the context of these activities, it is important to know that the focus question was given to the students in advance; then, during the interactive lesson, the emerging concepts were gathered, sometimes hierarchically organized, and then partial conclusions were negotiated, "dictated" from students, and then recorded on the whiteboard. However, during the synthesis phase, students could only view the concept labels and the focus question. This strategy was deliberately designed to train or make learners' *short term memory* more flexible, because the modality and quantity of access to it change considerably from the highly scaffolded interactive discussion to the individual task with reduced guidance. In the first phase, thinking is dominated by external language, whereas in the individual phase *internal language* is more solicited. So we can hazard that - as far as processes of reflection and voluntary access to short - and long - term memory are entailed, it is in this second phase that the learner is operating more consciously within their zone of proximal development, whereas during public debate or lecture, working memory is overloaded.

The following text and concept maps, attempting to answer the same focus question, can help us to understand what could happen with students endowed with different zones of proximal development.

Focus question (Nov. 7th 2015): "*Are there connections between the two ways of classifying food?*"

M.V.: "The nutritional characteristics of food groups are not entirely independent of food's origins, one example being that protein-rich foods are distinct into two different groups, one of protein-rich food originated from animals, the second formed by protein-rich plants."

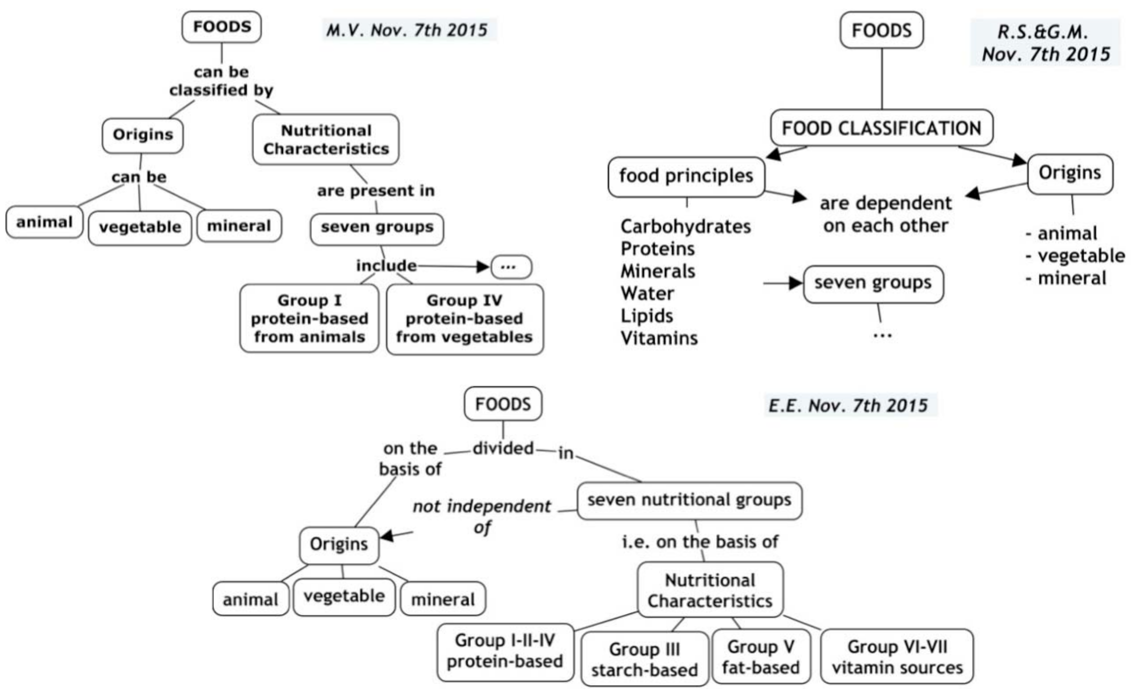

Figure 2. Only 7 student texts by 20 included an answer to the focus question. M.V.'s answer was the best one, but the animal and vegetal origins in groups I-IV were not made explicit (and maybe aware to M.V.) as it could have by means of a cross link-relationship to "Origins" concept. E.E. made an inexplicit dependence relation (also in her text) of nutritional groups with food origins; R.S.&G.M dependence cross-link between principles and origins was inacceptable also in the text answer, as was made in other 4 concept maps.

After the concept mapping training, two tests in November and December 2015 were used to attempt ranking students ability in constructing concept maps. In each testing session, students had an hour or more to answer a focus question by constructing a concept map of a complete topic. The following parameters were evaluated: answer to focus question (AFQ); distinction of linking phrases from concepts (DLPC); quality of propositions (QP); extent of revision needed (ER). The first two parameters were assigned 0 to 3 points without any explicit quantitative criterion; to QP 0 to 4 points, in reason of ratio of correct propositions by total number of propositions. The fourth parameter was inversely ranked from 3 (misconceptions and great amount of revision needed) to 0 (no revision needed), therefore it was subtracted from the sum. This gave a grade from zero to ten to the c-maps.

Then the class was divided into two homogeneous groups *M* and *T* on the basis of the concept-mapper-ranks. The parameter QP was the most correlated with ER parameter (r^2 = -0.74 in the first test and r^2 = -0.64 in the second test), so only the two parameters QP and ER were averaged for the two tests and taken in account to construct two rankings of the 24 students which resulted closely comparable. The two rankings were divided in 5 blocks of same score and one half students in each group of scores was randomly chosen for the "cmapper" group M, while the remaining members were recruited as "text writers".

Group *M* average rank was 3.3, with st.dev. 1.5, while *T* group resulted in average 3.5 and st.dev. 1.8. During January 2016, group *M* mapped syntheses about four lessons, in which new topics were being proposed, while group *T* wrote the synthetic answers to the same focus questions as plain texts.

A multiple-choice test to assess the concept mastery was assigned at the end of period (5th February 2016). The scores of *M* and *T* members were compared. The *M* grades averaged 7.6 (st. dev. 2.3) whereas the *T* group average score was 8.8 (st.dev. 2.0). Thus, there were no significant difference (Δ = 1.2 vs overall st. dev. = 2.2), notwithstanding there was a significant correlation (r^2 = 0.52) between the rankings as concept mappers and the test score of the entire class. The same significant correlation (r^2 = 0.53) was confirmed at the end of the following month, in which students of groups *M* and *T* exchanged their roles. In the assessment test of 4th March, the *M'* scores averaged 6.3 (st.dev. 1.2) while *T'* group average score was 5.6 (st.dev. 1.0). Once again there was no significant difference (Δ = 0.7 with an overall st. dev. = 1.1). It was the same group of students (*T*, or *M'*) who scored hardly better than the other (*M*, or *T'*) independently of the use of short texts or concept maps to elaborate the answers to the focus questions as a synthesis of the main concepts discussed in the lessons.

The appreciable correlation r^2 = 0.5 of concept mapping rank versus the scores of two different tests can be interpreted as a consequence of a multifactor development differential, that influenced all the four tests (two concept mapping tests and two multiple choice tests). In a third, later assessment test for conceptual mastery (23th April) of the same kind of multiple choice, the correlation fell to r^2 = 0.4, whereas the correlation coefficient between 2nd and 1st test, that was r^2 = 0.29, collapsed to r^2 = 0.08 between the first and third test, demonstrating that some of those multifactorial limitations to development had been evolving in the long term, and this is also confirmed by the good news that some low-score students entered at the races.

Despite the limited impact of concept mapping activity, these practices resulted in a considerably improved attention and quality of dialogue in the class, helping students to concentrate on understanding while taking notes during the interactive lectures, and to focus on the very *most general concepts*. Furthermore, it became clearer and clearer the role and importance of *generalization* in the construction of the narration, in planning and bridging past topics with the new ones, as a way to construct a *mental system* of scientific concepts. It became also clear that the construction of student's single synthesis-cmaps of every new topic, was not the better choice. To capture the synthesis in concept maps was much a more cumbersome and incomplete process than writing an organic text that summarized the topic with the filter of a focus question. Concept maps were constructed on paper by necessity, due to the lack of readily available computers and Internet connection. These limitations impaired the effectiveness of this technique, the same possibility to quickly elaborate, edit and share the concept maps. On the other hand, the texts were always rapidly and meaningfully produced as valid syntheses of what was worth capturing. In the last lesson of this first phase, two different focus questions were assigned, one – simpler - that was to be answered as a short written text and the other as a cmap, in the hope that this had facilitated the organization of concepts through a concept map. Once again, the task of synthesizing as a concept map was more time demanding and required to fix syntactic difficulties that weren't encountered in the text task, thus resulting in an activity lacking significance.

A radical change in the lesson plan and the strategy of using concept mapping were both needed. Thus, in the *second and unplanned phase* of this study, individual texting and concept mapping were substituted by other tasks, as peer-collaborative writing of simple phrases in which two superordinate concept-words were contained or answering in pairs to questions or simple problems which were prepared in advance. Then, a bottom-up concept map, prepared in advance, was shown and analyzed to review and strengthen the connections between the old and the new concepts and to fix the role of the unfamiliar concepts contained in the phrases, questions and problems. The process of bottom-up concept mapping will be discussed in the 5-6th paragraph.

3 The psychological basis for the development of generalization

Beginner learners of scientific subjects at secondary school level, are placed in front of a “conceptual mountain”, without the necessary equipment and abilities: thinking in concepts, metacognitive and problem solving aptitudes, experience of application of all these processes. The external resources to climb that mountain are situated in the “roped party”: the learning community which the learner is part of, the concepts, particularly the “peaked” ones, i.e. the *most superordinate and generative concepts*. Therefore, the most necessary tools are part of the obstacle: out of reach of the learner, while the internal resources are formed by the developing system of mental functions: memory, will, attention, imagination, perception (Mahn, 2016).

In the highly cohesive psychological system, as shown in the following Figure 3, the dramatic change that accompanies the appearance of thinking in concepts, when the adolescent becomes aware of her or his own thinking processes, can be only comparable with the analogously revolutionary change in perception that was caused by the acquisition of language, with its reflexes in the other growing functions.

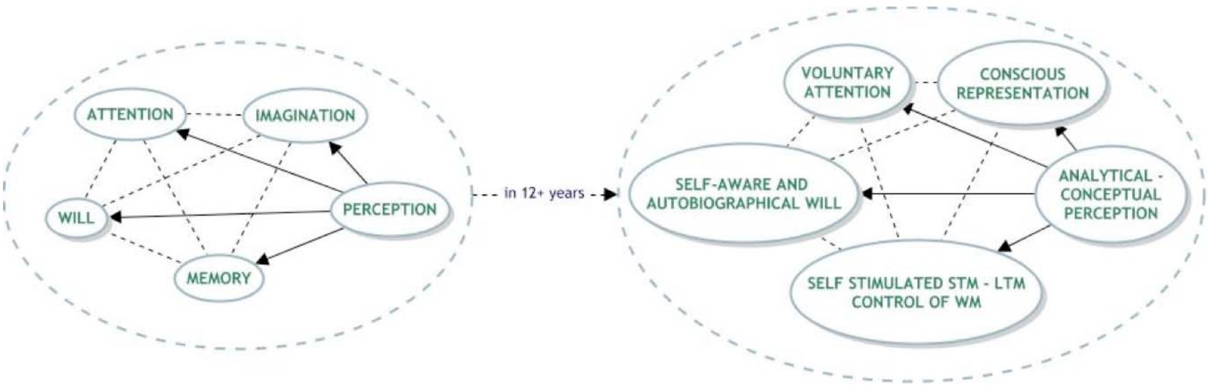

Figure 3. The five mental functions as they mutually affect each other, their own changing nature, the reciprocal laws of interaction while they evolve together with the whole psychological system and organic development, determine the development of psyche.

Volition (voluntary control of the use of concepts), rise of conscious awareness and systematicity (organization of concepts into systems in which there are subordinate and superordinate concepts) are interrelated characteristic descriptors of what is globally called “thinking in concepts”, stemming from the development of previous - more elementary - structures of generalization called “complexes” by Vygotsky (1987).

In the stage of complexes, it is only possible to use language to unite “complexes of distinct concrete objects or things on the basis of objective connections, connections that actually exist among the object involved”, while to think in concepts means to think abstractly, or to “view these isolated, abstracted elements independently of the concrete and empirical connections in which they are given” (Vygotsky, 1987, p.135, 156).

When this happens, the mediator discovers not only that the abstract level of generalization becomes possible, but also that this is somewhat *needed*, or “claimed” by the learner. But, the fact that the “transitional adolescents” are becoming prone to this higher process of generalization, does not imply that they will be able to do it autonomously or automatically. Rather, once the psyche has matured to make *possible* this specific qualitative leap in the process of meaning-making - typically in the age of adolescence - whether it will be actualized or not, depends on the presence of appropriate stimuli and sociocultural interactions in a fertile mediative environment.

The development of the five mental functions in Figure 3, besides being highly interconnected, as a background of psychical maturation, is also positively affected by the ability of working with concepts. It would be an error to believe that a single mental function (e.g. working memory, or attention) could be developed independently by the others to establish or improve thinking in concepts. Rather, exercising with the proper mediational stimuli to scaffold generalization, will foster analytical perception, awareness of the representations, control of working and long term memory, and so on. As for a muscle, the specialized use creates control and aptitude, as well as repeated control and exploitation of one aptitude, “specialize” the muscle.

In scientific subject matters as chemistry, there is the largest gap between everyday concepts and academic or scientific concepts. Generalization, conscious awareness and construction of systems of meanings are instrumental in expanding the “zone of proximal development” of the individuals in the learning community, in such a way to narrow the gap, by stretching the everyday concepts up, and reaching down from the general-academic and conscious concepts to what previously was going on spontaneously (Mahn, 2015).

A favorable educational environment adopts a series of scaffolding actions that imply a high rate of interactive speaking as imitation, development of examples, guided generalization, peer activities, plenary discussions, debates to reach a consensus, activities of writing and comparing written argumentation, short summaries, individual or collaborative concept mapping.

4 What is going on during the concept mapping of abstract relationships

One of the most common obstacles to the process of answering the focus question with a simple concept map, in the short term, as soon as a main idea was made clear, was that students didn’t know where-how to start (Kinchin, 2001).

This, in turn, can be understood as a consequence of the fact that a problem-solving like or critical-analytical focus question is better answered as an argumentative text instead of a structure made of ternary propositions hierarchically organized as a concept map. Organizing the conceptual structure can be considered as a second task, besides answering the focus question. Yet this task perhaps requires higher comprehension and awareness of the whole picture than the learners could have presumably got in the former stage of a new topic. There is also a third obstacle in constructing rigorous Novakian Cmaps, which is the syntactic one.

We see an example of how hard it can be to express, as a concept map, the fact (repeated from M.V. Fig. 2) that “a classification *based on the* <u>kind of nutrient substances</u> *is not completely independent from the* <u>classification based on food origin,</u> *because some of the* <u>nutritional groups of foods</u> *seem not to be only distinguished for their* <u>nutritional characteristics</u>, *but also for their* <u>different origin,</u> *despite these groups containing the same kind of* <u>nutrient chemical substance</u>.*”* (Italics for linking phrases, underlined concept labels). The argumentative answer by M.V. contains explicative and adversative connecting links, repeated concepts with similar meaning (e.g. kind of nutrient substance, nutritional characteristic). Moreover, it is not necessary to include the specific instances and every detail of groups in it. The *general concepts* are the only important ones to answer a focus question addressed to a critical examination of general relationships. In the textbook, the two classifications of food were considered as being independent. Therefore, the two concepts of *origin* and *nutritional characteristics* were expectedly mutually exclusive, whereas the true classification in nutritional groups is apparently more complex. So, *from the adult point of view*, we could elaborate a different perspective in which our cmap is a *description* of the most important classification in nutritional groups, instead of a comparison between two alternative classifications. The answer to the original focus question could be “embedded” in the description of the more systematic classifying criteria of nutritional groups, which includes food origins. But the real focus question would be now: “what are the criteria for distinguishing the seven nutritional groups?” This change is needed if we want the answer to be explicit. Nevertheless, these changes of perspective and focus question are out of reach of adolescent learners, whereas the plain text-answer falls within their ZPD, and it is equally useful to enforce the *general concepts* of *nutritional characteristics* and *homogeneous groups of nutrient substances*. Furthermore, both the adult concept map and student’s argumentative answer are equally likely to trigger or not trigger the need to question and investigate the actual nature of proteins in animal and plant food. Whether the deepening and further search of information would be stimulated by the constructivist activity (Wexler, 2001, p. 251) or not, depends on the amount of reflection that an adolescent learner may apply and, in the most probable case in which learner’s reflection is limited, it depends on the *degree of inquiry and awareness of the mediator*. This latter is another aspect that will determine the fundamentals and the role of bottom-up concept mapping. However, before giving our reasons for introducing a different use of concept maps, one more factor should be considered in examining what is going on when learners have to constrain abstract relationships between new general concepts into a concept map.

The learner has a pool of new and unfamiliar concept words in short-term memory and a focus question which invites him/her to examine the criteria of two separate classifications. The scaffolding of previous analysis of these criteria can be voluntarily rehearsed in the form of short claims which combine spontaneous, personal and vaguely defined concepts, and some of these new labels, in an unstable and fluctuating representative thinking. This is enough to saturate working memory and to eventually obscure the real nature of the task or problem. This latter could be neatly defined by the adult which already masters the system of concepts (inasmuch s/he has formulated the specific focus question), but the learner can hardly try to remember and assemble fragments of understanding of what was agreed during the discussion into plain written sentences, ignoring the formal - hierarchical structure of concepts. The learner just can't do all the same in the form of a concept map. The most likely outcome is a detailed "dumbing down" which s/he *describes* subordinate concepts (e.g. groups and subgroups of food in this example) almost ignoring the focus question.

Owing to these reasons the short texts in phase 1 outscored the cmaps in regard for pertinence of the answers to focus questions. A concept map autonomously made by a 15-year-old student is thus more similar to a way of ordering hierarchically a series of concepts and inclusive relationships, once these become completely elucidated and the student has gained conscious awareness. That was what happened in all the observed experiments during phase 1, and it is also what was observed in the study of concept map *complexity* by Dowd *et al* (2015), with older undergraduate students:

"We found no correlation between increased complexity and improved scientific reasoning and writing skills, suggesting that sometimes students *simplify* their understanding as they develop more expert-like thinking."

The wider hypothesis of this study is that to *simplify* understanding is equal to add clarity, differentiation and awareness to the high rank structure's concepts: those concepts that are usually overlooked as bare "title or subtitle-labels" when a lesson is given and attended.

5 Bottom-up Concept Mapping

The conclusion of the previous paragraph leads us to reconsider the "top-down" conception of concept mapping, deliberately entailed in the "expert skeleton concept maps" (Novak & Cañas 2010, Novak, 1983).

The common idea that more complex concept maps could be seen as indicators of better understanding has been previously criticized by Johnstone & Otis (2006): "Students with 'poor' maps were distributed, almost equally, between the lowest and highest quartiles [in the assessment batteries]", and more recently by Kinchin (2014, 2015). On the other hand, Novak acknowledges that *superordinate learning*, the opposite process "where several concepts are recognized as subconcepts of some more inclusive concept or proposition", occurs rarely, and "contributes significantly to development of cognitive structure, and this characterizes the knowledge of experts" (Novak, 2002). Along with Novak (ibid.), we agree that "superordinate concepts are relatively few in number in any knowledge domain", but not with the (apparently) logical consequence that "so most learning in usually subsumptive learning" (ibid.). The superordinate concepts are few, but also more abstract and hard to learn and incorporate in the classroom - everyday discourse. They have such an importance in meaningful learning, in thinking in concepts, and in the development of expert knowledge, that they should deserve more time and dedication in lesson planning. The teacher is there to mediate what is unlikely students would do spontaneously. Then, in order to compose the problem, we need to take into account three principles:

I. In the mediative environment learners can access superordinate concepts even though they are not expert, as long as the subordinate concepts fall within their ZPD. This is the objective led by the teacher-mediator.

II. Although superordinate concepts are relatively context-independent, it is essential that they are accompanied by some direct representation (direct observation, analogy, metaphor) and instances or context applications. Piihl & Philipsen (2011), refer to these terms as "mode 1 curriculum", that is the context-independent knowledge that learners acquire in lectures, can be better taught through a context-dependent setting (mode 2 curriculum), created by solving practical problems. This implies the teacher to be able to construct the knowledge domain in advance in novel perspectives and "flavors".

III. Therefore, the domain of superordinate concepts can be "constructed" and its epistemology creatively adapted to the needs of the class and even to the contingency in the program development, agreeing with Novak that "also the epistemological process where new concepts in a discipline are constructed, subject to all the human frailties we see in concept and propositional learning" are recognized (Novak, 2002). Eventually, we get to the main idea of phase 2, that is the ESCM can be used as advance organizers, first, to introduce new themes with lots of examples and context - without expanding it, and subsequently it can be expanded uphill as well.

The remaining part of the study was directed at investigating the integration of ESCMs as advanced organizers to underpin superordinate learning and construction of the "whole picture" (especially in the transition between connected chemistry topics) while the class was progressing towards the end of course. This part of the experiment will possibly lay down the basis for a future experimental research setting, which will necessarily entail an evaluation of a different kind of syllabus development, characterized by situatedness, dynamicity, generativity and open-endedness.

The nature of the upward development of expert skeleton concept-maps was initially enlightened by the analysis of the following case, which was encountered during the first year course.

Every chemistry or physics textbook has a chapter or paragraph about rules for establishing the number of significant digits in the result of a mathematical calculation between data with given numbers of significant digits. As a meaningful learning test-bench in a first year class, an attempt was tried to convey the *reasons* for applying such rules, through examples, practical demonstrations etc. Anyway - independently by the correctness of students' calculations - there was a large percentage of students who didn't utilize such awareness in their assessment tests. They were not voluntarily using the high level concepts of *data*, *measurement* and *uncertainty of measure*. It became clear that both students *and textbooks* were unaware of the relationships between these concepts, so the following definition was utilized and mapped in a series of lessons:

"*numbers can be divided in pure numbers without meaning (e.g. 8.5 or 3/2) and numbers with associated informative meaning which we should name "DATA". Information data can be divided into two classes: exact data (e.g. the number of sides of a triangle) and measurement data; the former have infinite significant digits, the latter have a limited number of significant digits because they suffer from measurement uncertainty*".

Where textbooks begin with the latter of these six concepts, the students actually *needed* the two higher levels of superordinate concepts.

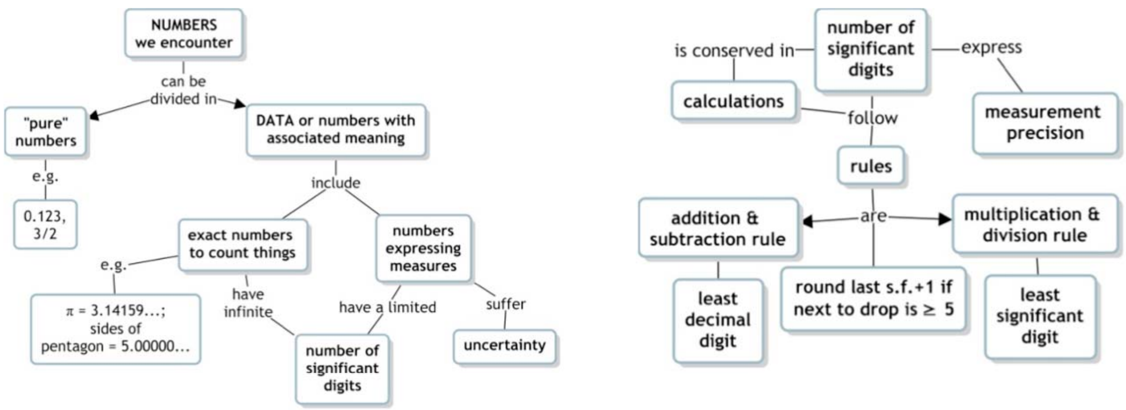

Figure 4. The left cmap was the first concept map developed upwards, to help students understanding rules of significant digits. The right "downward" map can be deduced from any textbook, where the most inclusive concept is exclusively context-related.

The concepts of *number of "significant digits"* and "*measurement precision/uncertainty"* can be meaningfully understood only in case they are subsumed under the concept of *data* and differentiated from *exact data*. Moreover, *data* concept should be differentiated from "number without associate information", or "*pure" number* to pretend the learner would discriminate between the meanings of *number* and *measure*. After the intervention, although the class had considerably improved in the second assessment test, they were still failing in distinguishing exact data from measurement data. After a close exam, it appeared that they had previously based themselves on an exterior (pseudoconceptual) element: the absence or presence of measurement units attached to the numbers. They had implicitly created this rule - to cope with the demanding - initially not scaffolded - conceptual requirement of distinguishing whether a data was exact or not. They were unable to voluntarily use representative thinking to make a clear distinction, because they were *observing the symbols instead of the represented things*. Two important issues are that *a)* textbooks do not specify that rules for significant digits don't apply to pure or exact values, and *b)* the teacher was not aware of these obstacles to the understanding of such an apparently "simple" topic. Had he started from the beginning with that skeleton upward cmap and related examples, first of working with the rules, he could have saved a lot of time and obtained more abundant results.

We can generalize the findings by Dowd *et al*. (2015): "sometimes students simplify their understanding as they develop more expert-like thinking", as probably entailing that there are students with the ability to make more conscious generalizations and to fill autonomously the lack of specification of superordinate concepts which is typical of instruction, even among concept-mapper teachers. Only acknowledging this point we could hope to systematically empower both the "geniuses" and the "developing" students. By examining more cases of revision of the higher order concepts of knowledge domain, it became clear that:

1. It is the bottom-up exploration of a few concepts of ESCM that permits the teacher to "re-discover" and gain a higher level of awareness about the topic, as well as to find out new teaching strategies;
2. Mediation at professional level with adolescents can have more chances to generate conscious awareness and to open the trail to thinking in concepts if the teacher has a higher measure of awareness to transfer to the learner.
3. The concept maps that we were looking for were actually dynamical structures of mind, made of a reduced number of concepts (even just two) and simple inclusive relationships, the ESCM being just simplified advance organizers, artifacts to facilitate sharing and scaffolding.

Once the "trailblazer" role of the teacher was adjusted, it remained to establish how to regulate the development of the bottom-up skeleton concept maps in scaffolding the connections between learning units and in organizing the activities around these advance organizers. This will be exemplified in the next paragraph.

6 How to structure generalization

Every superordinate concept of a knowledge domain constitutes the basic-level concept of a previous or subsequent domain:

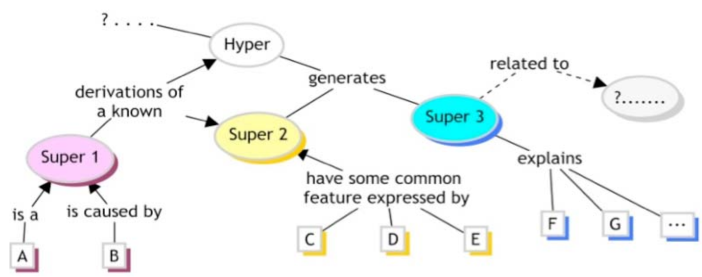

Figure 5. A sequence of generic sub-domains or learning units can be viewed as sub-structures having at least one common superordinate concept. Linking phrases and arrow lines show typical bottom-up inclusion relationships. These can be easily reverted to usual top-down - inclusive - links when substructures are constructed piece by piece from basic concepts A, B, C,...

Once the basic-level concepts (rectangles in Fig. 6) were introduced, several focus questions, probing questions, concrete examples and laboratory demonstrations were used to help the representational thinking to do the upward step to the superordinate concepts (ovals in Fig. 6) and to connect these latter to others. In this way superordinate meaningful learning was possible every time a difference, a regularity, analogy or commonality was *perceived*. Figure 6 shows a merge of ten bottom-up cmaps constructed-used during phase 2 of study.

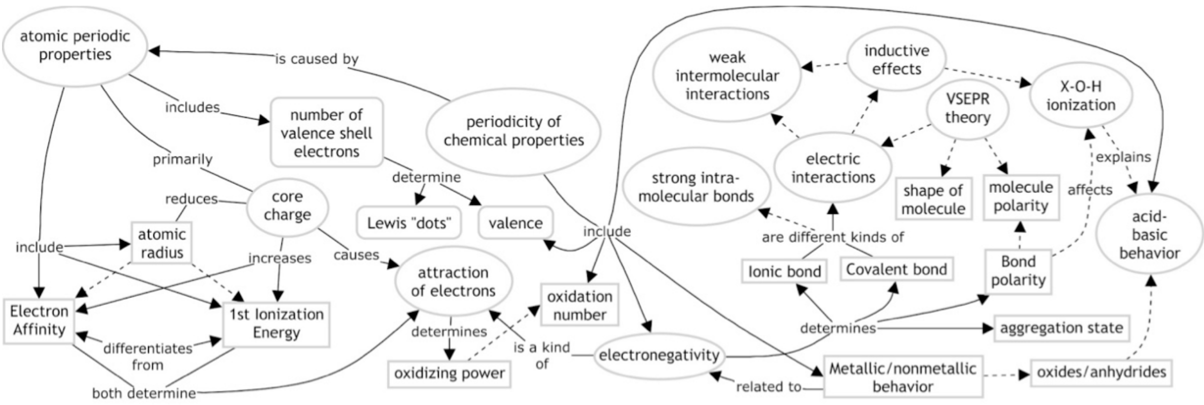

Figure 6. Summary of 10 bottom-up connected concept maps and learning units about12 key superordinate concepts (ovals).

The effect of bottom-up strategy is equivalent to Bruner's "spiral" curriculum (Bruner, 1960), because of recursive reinstatement of previous intuitive superordinate concepts ("great issues") on different grounds and psychical resources of learners, with two differences: here the recursion time can be as short as one month, and the curriculum is dynamically and sensitively created to suit the class, not "respectful" of a given standard.

To establish and reinforce the higher order relationships between any new-unfamiliar superordinate concept and a given basic-level concept, during the late experiments a task was assigned that consisted of writing meaningful propositions - that contained a couple of concept labels - in peer collaboration. Also proper focus questions were used in connection with construction of bottom-up cmaps to solicit *progressive differentiation*, *combinatorial learning* and *superordinate integrative reconciliation* (Novak, 1994) between similar or unrelated basic-level concepts. The next bottom-up Cmaps have been developed and connected during April 2016.

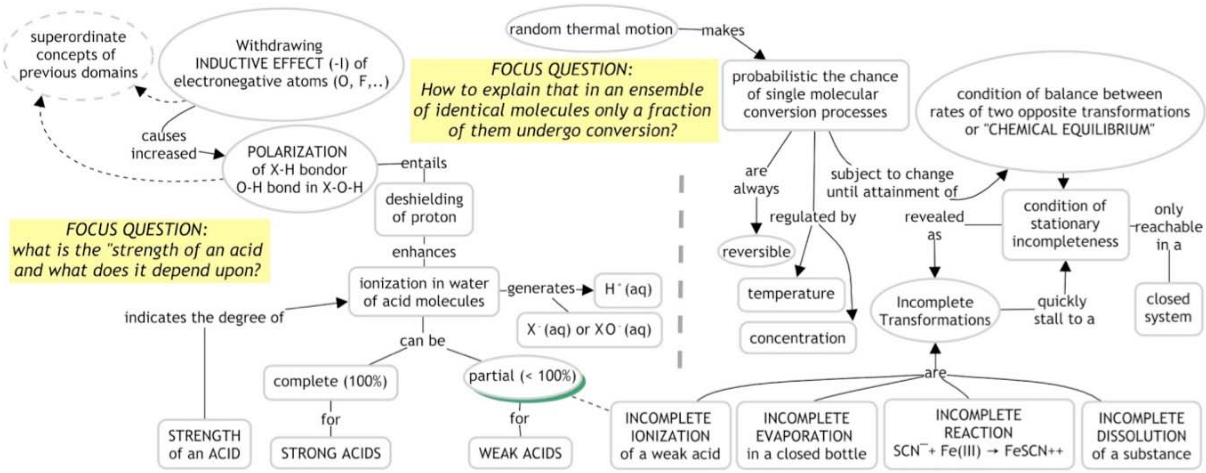

Figure 7. The two bottom-up learning units have been applied and used as advance organizers in multiple activities, including top down development of concept maps of some basic-level concepts. The two units are united by the basic-level concept of "incomplete ionization".

After the unit dedicated to chemical equilibrium and its generalization, the class went back again over the concepts related to acid & base, developing the domain in a more rigorous and less intuitive mind setting, thanks to equilibrium concepts. This creative form of "spiral curriculum" maximizes the connections (*integrative reconciliations*) and optimizes the construction of systems of scientific concepts, i.e. "maps *in the brain.*"

7 Summary

A qualitative leap in adolescent learner capacity to think in general concepts can be trained by helping them to assemble and perceive those ways of thinking that they had not previously combined, as long as these capacities have been matured in their zone of proximal development. In the *bottom-up* strategy each novel arrangement of relationships among concepts are designed as simple advance organizers, in the form of expert skeleton C-maps (ESCM), led by superordinate concepts that can be purposefully expanded upward as well as downward. What is critical with these organizers is not whether they are comparative or expository (Woolfolk, 2010), but that they are effective in transferring teacher's awareness to the learners, an objective that can be obtained even with a *single* overarching concept, like the *atoms* concept in Fig.8.

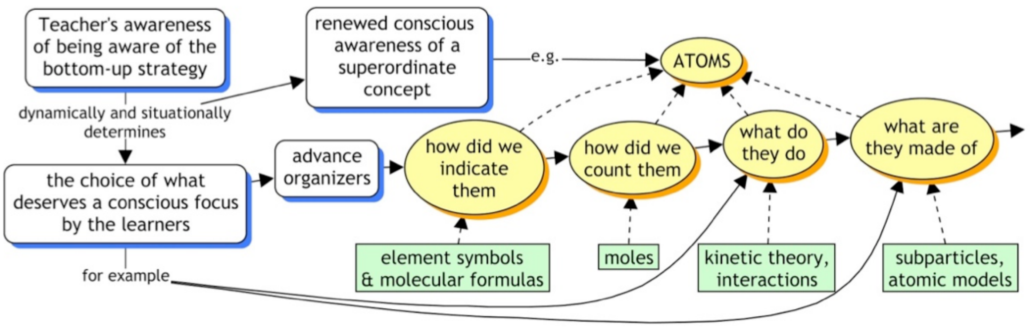

Figure 8. Bottom-up strategy is based on the transfer of teacher's awareness to the learner. This C-map shows how the strategy was applied to a series of four first-class units, each one with its single-concept advance organizer, which recursively changed the *atoms* concept.

References

Bruner, J. (1960). *The Process of Education*, Cambridge, Mass.: Harvard University Press. Chapter 3.

Dowd, J. E., Duncan, T. & Reynolds, J.A. (2015). Concept Maps for Improved Science Reasoning and Writing: Complexity isn't Everything. *CBE – Life Sciences Education*, 14: 1 – 6.

Johnstone, A. H., & Otis, K. H. (2006). Concept Mapping in Problem Based Learning: A Cautionary Tale. *Chemistry Education Research and Practice*, 7, 84–95.

Kinchin, I. M. (2001). If Concept Mapping is so Helpful to Learning Biology, why aren't We all doing It? *International Journal of Science Education*, *23*(12), 1257-1269

Kinchin, I. M. (2014). Concept Mapping as a Learning Tool in Higher Education: A Critical Analysis of Recent Reviews. *The Journal of Continuing Higher Education*, 62: 39 – 49.

Kinchin I. M. (2015). Blog https://profkinchinblog.wordpress.com/tag/concept-map/ (accessed May 2, 2016)

Mahn, H. (2015). Classroom Discourse and Interaction in the Zone of Proximal Development, in The Handbook of Classroom Discourse and Interaction (ed N. Markee), John Wiley & Sons, Inc, Hoboken.

Mahn, H. (2016.) Int. Vygotsky Learning Community, Resource Library, lesson #4 (reserved to members)

Novak, J. D., & Gowin, D. B. (1984). Learning How to Learn. New York: Cambridge University Press.

Novak, J. D. (1994). A View on the Current Status of Ausubel's Assimilation Theory of Learning. *Giornale Italiano di Pedagogia, Sperimentale, Didattica, Docimologia, Tecnologia dell'istruzione*, 2(4), 7–23.

Novak, J. D. (2002). Meaningful Learning: The Essential Factor for Conceptual Change in Limited or Inappropriate Propositional Hierarchies (LIPHs) Leading to Empowerment of Learners. *Science Education* 86(4): 548-571.

Novak, J. D., & Cañas, A. J., Expert Skeleton Concept Maps, Accessed from: http://www.cmappers.net/docs/skeletoncmaps.php, 2016.

Piihl, J., & Philipsen, K. (2011). A Research-based Approach to University Curriculum Development that Prepares Students for Subsequent Practice. In C. Nygaard, N. Courtney, & C. Holtham (Eds.), *Beyond Transmission—Innovations in University Teaching* (pp. 27–43). Faringdon, UK: Libri Publishing.

Tifi, A. Concept Mapping and the Development of Argumentation in the ZPD, In P. Correia, M. E. I. Malachias, A. J. Cañas & J. C. Novak (Eds), *Concept Mapping to Learn and Innovate*. Proc. of the Sixth Int. Conference on Concept Mapping (Vol. x, pp. xxx-xxx). Santos, Brazil: Universidade de São Paulo.

Wexler, M. N. (2001). The Who, What and Why of Knowledge Mapping. *J. of Knowledge Management*, *5*, 249-263.

Vygotsky, L. S. (1987). *Problems of General Psychology. The Collected Works of L. S. Vygotsky: Vol. 1.* In *Thinking and Speech.* New York, NY: Plenum.

Woolfolk, A.E., Winne, P.H., Perry, N.E., & Shapka, J. (2010). *Educational Psychology* (4th ed). Toronto: Pearson Canada.