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Article

Uncovering Types of Knowledge in Concept Maps

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Abstract: Concept maps have been shown to have a positive impact on the quality of student learning in a variety of disciplinary contexts and educational levels from primary school to university by helping students to connect ideas and develop a productive knowledge structure to support future learning. However, the evaluation of concept maps has always been a contentious issue. Some authors focus on the quantitative assessment of maps, while others prefer a more descriptive determination of map quality. To our knowledge, no previous consideration of concept maps has evaluated the different types of knowledge (e.g., procedural and conceptual) embedded within a concept map, or the ways in which they may interact. In this paper we consider maps using the lens provided by the Legitimation Code Theory (LCT) to analyze concept maps in terms of semantic gravity and semantic density. Weaving between these qualitatively, different knowledges are considered necessary to achieve professional knowledge or expert understanding. Exemplar maps are used as illustrations of the way in which students may navigate their learning towards expertise and how this is manifested in their concept maps. Implications for curriculum design and teaching evaluation are included.

Keywords: semantic density; semantic gravity; Legitimation Code Theory; expertise; theory-practice

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1. Introduction

The primary focus of 21st century education is to support students to develop meaningful knowledge that can be applied to a range of evolving, real-world settings [1–3]. The world with all its complexity—including a rapid growth of information and knowledge, along with increased pressures on the educational system—creates a challenge to help students to develop the skills to navigate these complexities. Therefore, the key role of curricula at school and at university is to promote theoretical knowledge that underpins evolving practice, and to help students to navigate between theoretical and everyday knowledge and between different kinds of theoretical knowledge [3]. Additionally, learners in higher education have to be prepared with appropriate, authentic contextual knowledge to ensure graduate employability [4].

In any discipline, novices tend to have loosely organized knowledge, where concepts and strategies are not well linked, while experts have a highly organized and well-structured knowledge base that allows them to use information meaningfully to solve problems [5,6]. Rather than adopting a trial-and-error approach that is typical for a novice, we need experts that can use a principles-based approach to solve problems [7]. With this in mind, several researchers have demonstrated the benefits of concept mapping in teaching, learning and assessing scientific subjects. The use of concept maps has been shown repeatedly to be an effective tool for improving conceptual understanding [8–12], developing higher-order thinking skills [13], revealing misconceptions [14,15] and eliciting achievements and grades [16]. Therefore, we ask: what do concept maps reveal if we explore different types of knowledge (novice, theoretical, practical and professional) in students' concept maps?

The scoring of concept maps and the awarding of a single number to summarize map quality may give an indication of how much information a student has acquired during his/her study, but it does not provide any indication of the types of knowledge that have been acquired (e.g., conceptual or procedural) or the relationships that the student has identified between knowledge types. This recognition if different knowledges has been described as essential for developing the basic characteristic of the expert student [17] who needs to recognize the existence and complementary purposes of different knowledge structures. This has been overlooked in the research literature on concept mapping that has tended to foreground the development of conceptual knowledge to the exclusion of procedural knowledge. The focus on the development of a discrete single map structure has emphasized this bias in knowledge type, with procedural knowledge often being buried within a map of conceptual knowledge. Kinchin and Cabot have discussed how expertise requires the oscillation between linear structures of procedural knowledge and networked structures of underpinning conceptual knowledge, but they did not offer any framework to assess the relationship between the two or how this may evolve over time [18].

In this paper we explore how different types of knowledge are embedded within a concept map and interact to each other. Concept maps that represent learners' knowledge structures have been associated with meaningful learning theory [19] and the promotion of higher order thinking skills [13]. Here, we present a major shift in emphasis in concept map evaluation by considering the analysis of concept maps in relation to the semantics dimension of Legitimation Code Theory [20]. This not only provides a commentary on the student's progress, but also offers a critique of the curriculum experienced and the way in which it facilitates (or not) a student's development from novice to expert. Here, expertise is considered to be derived from the purposeful interaction of different knowledges (as described by [21]). We present examples of student maps that illustrate the way in which students may navigate the curriculum and argue that, in most cases, students do not reach the level of professional understanding.

The expert structure that represents professional knowledge is explicit in the integrated nature of theoretical knowledge and the way in which this underpins the procedural knowledge that constitutes the visible practice that defines a professional [22]. The derivation of chains of practice from theoretical knowledge is one of the hallmarks of expert knowledge [18]. However, we should not be surprised that this expertise is rarely exhibited by students, who grapple with their understanding of concepts before they are able to distinguish between conceptual and procedural knowledge, or that it is rarely depicted in concept maps that generally aim to combine procedural and conceptual knowledge within a single structure. The example of professional knowledge given in Figure 1 (of local anesthetics in dentistry) shows how knowledge that has a high semantic density and low semantic gravity, SD+SG- (such as physiology and pharmokinetics), determines the structure of the theoretical knowledge to the right, whilst the chain of practice to the left is composed of concepts such as instrument assembly and techniques, which exhibit lower semantic density and high semantic gravity (SD-SG+). In this paper, we explore the possibility of locating elements from the practical and the theoretical in students' emerging understanding of a discipline as an indicator of their current status on the journey through secondary and higher education towards professional knowledge.

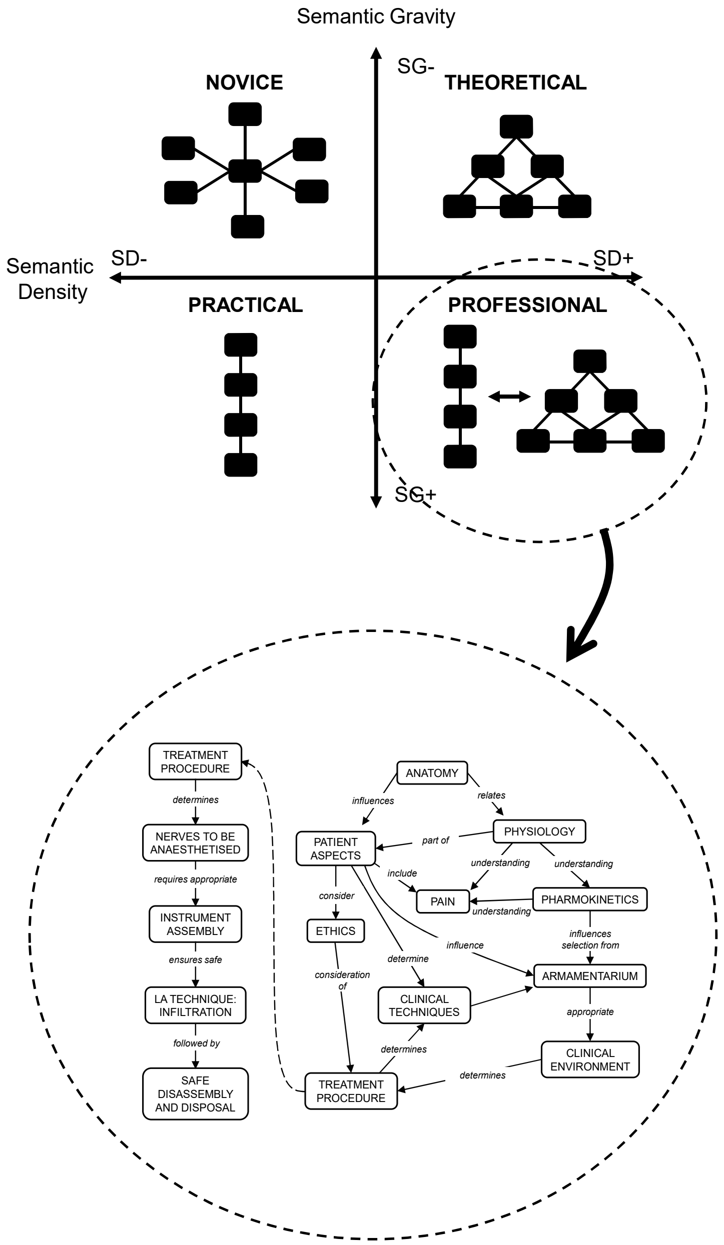


Figure 1. The semantic plane in which each quadrant has been populated by the archetypal map morphology (spoke, chain and network) that is likely to be found there, with (inset below) an example of a well-defined expert knowledge structure in which practice and theory are clearly delineated as complementary chain of practice and network of understanding [17,20,23].

2. Theory of Concept Maps

Concept maps have their roots in Ausubel's meaningful learning theory, and they emphasize the connections among concepts that represent individuals' knowledge structure [10,24,25]. There are three elements from Ausubel's theory that Novak and his research team found useful to develop in the concept mapping method:

(1) Construction of new meaning involves conceptual connections between new information and prior knowledge.
(2) Hierarchically organized cognitive structure where more general concepts are higher level in the hierarchy and less general are positioned under the more general concepts.

(3) Meaningful learning takes place when relationships between concepts are explicit and are better integrated with other concepts and propositions [10].

Concept maps are composed of concepts that are written in boxes and connected with arrows that are labeled to indicate the relationship between concepts [26]. The labeled connections between concepts are called links, and each 'concept-link-concept' forms a proposition that can be read as a stand-alone meaningful expression. Cross-links, which might sometimes be formed, show the relationships between two different areas of the map [27]. Concept mapping is a skill that encourages nonlinear thinking [28]. The construction process of concept mapping helps the learner to actively construct their knowledge and, as suggested by Hyerle [29], helps students to "think inside and outside the box". The important function of this graphic representation is to display the overall arrangement of concepts and the enhancement of metacognitive skills [7,12]. According to Salmon and Kelly, concept mappers with these skills are able to (1) define specific thinking process as recurring patterns; (2) support the transferring these patterns across disciplines; (3) guide the building of simple to complex mental models and (4) reflect how the frame of reference influences their meaning-making, thinking patterns and understanding [7].

Kinchin expresses the benefits of using concept maps by saying, "This is a tool that helps me not only to see how the students are putting ideas together (or not), but can also help the students to diagnose their own difficulties" [17]. Much school learning is achieved through rote learning, while using strategies like note-taking, rewriting the textbook pages, summarizing as bullet points and completing 'fill-the-gap' test that are not as productive as concept maps to develop well-organized knowledge. Thus, learners who are used to learning through rote learning find the higher level thinking that is required to construct a concept map challenging [13]. Concept mapping has also been proposed as a useful tool to support the learning of complex topics, where learners have fragmented understanding and might face difficulties integrating all components to form a meaningful overview [12]. The external scaffolding that the concept mapping process involves can be very helpful to support deep thinking and complex learning [7].

Concept Maps—Hierarchy and Scoring

Concept maps are unique for their graphical structures that exhibit how one concept is sub-ordinate to other concepts and how learners' understand the concepts [12,30]. A hierarchical concept map (also called a "Novakian concept map") is recognizable for its top-down fashion, where more general subordinate concepts are on top and more specific concepts are at the bottom. For instance, Novak and his colleagues claim, "A well-organized cognitive structure (which is necessary for meaningful learning) usually leads to graphically well-organized concept maps; in turn, building good concept maps helps to build a good knowledge structure" [31].

Several authors [11,30,32–34] associate the map hierarchy with the learning context. As stated earlier, the propositional structure is an essential part of concept mapping and shows learners' meaningful learning. However, not all 'concept-link-concept' triads form a meaningful proposition because they might miss the proper structure, have no logical meaning or constitute a large grammatical structure (e.g., sentence) that has no meaning independently within this bigger structure [35]. There are many authors, who consider different aspects of quality and complexity of concept map structure within their scoring rubrics.

The semantic scoring rubric of Miller & Cañas consists of six key criteria that are inherent for all concept maps [35]: (1) the presence of focus question and root concept, (2) the correct propositional structure—link reworking and overall map reorganization; (3) the presence on inaccurate propositions (misconceptions); (4) the presence of dynamic propositions that involves, movement, action, change of state or dependency relationships (e.g., roots absorb water, electric charge generates electric fields, etc.); (5) the number of quality cross-links that establish correct, suitable, and instructive relationships and (6) the presence of cycles in which the direction of the arrows allows traversing the entire closed path in a single direction. All of these six levels are also translated to the content-quality scale that is followed by the categories of unevaluated, very low, low, intermediate, high and very high.

Other studies have suggested that the structure of the concept map carries important information about the understanding and quality of learners' knowledge [11,12,30,36]. Many authors [7,30,37–40] emphasize the effectiveness of the qualitative scheme that differentiates three morphological types of concept map categories—spoke, chain and network [11]. Their model is based on map morphology that has following characteristics [12,41,42]:

(1) Spoke graphical structure—(a) concepts form only a single level and all subordinate concepts are in relation to the root concept; (b) subordinate concept are not connected to the neighboring subordinate concepts; (c) deleting concepts from the map (except deleting the root concept), does not impact the overall structure; d) the links that are built-in to the spoke structure are simple, do not create cross links and do not impact neighboring subordinate concepts.

(2) Chain graphical structure—(a) the root concept is linked to the subordinate concept and forms a sequence with the next concepts. There is no hierarchy, but concepts are listed in multiple levels in relation to the root concept; (b) subordinate concepts are connected only with the next following concept; (c) deleting concepts impacts only the subordinate concept lower down in the sequence; (d) the links are compound and therefore the meaning is readable only as a whole.

(3) Network graphical structure—(a) concepts are related to the root concept and form multiple levels defined as a "highly integrated and hierarchical network (of concepts) demonstrating a deep understanding of the topic" [11]; (b) removing or adding concepts does not impact the overall structure, as the cross links maintain the integrity of the map; (c) network is structured across different levels with interconnections, and indicates deep understanding and meaningful learning strategies.

Extreme versions of each of these morphological types are depicted within the quadrants of the semantic plane (Figure 1) to indicate the stereotypical structures that may be found to depict novice knowledge, theoretical knowledge and practical knowledge. However, each of these extremes is not 'fixed' and may evolve into another in response to student learning. For example, a spoke structure may develop into a chain or a network over a period of time as the student's understanding develops and is more systemized and complex in response to further learning [12]. Besides that, Kinchin discusses what is a "good" and "poor" map by comparing the exam results with the maps [12,43]. He concludes that "poor" maps are not always indicators of poor performance and "good" maps not always predictors of good performance. There is no one common determination whether a concept map is really good in terms of indicating the presence of a sophisticated understanding. In addition, Kinchin [17] claims, "bigger does not always mean better when evaluating concept maps."

Cañas [31] uses the idea of an "excellent map," and considers that both content and structure are important to determine the map quality. Cañas and colleagues [31] describe excellent concept maps as being concise and explanatory, exhibiting a high degree of clarity and presenting a clear message. In addition, excellent maps should also be well balanced, well-structured and demonstrate learners' understanding.

3. Materials and Methods

Exemplar student concept maps (here constructed by students during school science lessons) are translated into commentaries on the types of knowledge depicted by converting the linking phrases between concepts into descriptions of their semantic density and semantic gravity (see Figure 2). In terms of semantic gravity (SG), each proposition is considered in relation to the way in which the student has articulated the degree to which the knowledge is either tied to a particular context (SG+) or offers a more generalizable view (SG-) (see Table 1). We distinguish here between knowledge that is very context bound (SG++) and that which is less tightly bound (SG+) to offer a more nuanced description of the knowledge quality. Propositions are also evaluated according to the semantic density that is depicted (SD), where students may be using simple, everyday descriptions in their explanations (SD-) or may be offering much more technical summaries that exhibit considerable condensation of meaning (SD+). Again, the degree of condensation is considered by using SD+, SD++, SD- and SD– (see Table 1). In this way, each of the quadrants of the semantic plane itself has four sub-quadrants into which propositions may be plotted, giving up to 16 variants across the semantic plane. Once each proposition has been translated to indicate its semantic profile (SD±SG±), this is then plotted on the semantic plane (Figure 2) to indicate the semantic range depicted within the map. When using this method, researchers may need to establish the degree of inter-rater reliability to decide on ++ or + and on – or -. In this study we had three authors who were familiar with the content and agreed upon the level of density and gravity within each proposition.

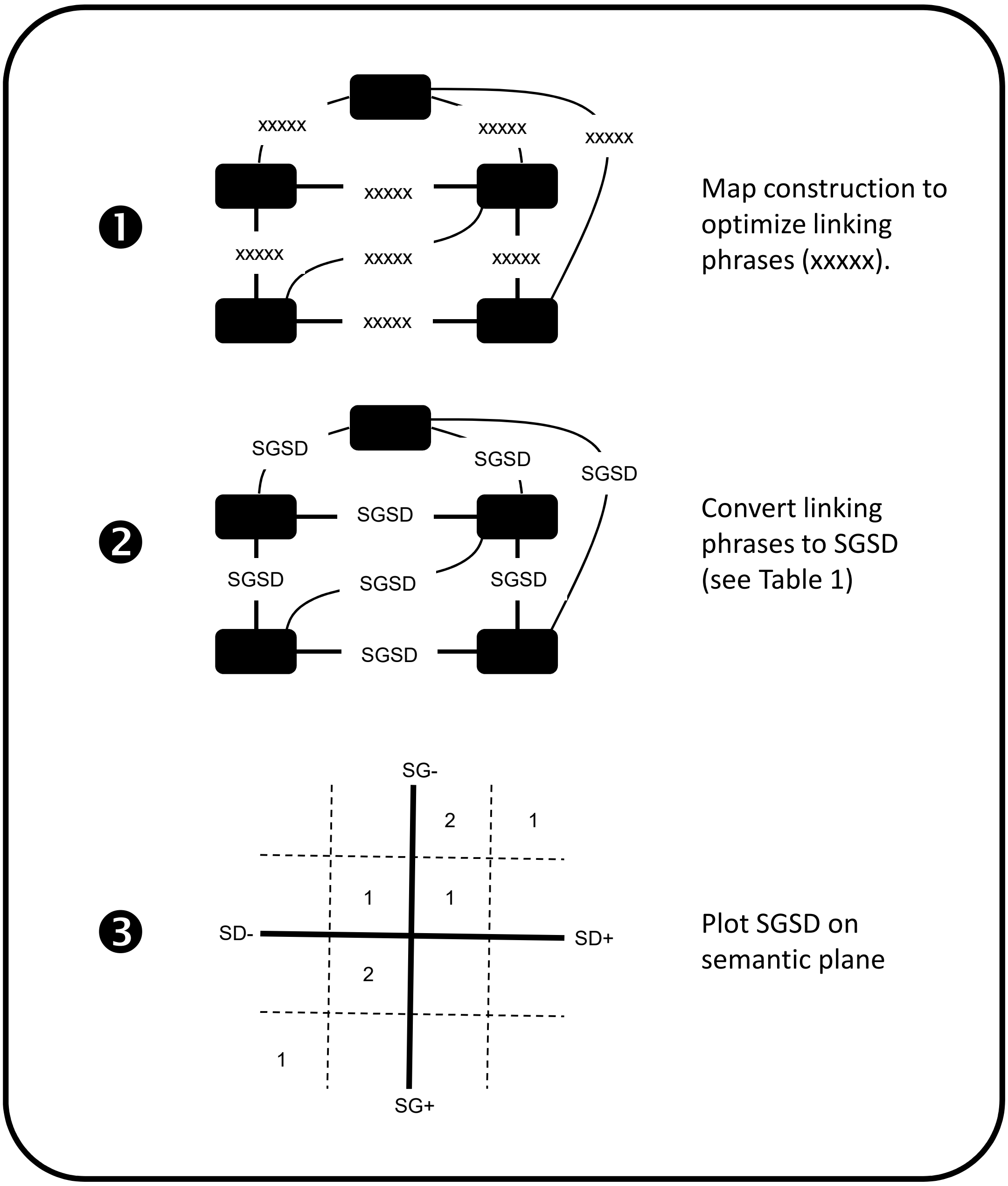


Figure 2. A three step process of map construction (1), translation (2) and plotting (3) on the semantic plane.

Table 1. Proposition analysis translation device. Modified from [44].

Novice Knowledge		
SD-; SG-	**SD-** - student needs to interpret only one concept to form a theoretically/scientifically correct proposition - proposition does not need to be manipulated to the given context (the whole concept map)	**SG-** - student uses concept from different sections of curriculum - propositions create unified theory that is applicable to a broader context
SD-; SG–	**SD-** - student needs to interpret only one concept to form a theoretically/scientifically correct proposition - proposition does not need to be manipulated to the given context (the whole concept map)	**SG–** - student uses abstract concepts (e.g., biology, chemistry, physics) and integrates them with general everyday knowledge that is applicable in a wide range of contexts propositions might unify scientific principles by highlighting links between ideas
SD–; SG-	**SD–** - student uses general everyday language and there is no theoretical knowledge needed to form a proposition - forming a proposition does not need understanding or interpretation of scientific terminology (e.g., biology, chemistry, etc.)	**SG-** - student uses concepts from different sections of curriculum - propositions relate to ideas that are applicable to a broader context
SD–; SG–	**SD–** - student uses general everyday language and there is no theoretical knowledge needed to form a proposition - forming a proposition does not need understanding or interpretation of scientific terminology (e.g., biology, chemistry, etc.)	**SG–** - student uses abstract concepts (e.g., biology, chemistry, physics) and integrates them with general everyday knowledge that is applicable in a wide range of contexts - propositions might unify scientific principles by highlighting links between ideas
Theoretical Knowledge		
SD+; SG-	**SD+** - student uses specialized scientific concepts - student needs to identify concepts before they can be interpreted to form a meaningful proposition	**SG-** - student uses concepts from different sections of curriculum - propositions relate to ideas that are applicable to a broader context
SD+; SG–	**SD+** - student uses specialized scientific concepts - student needs to identify concepts before they can be interpreted to form a meaningful proposition	**SG–** - student uses abstract concepts (e.g., biology, chemistry, physics) and integrates them with general everyday knowledge that is applicable in a wide range of contexts - propositions might unify scientific principles by highlighting links between ideas
SD++; SG-	**SD++** - student needs to identify concepts (multiple steps required) to form a meaningful/scientifically correct proposition that interacts with the whole concept map	**SG-** - student uses concepts from different sections of the curriculum - propositions relate to ideas that are applicable to a broader context
SD++; SG–	**SD++** - student needs to identify concepts (multiple steps required) to form a meaningful/scientifically correct proposition that interacts with the whole concept map	**SG–** - student uses abstract concepts (e.g., biology, chemistry, physics) and integrates them with general everyday knowledge that is applicable in a wide range of contexts - propositions might unify scientific principles by highlighting links between ideas
Practical Knowledge		
SD-; SG+	**SD-** - student needs to interpret only one concept to form a theoretically/scientifically correct proposition - proposition does not need to be manipulated to the given context (the whole concept map)	**SG+** - student uses scientific concepts that are embedded in practical contexts - proposition might express an example that is used commonly in everyday life
SD-; SG++	**SD-** - student needs to interpret only one concept to form a theoretically/scientifically correct proposition - proposition does not need to be manipulated to the given context (the whole concept map)	**SG++** - student uses scientific concepts that only require a recall of the definition or rule - proposition expresses the knowledge that is located in a specific section of a curriculum
SD–; SG+	**SD–** - student uses general everyday language and there is no theoretical knowledge needed to form a proposition - forming a proposition does not need understanding or interpretation of scientific terminology (e.g., biology, chemistry, etc.)	**SG+** - student uses scientific concepts that are embedded in practical contexts - proposition might express an example that is used commonly in everyday life
SD–; SG++	**SD–** - student use general everyday language and there is no theoretical knowledge needed to form a proposition - forming a proposition does not need understanding or interpretation of scientific terminology (e.g., biology chemistry, etc.)	**SG++** - student uses scientific concepts that only require a recall of the definition or rule - proposition expresses the knowledge that is located in a specific section of a curriculum

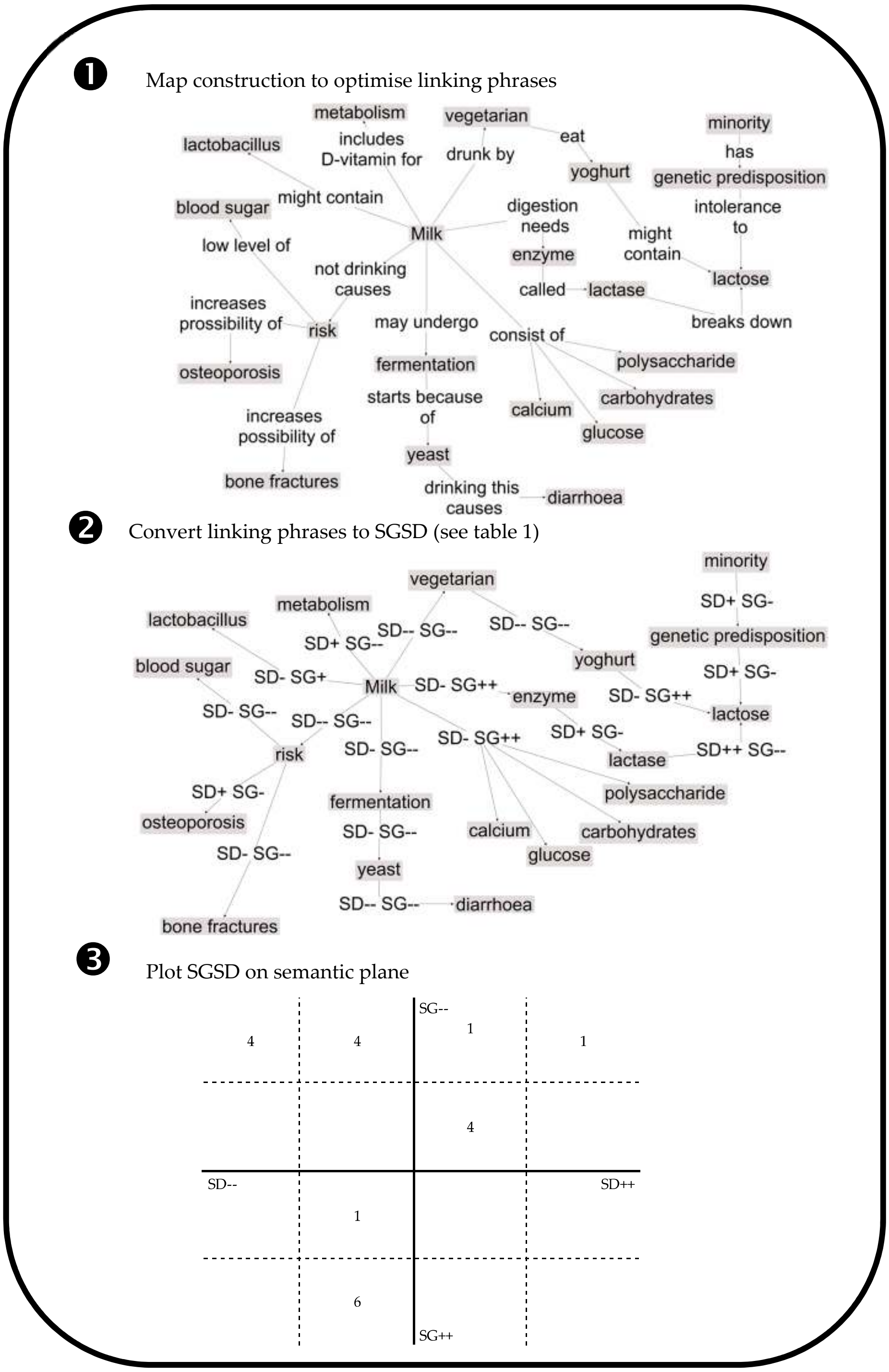
Table 1. *Cont.*

	Professional Knowledge	
SD+; SG+	**SD+** - student uses specialized scientific concepts - student needs to identify concepts before they can be interpreted to form a meaningful proposition	**SG+** - student uses scientific concepts that are embedded in practical contexts - proposition might express an example that is used commonly in everyday life
SD+; SG++	**SD+** - student uses specialized scientific concepts - student needs to identify concepts before they can be interpreted to form a meaningful proposition	**SG++** - student uses scientific concepts that only require a recall of the definition or rule - proposition expresses the knowledge that is located in a specific section of the curriculum
SD++; SG+	**SD++** - student needs to identify concepts (multiple steps required) to form a meaningful/scientifically correct proposition that interacts with the whole concept map	**SG+** - student uses scientific concepts that are embedded in practical contexts - proposition might express an example that is used commonly in everyday life
SD++; SG++	**SD++** - student needs to identify concepts (multiple steps required) to form a meaningful/scientifically correct proposition that interacts with the whole concept map	**SG++** - student uses scientific concepts that only require recall of the definition or rule - proposition expresses the knowledge that is located in a specific section of the curriculum

4. Results

The maps considered here were constructed by students aged 16–17 years in an Estonian high school. This data collection was a part of the large-scale study (LoTeGym) that was undertaken from 2012–2014 [45]. The concept mapping instrument was linked with interdisciplinary scenarios from a cognitive test. The test instrument consisted of four interdisciplinary everyday life related scenarios, where each focused on one science subject (biology, chemistry, geography and physics). The aim of the test was to evaluate students' ability to give a scientific explanation, pose scientific questions, solve scientific problems and to make reasoned decisions. Students were given 30 different types of concepts (science processes, everyday social issues-relates, etc.) to map on the topic of 'Milk—is it always healthy?' Some of these concepts were representations of 'everyday' knowledge (i.e., the practical application of the theoretical concepts derived from biology, chemistry and physics). After a period of training to see exemplar maps and to gain some familiarity with the software, a cohort of 187 students were given 45 min to construct a concept map. The concept mapping was carried out using the computer program CmapTools. To ensure consistency of the data collection, the introductory training sessions before the concept mapping task was undertaken by the same researcher. All students were given an example of how to construct a concept map before the main maps were constructed. One supervisor was in the classroom to assist with possible technical problems and to ensure adherence to the structural grammar of Novakian concept maps [26]. Whilst it was noted from preliminary observation that most of the maps display a gross morphology indicative of novice understanding (a spoke structure), there was a large degree of variation in the ways in which the concepts were arranged and in the quality of the propositions used to link concepts. From this cohort, two exemplars are illustrated below as worked examples to showcase the method for map analysis.

Figure 3 shows the map produced by one student. A quick observation indicates this to be a spoke-type map [11], in which chains of propositions radiate out from the central concept, but little cross-linking is evident between the chains. Once the propositions are converted to indicate the degree of semantic density and semantic gravity, it can be seen that >1/3 of the propositions are categorized as SG-SD- (indicative of novice knowledge). The remaining propositions are divided almost equally between the theoretical and practical quadrants of the plane, but none are ascribed to the lower right hand quadrant (professional knowledge).

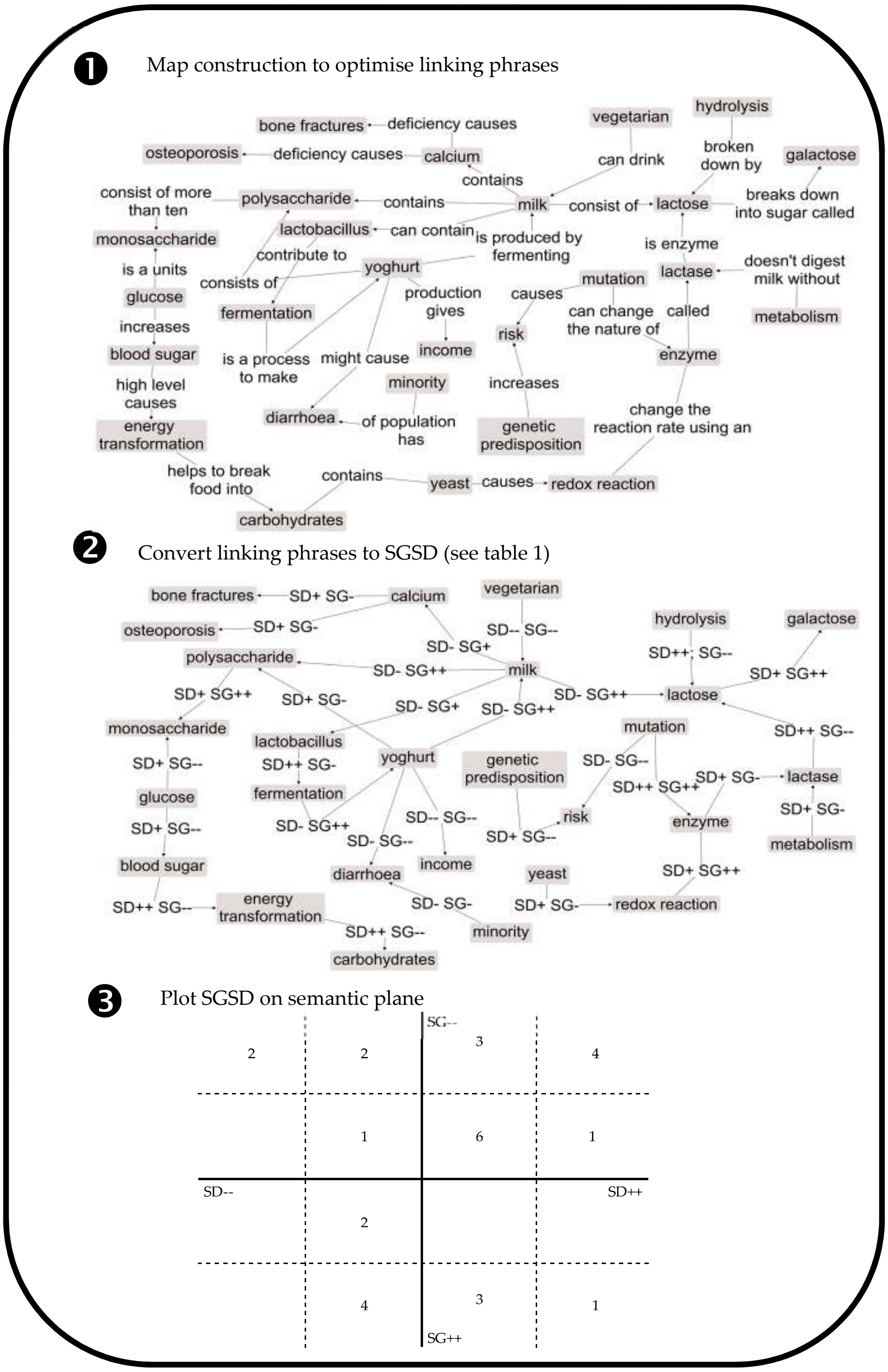

❶ Map construction to optimise linking phrases

❷ Convert linking phrases to SGSD (see table 1)

❸ Plot SGSD on semantic plane

Figure 3. An example of a student map exhibiting a strong 'spoke' structure that suggests a novice understanding, which is emphasized by the presence of 8 propositions in the top left quadrant of the semantic plane.

The map in Figure 4 may also be designated as a novice map; however, there appears to be some development from the map in Figure 3, as the student here shows a greater attempt to show some cross-linking of concepts, moving from the spoke structure towards a more integrated network structure [11]:



❶ Map construction to optimise linking phrases

❷ Convert linking phrases to SGSD (see table 1)

❸ Plot SGSD on semantic plane

Figure 4. An example of a student map that suggests some emerging integration that builds on a novice structure, reinforced by the broad distribution of propositions across the semantic plane.

Whilst charting the position of the propositions across the semantic plane still indicates some novice knowledge (5 propositions), the majority of propositions represent theoretical (14 propositions) and practical knowledge (6 propositions), with some also being classified as professional knowledge. This suggests some semantic weaving on the part of the student.

5. Discussion

Disagreements within the research community about the most appropriate methods of analysis of concept maps have the potential to inhibit the widespread classroom use of the tool to support learning [43]. The benefits and drawbacks of traditional quantitative or qualitative approaches to map analysis are compounded by the fact that researchers have not previously discriminated between the types of knowledge that have been embedded within maps. The application of the semantics dimension of Legitimation Code Theory offers a new approach that is explicit in the need to consider understanding to be composed of qualitatively different knowledges that need to communicate with each other in the pursuit of expertise.

The consideration of the degree of semantic density and semantic gravity exhibited within map propositions offers a more nuanced consideration of map quality that is achieved by considering map morphology alone. However, it allows for the consideration of that which is 'yet-to-be-known' (rather than assessment of 'correctness') so that maps of contested values and beliefs can be assessed using the same approach as maps of agreed factual content [17]. The significance of the semantic profiles that students exhibit in their concept maps offers a window into some of the issues they experience on their educational journey—particularly as they move between school, university and professional life. For example, the differences in the structuring of knowledge that exist between a high school and a university biology curriculum (that has been observed by Kelly-Laubscher and Luckett [46]), suggest the existence of a possible mismatch between the semantic range that students are expected to navigate at university against that which they will have experienced in secondary school. This may cause problems for students' transition from school to university when their school education is assumed to have given them the necessary prerequisite knowledge to embark upon their undergraduate studies. Tracing the changes in the semantic profiles that students exhibit provides a visualization of the progress that students are making against desired outcomes, offering a way of monitoring student progression and curriculum effectiveness. However, we cannot assume homogeneity of the knowledge quality held by students as they enter university, even when they have covered the same content at school. The two examples shown here display differences in students' semantic profiles such that the student represented in Figure 4 appears to exhibit a greater semantic range within his knowledge structure of this content area, suggesting a better preparedness of undergraduate study. To confirm this, we need to explore a greater range of curriculum content with the students to see how key areas of the curriculum have been structured in the students' minds.

6. Conclusions

This new approach to concept map analysis raises a number of new opportunities and challenges for the research community:

By considering concept maps to be composed of different types of knowledge, it offers the possibility of asking a new set of research questions that might be addressed through concept mapping. Where powerful knowledge [47] is seen as the goal of professional education, then the semantic weaving between theory and practice is required to achieve expertise [21]. The assessment of this plurality of knowledges requires the mapping of semantic density and semantic gravity.

Beyond just assessing the 'correctness' of propositions within a map, the application of Legitimation Code Theory to concept mapping allows for the assessment of the ways in which the mapper is able to link theoretical knowledge with practical knowledge. This lifts the map above the assessment of factual recall and considers the higher order thinking skills that are required for students to achieve mastery of their discipline. This mastery has been shown to be dependent upon the learner's ability to oscillate between complementary knowledge structures consisting of chains of practice (exhibiting low semantic density and high semantic gravity), and underpinning networks of understanding (exhibiting high semantic density and low semantic gravity) [18,22]. The method of applying Legitimation Code Theory to concept mapping described in this paper provides a way to make the knowledges that underpin that expert practice explicit, so that they may be modeled for students. Further, this paper suggests that when assessing students' knowledge using concept maps, the use of a single map may be insufficient in order to obtain an authentic representation. As procedural and conceptual knowledge may be constructed differently and activated in different contexts, it may be better to encourage students to separate them structurally, whilst also recognizing the ways in which they interact in expert practice (as in Figure 1). This represents a significant methodological shift from many of the research papers that have previously explored learning using concept maps and that had assumed that complex knowledge may be captured in a single map structure.

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