Concept Map-Based Formative Assessment of Students' Structural Knowledge

Concept Map-Based Formative Assessment of Students' Structural Knowledge:

Theory and Practice

By

Alla Anohina-Naumeca

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INTRODUCTION

> "The goal of formal education is to help students develop the types of knowledge representations, ways of thinking, and social practices that define successful learning in specific domains".
>
> (Elvira et al. 2016)

It is undoubtedly the fact that in the last two decades a knowledge-based society has developed around the world (UNESCO 2005). It has brought with it a new economic model which is based on knowledge and is called a knowledge-based economy. In the European Union, the Lisbon Strategy set out an objective for Europe to become the most competitive and dynamic knowledge-based economy in the world (The European Council 2000). The knowledge-based economic model considers the creation, distribution and use of knowledge as the most important value (Novak 2002) and a driving force of productivity and economic growth (OECD 1996), because knowledge provides the basis for the necessary innovations in products and processes, effective decision-making, problem-solving and competitiveness. As a result, the knowledge-based economy requires more highly-skilled labour (OECD 1996). Europe's capacity to compete in these circumstances depends on whether its higher education institutions can meet the rapidly growing demand for highly qualified workers (Schleicher 2006). Tynjälä (1999) points out that the proliferation of internationalisation, knowledge-intensive work, information technology and new working organisation forms (networks and teams) raises serious challenges for the formal education system as the preparation of experts for the labour market is expected from it. This fact requires that graduates of formal education are able to adapt to the working environment quickly and to effectively engage in professional activities. In the field of higher education, this means that it is necessary to achieve a situation where graduates' knowledge, skills and attitudes, in both their characteristics and content, are similar as much as possible to the knowledge, skills and attitudes of experts in the corresponding industry.

In fact, the idea that formal education should establish the necessary preconditions and foster student development towards expert-level performance has already been promoted for many years (see, for example, Alexander 2005; Boshuizen, Bromme, and Gruber 2004; Geisler 1994;

Goldman, Petrosino, and CTGV 1999). In this context, Kinchin (2016) and Sternberg (1998, 2003a) have already introduced the concept of the "expert student". Tynjälä (1999) emphasises that educational institutions play an essential role in creating (or hindering) the prerequisites that contribute to the development of student expertise. In turn, Kinchin and colleagues (2008) have considered such a development as a critical element in higher education.

In the context of knowledge, it should be emphasised that expert knowledge differs in its organisational aspects from the knowledge of less experienced professionals. Pedagogical and psychological studies carried out in this field indicate that expert knowledge has a larger number of meaningful relationships between domain concepts (Etringer, Hillerbrand, and Claiborn 1995; Glaser, Lesgold, and Lajoie 1987; Hoffman 1998; Hoffman and Lintern 2006; Yielder 2009) and these relationships determine expert abilities to recall knowledge more easily and to judge, make decisions and solve problems in a more effective way (Ifenthaler, Masduki, and Seel 2011; National Research Council 2000). In other words, experts have quantitatively and qualitatively different structural knowledge, which generally refers to the knowledge of relationships between concepts of a specific domain (Jonassen, Beissner, and Yacci 1993). Consequently, in order to facilitate the development of students towards expert-level performance, it is necessary to develop students' structural knowledge on a continuous basis in the study process by promoting the creation of meaningful relationships between taught concepts rather than fostering memorisation of unrelated facts and concepts. Koponen and Pehkonen (2008) point out that the primary and foremost purpose of education is to ensure that students learn organised and hierarchically arranged knowledge.

The teaching and learning practice of higher education institutions is changing in accordance with global economic changes. As a result, learning in higher education is nowadays considered in the framework of the constructivist approach to learning as a process in which students actively construct their knowledge (Nicol and Macfarlane-Dick 2006) by relating new information with the previously mastered knowledge instead of transferring knowledge from the teacher to students. Consequently, a student-centred learning approach is emphasised that envisages the active participation of students in the study process, and the development of deep understanding, student autonomy and responsibility for learning (T4SCL Project 2010a, 2010b; Nicol and Macfarlane-Dick 2006). In this context, a formative assessment has been put in the forefront in the field of students' evaluation and assessment. The formative assessment aims at developing

and improving the learning process and its aspects through the implementation of adjustments in the study process based on the analysis and use of feedback (information acquired in student assessment). As a result, this assessment type could be particularly suitable for the continuous development of students' structural knowledge. Nowadays, formative assessment is no longer understood as the teacher checking students' work and providing comments on its quality. Its modern understanding relates this type of assessment to promoting students' self-regulation, reflection, autonomy and responsibility for learning through the use of collaborative student self- and peer assessment activities (Andrade 2010; Boud 2014; Boud and Molloy 2013; Molloy and Boud 2013; Nicol 2014; Nicol and Macfarlane-Dick 2006; Sadler 2012). Nicol and Macfarlane-Dick (2006) stress that formative assessment and feedback should be used in higher education to help students develop self-regulatory skills.

In the context of structural knowledge, it should be noted that changes in the socio-economic system and the rapid development of information and communication technology have led to a number of new trends in higher education (student mobility, employment during study time, wide availability of learning resources on the Web, and other trends), which have opened new opportunities for knowledge acquisition. In this situation, the teacher should be aware that, in every lecture that s/he offers to students, new concepts are defined, new relationships between the concepts previously learned are revealed, and the concepts previously learned are considered in the new context, and all of this is integrated with the knowledge that the student has already acquired, inter alia outside the study institution, for example, studying at another university in the framework of a mobility programme, participating in a Massive Open Online Course or collaborating with students with different educational experience or cultural background. As a result, today's university teachers have almost entirely lost their influence on the way students learn and what knowledge they acquire. In the past, when the possibilities for acquiring knowledge were not so broad, the university teacher was able to influence student learning in many ways, among other things by choosing the content of lectures, offering certain learning activities and recommending the literature recognised in the corresponding science field. Thus, the teacher was able to at least partially anticipate the development of student structural knowledge. All of the above-mentioned factors indicate that students' structural knowledge contains many missing, false and incorrect relationships between concepts because, according to Kinchin (2015), much of the learning in universities is fragmented in its

nature as it is promoted by cycles of non-learning when students acquire facts without any change in their knowledge. It again emphasises the necessity to apply teaching methods directed towards the continuous assessment and development of students' structural knowledge throughout the study process, so the university teacher can be sure that students' structural knowledge matches the knowledge structure accepted in a scientific field and that it contains few misconceptions and false beliefs, which may hinder further learning and achievement of learning outcomes.

However, teachers in higher education institutions could lack an understanding of structural knowledge and formative assessment, or they could lack awareness on how to implement the formative assessment of students' structural knowledge in their instructional practice. This book provides a guide for the assessment and development of students' structural knowledge, describing in detail not only the theoretical bases of structural knowledge and formative assessment but also offering a set of practical scenarios that can be adopted by other teachers and integrated in their professional practice. The theoretical foundations presented in this book come from the author's doctoral thesis "Formative assessment of students' structural knowledge" that was developed and defended in 2018 at the University of Latvia. They are also partly presented in the author's previous publications:

- Anohina-Naumeca, Alla. 2016. "The conceptual model of formative assessment of structural knowledge." In *Learning, Design, and Technology: An International Compendium of Theory, Research, Practice, and Policy,* edited by J. Michael Spector, Barbara B. Lockee, and Marcus D. Childress, 1-41. Springer International Publishing.
- Anohina-Naumeca, Alla. 2015. "Justifying the usage of concept mapping as a tool for the formative assessment of the structural knowledge of engineering students." *Knowledge Management & E-Learning: An International Journal* 7, no. 1: 56-72.
- Anohina-Naumeca, Alla. 2014. "Finding factors influencing students' preferences to concept mapping tasks: Literature review." *Procedia–Social and Behavioral Sciences* 128: 105–110.
- Anohina-Naumeca, Alla. 2012. "Determining the set of concept map based tasks for computerized knowledge self-assessment." *Procedia–Social and Behavioral Sciences* 69: 143-152.
- Anohina-Naumeca, Alla, and Vita Graudina. 2012. "Diversity of concept mapping tasks: Degree of difficulty, directedness, and task constraints." *Proceedings of the 5th International Conference on*

Concept Mapping, Valletta, Malta, 2012, 164-171. Valletta, Malta: University of Malta.

The practical assessment scenarios described in the book have been used and verified multiple times by the author of the book in her instructional practice, as since 2005 she has regularly assessed students' structural knowledge in her study courses and surveyed students with the aim of understanding the benefits of the formative assessment of structural knowledge through different assessment activities.

The book includes four chapters. Chapter 1, with the aim of defining the concept of structural knowledge, discusses the general understanding of the terms 'knowledge' and 'structure' and provides an analysis of theoretical foundations of structural knowledge. Furthermore, it examines the definitions of the concept 'structural knowledge' proposed by other researchers, lists the reasons for the importance of the assessment and development of students' structural knowledge, and provides the definition of structural knowledge elaborated by the author of the book.

Chapter 2 describes types of student assessment from the viewpoint of the assessment purpose. Particular attention is devoted to formative assessment as a tool for the continuous development and improvement of structural knowledge. In addition, a conceptual model of the assessment of structural knowledge is developed and presented in the chapter.

Chapter 3 deals with concept maps as a pedagogical tool for the representation and assessment of structural knowledge. It defines epistemological ideas and learning principles underlying concept maps, constituting elements and creation procedure, the ways of using the concept maps in the study process, and the advantages and drawbacks of this instrument. Furthermore, possible concept mapping tasks are analysed, and a justification of the suitability of the concepts maps for the formative assessment of structural knowledge is given.

Chapter 4 presents the practical assessment scenarios of students' structural knowledge, paying attention to general considerations that the teacher should be aware of before the use of any scenario, and describing common and specific aspects of scenarios.

CHAPTER ONE

STRUCTURAL KNOWLEDGE AS AN ASSESSMENT OBJECT

> "To be knowledgeable in some area is to understand the interrelationships among the important concepts in that domain".
>
> (Goldsmith, Johnson, and Acton 1991, 88)

There is no generally accepted definition of structural knowledge. Instead, many explanations and synonyms are offered. However, to understand the concept, it is not enough to study how other researchers interpret it: it is necessary to figure out what is knowledge, what is a structure, and how structural knowledge is acquired. This chapter therefore aims at explaining the concept of structural knowledge by defining it, identifying its theoretical foundations, and justifying the importance of this type of knowledge as an assessment object. Section 1.1 discusses the general meaning of the concepts of knowledge and structure. Section 1.2 provides an analysis of the definitions of structural knowledge offered by other researchers. Section 1.3 examines the theoretical foundations of structural knowledge and defines the concept in its narrow and broader meaning. The chapter ends with a summary of the main points.

1.1 Defining Knowledge and Structure

As the concept of structural knowledge is a combination of two words—knowledge and structural,—it is necessary, first, to establish a general understanding of both these words. Knowledge is a complex phenomenon and therefore has no unambiguous explanation. It is defined in various ways, such as "the process and products of cognition" (Lohithakshan 2002, 228); as "an intended educational outcome", that includes "concepts, principles, and practices in a particular field" together with "the general data, information, and experience that are essential to effective performance in learning and applying what has been taught" (Collins and O'Brien 2003, 197); or as "any internal information, understanding, or capacity to accomplish tasks" (Matsumoto 2009, 274). Eysenck and Keane

(2000, 306) understand knowledge as all the information that an individual has "inherited genetically or learned through experience", and it underlies all daily human activities and behaviour. Seel (2010) considers that knowledge is understood as a theoretical construct—in other words, it cannot be observed, but can be assessed on the basis of the behaviour of an individual or verbal claims made during cognitive tasks. Sternberg (2003b) has also pointed out that there is no known empirical method for observing how knowledge is organized in the human mind.

In cognitive psychology—which, according to Smith (2001), has taken the dominant position in psychology since the second half of the twentieth century, focusing directly on internal representations of environmental phenomena and aspects in the human mind—knowledge is the sum of all the content stored in the long-term memory (Goldstein 2008; Quinlan and Dyson 2008; Rutherford 2005). As a result, this concept is most often explained by offering a classification of knowledge in different types. Traditional knowledge types are declarative or factual knowledge, and procedural knowledge, or knowledge of how to complete specific functions and procedures (Anderman and Anderman 2009; Ifenthaler 2010; Matsumoto 2009; Rutherford 2005; Sternberg 2003b). However, some researchers have also defined other types of knowledge, such as schematic knowledge ('knowing why') and strategic knowledge, defining when, where and how knowledge is applied (Shavelson, Ruiz-Primo, and Wiley 2005), or situational knowledge, related to problem situations in a domain, and strategic knowledge of what needs to be done to acquire a problem solution (De Jong and Ferguson-Hessler 1996). Tristan (2013) has described 54 knowledge types in education-related literature in English: this fact once again emphasizes the complex nature and ambiguity of the concept of knowledge.

Thus, summarizing all the above mentioned, the following statements describing knowledge are sufficient for further analysis of the concept of structural knowledge: a) knowledge is content stored in the human long-term memory, b) knowledge may be of different types, and c) knowledge can be assessed by offering cognitive tasks that are relevant to the purpose of the assessment.

According to different dictionaries (Cambridge Dictionary n.d.; Dictionary.com n.d.; English Oxford Living Dictionaries n.d.; Merriam-Webster Inc. n.d.), the word 'structural' is closely related to the concept of structure that is more generally understood. Systems theory, which studies the concepts and principles attributable to any type of system in the world, defines a structure as a universal feature of various systems (regardless of their nature and field of use). Structure is a set of certain elements and the

relationships between them, taking into account that the relationships which link the elements in a whole and enable the appearance of new characteristics of the system allow consideration of the structure because, without relationships, it would be simply an isolated set of elements (Dekkers 2015). Therefore it should be concluded that the term 'structural' in the concept of structural knowledge specifies the type of knowledge (as it is in case of declarative, procedural, and other types), allowing structural knowledge to be defined as knowledge of relationships between certain elements. To ascertain the essence of elements and relationships, the definitions of structural knowledge proposed by other researchers are analysed further in the book.

1.2 Existent Definitions of Structural Knowledge

Although the concept of structural knowledge is not a new one, there is a certain confusion regarding its clear definition in the scientific literature. Firstly, many other concepts are mentioned or used as synonyms for structural knowledge. Table 1-1 represents the existent synonyms and shows that the most commonly used synonyms for structural knowledge are a knowledge structure and a cognitive structure. Secondly, there exists a considerable number of different definitions of structural knowledge instead of one commonly accepted definition (Jonassen, Beissner, and Yacci 1993; London 2011; Murphy and Suen 1999). Table 1-2 summarizes the original explanations of structural knowledge and its most common synonyms (knowledge structure and cognitive structure) found in the scientific literature.

Table 1-1. Synonyms of structural knowledge

Synonym	Information source
cognitive microstructures	Murphy and Suen 1999
cognitive organization	Hoeft et al. 2002
cognitive structure	Ifenthaler 2010, 2011; Ifenthaler, Masduki, and Seel 2011; Jonassen 2000, 2004, 2011; Jonassen, Beissner, and Yacci 1993; Murphy and Suen 1999; Naveh-Benjamin et al. 1986; Shavelson 1974; Tsai and Huang 2002

Table 1-1. Synonyms of structural knowledge (continued)

Synonym	Information source
conceptual knowledge	Jonassen 2000, 2004, 2011; Jonassen, Beissner, and Yacci 1993; Tennyson and Cocciarella 1986; Trumpower and Goldsmith 2004; Trumpower and Sarwar 2010b; Zeppuhar 1999
conceptual networks/ representations/ structures	Murphy and Suen 1999
conceptual understanding	Broers 2009
connected understanding	Schau and Mattern 1997; Schau et al. 2001; Trumpower and Sarwar 2010b
internal connectedness	Jonassen, Beissner, and Yacci 1993
integrative understanding	Jonassen, Beissner, and Yacci 1993
knowledge structure or structure of knowledge	Burkolter et al. 2010; Clariana 2010; Curtis and Davis 2003; Harper et al. 2004; Hoeft et al. 2002; Ifenthaler 2010, 2011; Ifenthaler, Masduki, and Seel 2011; Jonassen 2000, 2004, 2011; Jonassen, Beissner, and Yacci 1993; Murphy and Suen 1999; Nash, Bravaco, and Simonson 2006; Takahashi, Takahashi, and Wisenbaker 1999; Trumpower and Goldsmith 2004; Von Minden, Walls, and Nardi 1998; Zeppuhar 1999
memory/semantic structures	Murphy and Suen 1999
structural understanding	Diekhoff 1983

Research works on structural knowledge and its assessment (for example, Broers 2009; Clariana 2010; Clariana and Wallace 2009; Cutting et al. 2014; Dabbagh 2001; Ge and Land 2003; Hoeft et al. 2002; Hoole 2006; Ifenthaler 2010, 2011; Ifenthaler, Masduki, and Seel 2011; Kiewra et al. 1999; London 2011; McAleese 1998; Meyer 2008; Murphy and Suen 1999; Pickle et al. 2005; Sarwar 2012; Tsai and Huang 2002; Turns and Kirlik 1998; Zeppuhar 1999) most often cite Jonassen and, in particular, his book *Structural knowledge: Techniques for repressing, conveying, and acquiring structural knowledge* (Jonassen, Beissner, and Yacci 1993). The book not only defines the concept of structural knowledge, but also describes a range of tools that a teacher can use to identify, assess, and develop student structural knowledge in the study process. Shavelson is

the second most commonly cited researcher in the field of structural knowledge (for example, he is quoted in Ifenthaler 2011; Ifenthaler, Masduki, and Seel 2011; London, 2011; Meyer 2008; Murphy and Suen 1999; Naveh-Benjamin et al. 1986; Tsai and Huang 2002). Therefore, before the analysis of definitions offered by other researchers, an examination of the research works of Jonassen and Shavelson is carried out.

Table 1-2. Definitions and explanations of the concept 'structural knowledge' and its most common synonyms

Information source	Explanation
(Beissner, Jonassen, and Grabowski 1994, 20)	"Structural knowledge, the knowledge of relationships between concepts in a content area, is essential for comprehension and problem solving"
(Clariana and Wallace 2009, 287)	"Structural knowledge refers to the tacit and explicit associations between concepts in memory (or the lack of such relations) that allow for fluency in cognitive activity"
(Davis, Curtis, and Tschetter 2003, 192)	"Structural knowledge is defined as the unique way in which trainees organize and interrelate concepts, ideas, and rules within a knowledge domain or simply how trainees' knowledge is represented and arranged"
(Day, Arthur Jr., and Gettman 2001, 1022)	"Knowledge structures can be distinguished from declarative knowledge. Knowledge structures represent the organization of knowledge, whereas declarative knowledge reflects the amount of knowledge or facts learned"
(De Jong and Ferguson-Hessler 1996, 105)	The researchers have defined a structure as a quality of different types of knowledge (situational, conceptual, procedural and strategic knowledge).
(Diekhoff 1983, 227)	Structural knowledge id defined as "students' knowledge of the structural interrelationships that exist among concepts in a domain"

Table 1-2. Definitions and explanations of the concepts 'structural knowledge' and its most common synonyms (continued)

Information source	Explanation
(Goldsmith, Johnson, and Acton 1991, 88)	"...the configural property of knowledge that exists when someone knows the global relations among important concepts within a domain. If configurality is an important property of knowledge, then an adequate assessment of domain knowledge must be sensitive to it"
(Harper et al. 2003, 557)	Structural knowledge "refers to an internal representation and organization of information utilized by an individual"
(Ifenthaler 2010, 213)	"…an individual's cognitive structure is made up of the interrelationships between concepts or facts and procedural elements"
(Jonassen, Beissner, and Yacci 1993, 4)	"…an intermediate type of knowledge, structural knowledge, that mediates the translation of declarative into procedural knowledge and facilitates the application of procedural knowledge… Structural knowledge provides the conceptual bases for why; it describes how the declarative knowledge is interconnected"
(Koubek 1991, 25)	"Human knowledge structure is defined as the structure of interrelationships between concepts and procedures (elements) in a particular domain, organized into a unified body of knowledge... The above definition suggests two main components of knowledge structure: elements and their interrelationships. These elements can be further described through two additional dimensions, or parameters. First, the knowledge structure elements may either be declarative or procedural concepts, and second, these elements can exist at various levels of abstraction… In describing the second major component, relationships, two additional parameters can also be identified. First, the degree of relationship between elements can vary in degree, and second, more than one type of relationship can simultaneously exist between two or more elements"

Table 1-2. Definitions and explanations of the concepts 'structural knowledge' and its most common synonyms (continued)

Information source	Explanation
(Lopez et al. 2014, 742)	"Knowledge structures describe the mental structure of knowledge…Knowledge structures stem from a semantic theory of memory, which builds upon an associative model of learning and memory"
(Meyer 2008, 23)	"The connections in semantic memory can be interpreted as an independent type of knowledge (structural knowledge)"
(Murphy and Suen 1999, 2)	"The concept of structural knowledge itself is thought to consist of three components. Those three components are (1) relevant domain concepts, (2) the presence and/or nature of relationships between those concepts, and (3) the strength of those relationships"
(Preece 1976, 1)	The researcher has defined a cognitive structure as "the pattern of relationships among concepts in memory"
(Shavelson 1983, 81-83)	"Cognitive structure has been defined as the student's public understanding of subject-matter structure…I defined cognitive structure, broadly, as a hypothetical construct referring to concepts and their interrelations in memory"
(Shavelson, Ruiz-Primo, and Wiley 2005)	The researchers define structure as a characteristic of different types of knowledge (declarative, procedural, schematic, and strategic knowledge).
(Srinivasan et al. 2008, 1196)	"However, there is substantial evidence that a critical additional step in the development of expertise is the incorporation of that knowledge into an elaborate and well-integrated framework or knowledge structure"
(Takahashi, Takahashi, and Wisenbaker 1999, 1)	"… mental representations of the relationship among concepts, also called structure of knowledge…"

Table 1-2. Definitions and explanations of the concepts 'structural knowledge' and its most common synonyms (continued)

Information source	Explanation
(Trumpower, Goldsmith, and Williams 2003, 1409)	"Structural, or conceptual, knowledge is defined as the knowledge of concepts and their interrelationships with one another"
(Trumpower and Sarwar 2010b, 8)	"The term structural knowledge may be used interchangeably with terms such as conceptual knowledge, connected understanding, and knowledge organization. It is defined here as knowledge of the relationships among the key concepts (including, but not limited to, facts, procedures, ideas, and rules) in a domain"

Jonassen has mostly used the concept of structural knowledge in his works (see, for example, Beissner, Jonassen, and Grabowski 1994; Jonassen 2000, 2004, 2011; Jonassen, Beissner, and Yacci 1993; Jonassen and Marra 1994). This concept was adopted from Diekhoff (1983) (see Table 1-2 for reference). Jonassen and colleagues (1993) have offered the following characteristics of this type of knowledge:

- Structural knowledge is the knowledge of how concepts within a domain are interrelated—in other words, the knowledge of how declarative (factual) knowledge is interconnected.
- The underlying assumption of structural knowledge is a view that meaning for any concept comes from the pattern of relationships of this concept in relation to other concepts.
- Structural knowledge mediates the translation of declarative knowledge into procedural knowledge (knowledge of how to perform different functions and procedures) and facilitates the application of procedural knowledge.

Jonassen, Beissner, and Yacci (1993) indicated that structural knowledge is also conceptualized as a cognitive structure in cognitive psychology or as a knowledge structure in the information-processing field. Concerning the concept of cognitive structure, Jonassen referred to definitions by the researchers of cognitive psychology Shavelson and Preece, who defined cognitive structure as the organization of the relationships of concepts in human (long-term) memory (Preece 1976; Shavelson 1972). However, further use of both concepts in Jonassen's

research works may confuse readers, because the researcher claimed that structural knowledge is understanding an individual's cognitive structure (Jonassen, Beissner, and Yacci 1993) or structural knowledge models the cognitive structure (Jonassen 2000, Fig. 4.1). This, on the one hand, allows thinking that the two concepts—cognitive structure and structural knowledge—are synonyms; but, on the other hand, it can be concluded that structural knowledge is something different from cognitive structure. The similar situation is with the use of the concept of knowledge structure. Jonassen believed that knowledge structure refers to how people organize and integrate concepts in their memory, and it is a generic term like structural knowledge (Jonassen 2004; Jonassen, Beissner, and Yacci 1993). At the same time, the researcher argued that structural knowledge refers to one's knowledge structure (Jonassen 2004). However, the author later used all three concepts as synonyms, indicating that the knowledge structures that people store in their mind are also known as cognitive structures, structural knowledge, and even as conceptual knowledge (Jonassen 2000, 2004, 2011).

Shavelson, in his most cited work (1972), did not use the terms 'structural knowledge' and 'knowledge structure'. Instead, he defined the concept of cognitive structure as "a hypothetical construct referring to the organization (relationships) of concepts in memory" (Shavelson 1974, 226). In other early works, for example, (Shavelson 1983), the researcher mostly referred to the same term and its definition, but occasionally he mentioned the concept of structural knowledge as well (see, for example, Shavelson 1974). Later—for example, in Shavelson, Lang, and Lewin (1994)—the concept of knowledge structure appeared in his works and it was at the forefront in works issued at the beginning of the new century, though sometimes a mixture of knowledge structure, structural knowledge and cognitive structure was still used (see, for example, Shavelson, Ruiz-Primo, and Wiley 2005). In 2005, Shavelson and colleagues defined structure as a characteristic of different types of knowledge. As a result, in recent works (Lopez et al. 2014; Srinivasan et al. 2008), the terms 'structural knowledge' and 'cognitive structure' disappeared from the discourse and the concept of knowledge structure—defined as a mental structure of knowledge or, in other words, an organized network of knowledge elements (concepts, ideas and other elements)—became the central concept in the publications of Shavelson and his co-authors.

The distinction in the use of concepts previously discussed is most likely a matter of the researchers' scientific field. Shavelson, as an educational psychologist, used terms from the field of cognitive psychology. Jonassen, as a professional in the area of educational

technology and as an advocate of the constructivist approach to learning, preferred to use the term 'structural knowledge', which definitely is more understandable for teachers. However, irrespective of the concepts used, both researchers attributed structural knowledge to understanding relationships between concepts in a domain.

The analysis of definitions given in Table 1-2 allows the conclusion that there are two different viewpoints of the nature of structural knowledge:

- Structural knowledge is a separate type of knowledge (Curtis and Davis 2003; Day, Arthur Jr., and Gettman 2001; Jonassen, Beissner, and Yacci 1993; Kinchin and Cabot 2010; Meyer 2008; Turns and Kirlik 1998). In this case, it differs from declarative knowledge, which is considered to be acquired facts and ideas and does not imply understanding (Hoole 2006). Structural knowledge refers to the organization of declarative knowledge into meaningful patterns: it is an intermediate type of knowledge that mediates the translation of declarative knowledge into procedural knowledge (Jonassen, Beissner, and Yacci 1993). As a result, it is defined as 'knowing why' (Jonassen 2000; Jonassen, Beissner, and Yacci 1993).
- Structure is a feature of different types of knowledge. In this case, structural knowledge is conceived as a combination of knowledge type and its quality (structure) (De Jong and Ferguson-Hessler 1996; Shavelson, Ruiz-Primo, and Wiley 2005), or as the configurality of knowledge (Goldsmith, Johnson, and Acton 1991), relating it, for example, to a facet of declarative knowledge (Dacin and Mitchell 1986). However, elements of structural knowledge can also be of a procedural nature (Koubek 1991; Koubek, Clarkston, and Calvez 1994).

It is necessary, however, to agree with an opinion of Jonassen, Beissner, and Yacci (1993) that the available definitions make only a semantic distinction and do not affect the recognition of structural knowledge as an existing entity.

Further analysis of the definitions in Table 1-2 indicates that several statements are made most often when the concept of structural knowledge is defined. Firstly, structural knowledge is related to knowledge organization/representation/arrangement/structuring/integration in an individual's memory. Furthermore, some researchers have concretized the type of memory as long-term memory or semantic memory. Secondly, the definitions specify the nature of knowledge or, in other words, the knowledge units that constitute structural knowledge. Most of the

researchers have mentioned concepts in a domain, sometimes defining them in a general way as facts, ideas, information or declarative knowledge. Some researchers have indicated that knowledge units can also be of a procedural nature. Thirdly, there are relationships/connections/associations between knowledge units and, as a result, an integrated/connected conceptual network or framework is formed.

Therefore, in light of the results of the previous analysis, it is necessary to conclude that:

- The concept of structural knowledge is attributable to the organization of knowledge in the human mind.
- The concept of structure is reduced to the knowledge structure—i.e. structural knowledge is knowledge of the knowledge structure.
- In the knowledge structure, elements are considered to be units of knowledge, which, in a specific case, are reduced to concepts. Relations are relationships between knowledge units that, in a particular case, are attributed to relationships between concepts.
- As a result, structural knowledge is defined as knowledge of relationships between knowledge units (in a specific case, between concepts).

The analysis presented in this section raises the following questions:

1. Why do some researchers mention long-term memory and some semantic memory?
2. Why are concepts most often considered to be the main knowledge units of structural knowledge and why do some researchers also mention the procedural nature of knowledge units?
3. How are relationships established between concepts and what is their role as a component of structural knowledge?

To answer these questions, it is necessary to reconsider the theoretical foundations of structural knowledge. Although some previous studies have mentioned that structural knowledge is based on the theory of semantic organization of human memory (Lopez et al. 2014) or schema theory and semantic networks (Jonassen, Beissner, and Yacci 1993), a structured and detailed description of the theoretical foundations of this type of knowledge has not been provided in any of the known information sources. Studying this issue, it was concluded that these theoretical foundations lie in the field of knowledge organization studied in cognitive psychology and in aspects of knowledge acquisition presented in the constructivist approach to learning (Fig. 1-1).

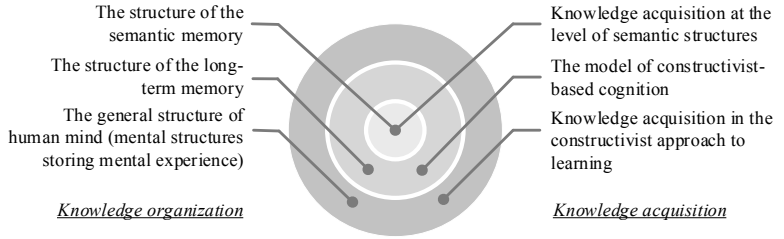

Fig. 1-1. Theoretical foundations of structural knowledge

1.3 Theoretical Foundations: Knowledge Organization in the Human Mind

In order to gain a better understanding of the nature of structural knowledge, the organization of knowledge in the human mind is analysed on three levels (Fig. 1-1), starting from the most abstract level of mental structures containing an individual's mental experience, proceeding to the mental structures of the long-term memory, and finishing with the organization of knowledge in the human semantic memory.

Section 1.1 has emphasized that structure is a universal property of any system. It is a set of certain elements and the relationships between them. The human mind is undoubtedly a system that processes the information that a person perceives from the environment through the sensory organs and stores it in the long-term memory. It is based on mental structures (Kholodnaya 2002; Sternberg 2003b) which, as can be concluded from the general definition of structure, consist of mental elements and the relationships between them. According to Kholodnaya (2002), who has summed up the international research experience in the field of cognitive psychology, mental structures store the fixed forms of a person's mental experience. She defines the mental experience as an individual system of intellectual resources which determines a person's intellectual activity, as well as partly properties of his/her personality and social interaction. Kholodnaya (2002) has highlighted that a person creates, accumulates and transforms mental structures during his/her whole life and these determine an individual's features of acquisition, interpretation and processing of incoming information. During the person's interaction with the environment, mental structures create a mental space within which a mental representation—or, in other words, a specific and detailed image of a current situation (e.g. event or task)—is being built (Kholodnaya 2002). Fig. 1-2 shows this idea.

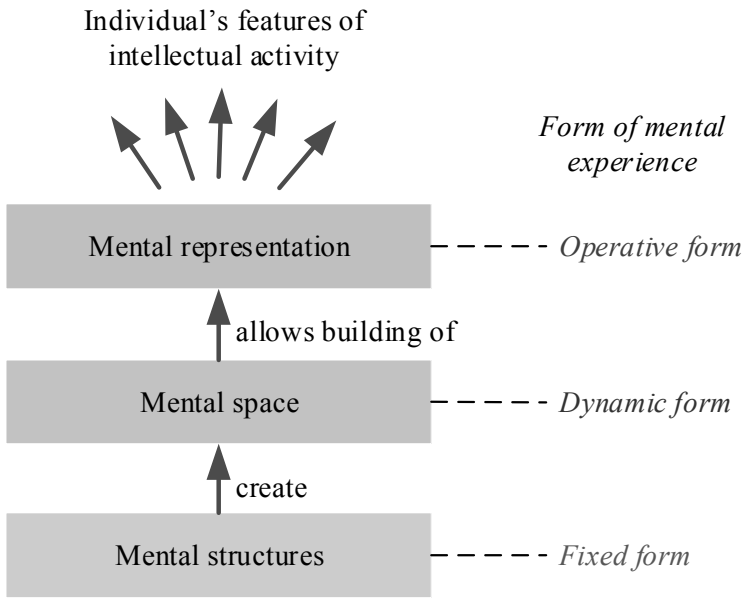

Fig. 1-2. The structure of the human mind (adapted from (Kholodnaya 2002))

Mental structures create three layers of mental experience (Kholodnaya 2002):

- Cognitive experience is associated with those mental structures which are responsible for the storage, arrangement and transformation of perceived information.
- Meta-cognitive experience is attributed to mental structures performing the regulation of human intellectual activity.
- Intentional experience is related to mental structures underlying an individual's intellectual dispositions (e.g. beliefs).

The abovementioned layer of cognitive experience refers to the concept of knowledge, which is well-known by teachers at different educational levels. Thus, knowledge is a part of the human individual mental experience. It is represented in an individual's mind and is stored in mental structures that consist of mental elements and the relationships between them. In this context, the word 'structural' in the concept of structural knowledge is related to the mental structures.

In cognitive psychology, the long-term memory is considered to be the main store of knowledge (Goldstein 2008; Quinlan and Dyson 2008). It is composed of several subsystems distinguished by the type of stored

knowledge. Typically, it includes an episodic memory that holds memories of personal experiences and a semantic memory that stores general knowledge in the form of concepts (Goldstein 2008; Howes 2006; Lieberman 2012; Quinlan and Dyson 2008; Rutherford 2005). However, Lieberman (2012) additionally defines two other subsystems: a perceptual memory that holds memories of past sensory inputs and enables them to be quickly identified, and a procedural memory that stores knowledge on how to perform different functions and procedures. Thus, mental structures constitute the long-term memory and they store different types of knowledge. As a result, the term 'structural' in the concept of structural knowledge denotes the mental structures of long-term memory.

Taking into account that concepts are an integral part of any knowledge domain, the human semantic memory is a subsystem of long-term memory actively involved during the learning process. This type of memory is sometimes also called the human conceptual system (Quinlan and Dyson 2008). Concepts are considered to be the basic organizational units of semantic memory (Braisby 2005). In general, they represent object classes (Eysenck and Keane 2000; Lieberman 2012; Quinlan and Dyson 2008; Ross et al. 2008) or, in other words, categories (Braisby 2005; Eysenck and Keane 2000; Goldstein 2008; Ross et al. 2008) that provide information about the basic properties of objects belonging to that category, allowing inferences to be made about objects belonging to other categories and helping to understand behaviours that would otherwise be difficult to understand (Goldstein 2008). The ability of an individual to form concepts constitutes a means of understanding the environment (Lieberman 2012; Sternberg 2003b), supporting such cognitive functions as classification, communication, prediction and conclusion, understanding and explanation (Ross et al. 2008). Concepts are stored in the mental structures of semantic memory, such as semantic networks, followed by more complex structures like schemas (Goldstein 2008). Their common feature is the existence of relationships between concepts.

The semantic network approach considers that concepts are stored in the human mind in the form of a network where nodes of the network represent concepts, and they have labelled links (relationships) between them (Goldstein 2008; Lieberman 2012; Quinlan and Dyson 2008; Sternberg, 2003b). Relationships between concepts determine the meaning of each concept. Semantic networks have a hierarchical structure that underlies such a characteristic as cognitive economy (Goldstein 2008; Lieberman 2012; Quinlan and Dyson 2008). The cognitive economy is related to the fact that knowledge that is typical for all objects of a category is stored at the higher level of the hierarchy, and other levels

automatically inherit knowledge from higher levels. Another feature of semantic networks is spreading activation (Goldstein 2008; Lieberman 2012), which means that, in case of the activation of any node, other nodes related to it are also activated, using the existent interrelationships between nodes. This mechanism allows easy recall of other concepts stored in the memory. However, the approach of semantic networks offers a simplified view of the organization of concepts in the human mind, and, in reality, it is considered that concepts are included in more complex structures such as schemas (Eysenck and Keane 2000; Sternberg 2003b).

Reed (2012) describes a schema as a general knowledge structure that provides a framework for the organization of knowledge in groups (clusters). Rumelhart and Norman (1976) consider a schema as a primary unit of the constructing and processing of meaning in the human information processing system. Several researchers have pointed to the close link between concepts and schemas: Eysenck and Keane (2000, 276) contend that a schema is "a structured cluster of concepts"; Sternberg (2003b) asserts that schemas are mental frameworks that represent knowledge as a group of interrelated concepts with a meaningful organization; while Roth (1990) sees a schema as a cluster of knowledge that includes concepts and the relationships between them, describing a more complex superordinate concept.

In general, schemas have the following characteristics:

- A schema is an abstract (theoretical) construct (Jonassen, Beissner, and Yacci 1993; Pritchard 2009).
- Schemas contain generalized knowledge (Anderson 1984; Eysenck and Keane 2000; Rumelhart and Ortony 1977; Seel, Ifenthaler, and Pirnay-Dummer 2013; Sternberg 2003b; Winn 2004).
- Schemas represent concepts that could underlay objects, procedures, events, activities, sequences of activities, situations and concepts (Eysenck and Keane 2000; Reed 2012; Rumelhart and Ortony 1977; Seel, Ifenthaler, and Pirnay-Dummer 2013).
- Schemas differ in their degree of abstraction (Rumelhart and Ortony 1977; Sternberg 2003b).
- Schemas are dynamic and, as a result, they can change with experience or learning (Winn 2004).
- Schemas are unique, and their complexity varies between individuals (Jonassen, Beissner, and Yacci 1993). Since there are no restrictions on the size, number, number of relationships between them and their development mechanisms, an adult can have an enormous number of schemas that are related in a variety of complex ways, also taking into account the fact that new

schemas are continuously created and existent ones are modified or elaborated (Pritchard 2009).

- Schemas ensure not only the organization and storage of knowledge (Lieberman 2012; Winn 2004) but also the interpretation and understanding of new information (Howes 2006; Lieberman 2012; Rumelhart and Ortony 1977; Winn 2004).

Concerning the structure of schemas, it is necessary to stress that schemas may have a nesting structure, where each schema can include other schemas (Kirschner 2002; Rumelhart and Norman 1976; Rumelhart and Ortony 1977; Sternberg 2003b; Sweller, van Merrienboer, and Paas 1998). Moreover, a schema consists of a) variables that correspond to conceptual categories and can be replaced with specific values (concepts or other schemas) when the schema is used (Eysenck and Keane 2000; Lieberman 2012; Rumelhart and Norman 1976; Rumelhart and Ortony 1977), and b) variable constraints that determine which values can be assigned to variables and what the possible default values are (Rumelhart and Ortony 1977). However, the most significant feature of schemas is meaningful relationships between the units of the schemas themselves and between different schemas (Anderson 1984; Eysenck and Keane 2000; Pritchard 2009; Rumelhart and Norman 1976; Rumelhart and Ortony 1977; Sternberg 2003b).

In fact, schemas include all the knowledge that an individual has acquired in his life. Pritchard (2009) has pointed out that the network of schemas in the human mind corresponds to the overall amount of knowledge available to the individual at the current time. In the context of the study process, this knowledge is usually called prior knowledge, or pre-existing knowledge, and is defined as all the knowledge, skills or abilities available to the student before the learning episode and which were acquired or developed in any way and any situation, including formal and often informal learning forms (Pritchard, 2009).

It is necessary to emphasize that prior knowledge is an essential concept in the constructivist approach to learning, because the acquisition of new knowledge is closely related to the quality and volume of pre-existing knowledge. Hay, Kinchin, and Lygo-Baker (2008) listed three dimensions of prior knowledge that can affect student learning:

- Conceptual richness: student learning is promoted and supported by rich prior knowledge and good coverage between what students already know and what they are learning at the present moment.
- The structure of prior knowledge: the organization of prior knowledge determines how much this structure can change during learning.

- Misconceptions: acquiring new knowledge can be hindered if prior knowledge has many misconceptions.

Thus, having considered the organization of knowledge in the human mind, answers to the first two questions posed in at the end of Section 1.2 were found, leading to the following conclusions:

- Taking into account that, in general, structure is defined as a set of elements and the relationships between them, and the human mind is composed of mental structures, it should be concluded that the mind and knowledge as its part comprise a set of mental elements and the relationships between them.
- The long-term memory stores different types of knowledge in its mental structures. Thus, defining structural knowledge in a more general way (considering relationships between knowledge units in general), it is correct to refer to the long-term memory.
- Concepts are a part of knowledge and they are stored in the semantic memory, which is a subsystem of the long-term memory. The semantic memory is composed of such mental structures as semantic networks and schemas. The elements of these structures are concepts (or their larger formations). Moreover, relationships exist between concepts. Therefore, it is correct to refer to the semantic memory when structural knowledge is defined in a more narrow way as understanding relationships among concepts.

To ascertain how the relationships between knowledge units are formed in general and between concepts particularly, aspects of knowledge acquisition are analysed in the next section.

1.4 Theoretical Foundations: Knowledge Acquisition

Like the knowledge organization discussed in the previous section, the acquisition of knowledge is also examined on three levels for better understanding of the concept of structural knowledge. Firstly, the general idea of the construction of knowledge in the constructivist approach to learning is analysed; then attention is paid to the implementation of this idea at the level of human cognition and mental structures (schemas) (Fig.1-1).

The central viewpoint of the constructivist approach to learning is that students construct their knowledge rather than knowledge being directly transferred from the teacher to students (Gagnon and Collay 2001; Jonassen 1999; Taber 2011). Moreover, knowledge is constructed by revising the relationships between the knowledge already known to the student, as well as creating new relationships between newly acquired