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High School Students' Understanding of the Human Body System

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Abstract In this study, 120 tenth-grade students from 8 schools were examined to determine the extent of their ability to perceive the human body as a system after completing the first stage in their biology curriculum - "The human body, emphasizing homeostasis". The students' systems thinking was analyzed according to the STH thinking model, which roughly divides it into three main levels that are arranged "pyramid" style, in an ascending order of difficulty: 1. Analysis of system components—the ability to identify the components and processes existing in the human body system; 2. Synthesis of system components—ability to identify dynamic relations within the system; 3. Implementation—ability to generalize and identify patterns in the system, and to identify its hidden dimensions. The students in this study proved largely incapable of achieving systems thinking beyond the primary STH level of identifying components. An overwhelming majority if their responses corresponded to this level of the STH model, further indicating a pronounced favoring of structure over process, and of larger, macro elements over microscopic ones.

Keywords Human body system · Systems thinking · High school

Introduction

Increasingly, science is adopting a systems approach to analyzing natural phenomena. In biology, for example, when analyzing the human body, biologists represent its functioning as a set of hierarchical structures that interact with each other to create a chain of events in

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the operation of the overall system. In response to this approach, science education has been focusing on teaching about complex systems because it represents a more integrated approach to understanding natural phenomena. Moreover, complex systems are based on important ideas that provide an integrating context across different science domains (Goldstone and Wilensky 2008).

However, most students do not develop such systems thinking because the learning that they do is focused on the components that comprise the system rather than on the integrated processes that build the system. This is certainly the case with students who are learning about a large complex system such as the human body (the topic of this study). One suggested way of building this integrated understanding is to organize systems thinking under the large-scale idea of homeostasis, which would provide students with a more complete picture of the human body, allowing them to integrate its multiple components. Homeostasis also enables a deeper understanding of the complexity of the human body, as it explains both the interactions between the environment and the body and the processes that occur on its different organizational levels.

In light of this understanding, in 2006 a new biology curriculum called *Human Biology: Emphasizing the Role of Homeostasis* was introduced into the Israeli high school system. It was introduced specifically to address the problems created by the previous curriculum, which taught human biology as separate components, a practice that led to compartmentalized learning. Instead, this program unifies human biology around homeostasis to provide students with a more integrated picture of human structure and function. In this study, we survey a sample of 10th grade students who had completed this curriculum to determine its efficacy by determining its effect on the students' ability to perceive the human body as a system, rather than as a collection of compartmentalized parts.

As a biological system, the human body is characterized by: organization, interactions, numerous hidden components and dynamic processes. Organization occurs on various levels, and at each level there is a group of components that act in coordination amongst themselves. Interactions between components permit a biological system to maintain stability. Without interactions, the system could not act as more than the sum of its parts. Living systems are organized in such a way that structures and processes are evident at various organization levels. The organization levels are connected via feedback loops, creating a hierarchical system. There are also extensive dynamics in a biological system at the microscopic level, designed to achieve equilibrium on the macro level, in which the freedom to attain such equilibrium is extremely limited.

In the past decade, the learning sciences have seen substantial growth in research about student understanding of complex systems (Hmelo-Silver and Pfeffer 2004; Hmelo-Silver et al. 2007; Jacobson and Wilensky 2006; Lesh 2006; Verhoeff et al. 2008). This increase in research stems from the nature of the world our students live in—one that is increasingly governed by complex systems. As Kitano (2002, p.1662) notes, to understand (biological) systems we must: *"Shift our notion of"what to look for' in biology from a mere examination of the system's components, to an understanding of its structure and dynamics. This is due to the fact that a system is not just an assembly of genes and proteins; its properties cannot be fully understood merely by drawing diagrams of their interconnections"*. Wilensky and Reisman (2006) suggested that teaching scientific facts without placing these within a larger context "misses the point," suggesting instead a "modeling approach" that encourages students to use their knowledge of the individual elements in a system to construct a model of the system as a whole.

Yoon (2008a) argues for the usefulness of the systems approach by citing it as the best pedagogical tool for providing students with the system thinking skills they require to overcome such common difficulties as the inability to understand the individual mechanisms that are active behind global phenomena. This confusion of levels is thought to be a main source of misunderstandings or misconceptions not only in the formal study of science but in everyday life experiences (Wilensky and Resnick 1999). Yoon applies the systems approach to the educational system itself, seeking to establish an educational heuristic based on a complex systems evolutionary approach to the learning system of the *classroom*, as well as the systems studied by the students within it. This focus on studying the interactions and dynamic processes in educational systems, Yoon claims, can be thought of as contributing to a larger shift toward understanding global events through a complex systems paradigm (2008b).

Jacobson (2001) as well as Wilensky and Resnick (1999) perceive the adoption of a systems approach as an identifying characteristic differentiating between "experts" and "novices". They have found that while "novices" such as undergraduate students favor simple causality, central control, and predictability in their analysis of systems, expert explanations show decentralized thinking, multiple causes, and the use of stochastic and equilibration processes. Understanding complex systems therefore involves thinking about multiple interdependent levels, nonlinear causality, and emergence—concepts which, though vital, are also counterintuitive and, as such, singularly difficult to master (Jacobson and Wilensky 2006).

Based on the above discussion it is possible to define two large-scale approaches for analyzing systems thinking. The first, which has been explicated by among others Yoon (2008a), Wilensky and Reisman (2006), and Jacobson and Wilensky (2006) is a domain general approach in which students must first understand the attributes that are common to different systems and then apply them to a specific context. The second approach is domain specific, in which students analyze the behavior of a particular system in the context of solving a problem. Thus, in this approach system thinking skills act as a cognitive tool that permits a student to analyze different characteristics of a system (Ben-Zvi Assaraf and Orion 2005; Duncan and Reiser 2007).

The Structure, Behavior, and Function (SBF) Model of systems thinking posited by Liu and Hmelo-Silver (2009) and Goel et al. (2009) expresses this domain specific approach. As Goel et al. (2009) explains it:

> *Briefly, (1) the structure portion of an SBF model of a complex system specifies the "what" of the system, namely, the components of the system as well as the connections among them. (2) Behaviors specify the "how" of the complex system, namely, the causal processes occurring in the system. A behavior typically comprises of multiple states and transitions among them. The transitions are annotated by causal explanations for them. (3) Functions specify understanding of the "why" of the system. A function a teleological interpretation of the components and processes in the system. (4) A component of a complex system can itself comprise a system and thus have its own SBF model. (5) The behavior of a system specifies the composition of the functional abstractions of its subsystems into the system functions.*

The assumption of the SBF model is that understanding the behaviors and functions of a system indicates a more elaborate network of ideas representing key phenomena and their interrelationship, thus indicating a deep understanding of a complex system. This understanding is expressed in, experts' explanations of the perceptually salient aspects of the system (i.e., external respiration) in terms of phenomena that were less perceptually salient (e.g., central nervous system control, cellular level phenomena).

Our research also falls within a domain specific approach, but we explain student thinking using the Systems Thinking Hierarchy model of Ben-Zvi Assaraf and Orion (2005).

Ben-Zvi Assaraf and Orion (2005) suggest that system thinking can be categorized according to eight hierarchical characteristics or abilities, which are evidenced by students in an ascending order. These eight characteristics compose the STH model, which was developed following a study of 8th grade students. The model's eight characteristics are arranged into three sequential levels: (A) analyzing the system components (characteristic 1); (B) synthesizing of system components (2, 3, 4, 5); and (C) implementation (6, 7, 8). Each lower level is the basis for developing the next level's thinking skills.

The characteristics are as follows:

1. Identifying the components and processes of a system (level A).
2. Identifying simple relationships among a system's components (level B).
3. Identifying dynamic relationships within a system (level B).
4. Organizing systems' components, their processes, and their interactions, within a framework of relationships (level B).
5. Identifying matter and energy cycles within a system (level B).
6. Recognizing hidden dimensions of a system (i.e. understanding phenomena through patterns and interrelationships not readily seen) (level C).
7. Making generalizations about a system (level C).
8. Thinking temporally (i.e. employing retrospection and prediction) (level C).

The STH model thus presents a progression from analyzing components at the most basic level to synthesis and generalization at the most advanced level; this progressive model contrasts with the SBF model, which distinguishes between the novice's focus on structural components and the expert's understanding that focuses on the behavior and function of a system. We decided to use the STH model in our analysis because we believe that it allows us to more precisely **detail** the changes in students' understanding of a system.

The Body as a Biological System

Biological knowledge of the human body consists of a wide variety of facts and principles. Nevertheless, in the context of systems this multitude is customarily centered upon the following three system characteristics: (a) hierarchy, (b) homeostasis, and (c) dynamism. Thus, we looked for references to these specific elements (defined below) in our analysis of the students' system comprehension.

Hierarchy

To understand biological systems, students must comprehend their levels of organization, since a system is characterized by hierarchies and it is impossible to understand one organization level without understanding the level beneath it (Hmelo-Silver et al. 2000; Knipples 2002; Penner 2000). Thus, to understand bio-systems one must refer to interactions between parts within a system and between various systems. This includes the ability to identify a system's functions, the ability to identify molecular interactions, and to understand interactions between the various organization levels (Duncan and Reiser 2007). Kresh (2006) describes the relationships between systems and their components in terms of a dual status, pointing out that a living system's components also function at the same time as "subwholes," i.e. smaller, complete systems in themselves. Thus, at any given time, entities within the hierarchical structure of life (from microscopic entities such as cells and molecules, to larger ones such as organs, families and tribes) exist both as "dependent parts" of a larger system, and as "independent wholes" with subordinated parts of their own (p. 6).

A complete understanding of bio-systems is only possible when a description of the various organization levels is included, up to the level of the whole organism (Cohen 2000). For example, Hmelo-Silver et al. (2000) reported that sixth-grade students encountered difficulties in learning about the human respiratory system because of their inability to understand that such systems operate on the macroscopic and microscopic levels. Furthermore, they contend that these systems cannot be understood without understanding the functioning of the whole system. Building knowledge leading to an understanding of the relationship between "micro" and "macro" systems requires an abstract (or formal) level of thinking (Frieder et al. 1987).

Homeostasis

Homeostasis refers both to the maintenance of a stable internal environment and to the regulatory processes (operating via feedback) leading to that stability, and these meanings can be difficult to assimilate for many students. Understanding homeostasis is difficult because some processes are hidden to the eye and/or involve dynamic perception (Westbrook and Marek 1992; Jungwirth and Dreyfus 1992). For example, preserving stability is (partly) based on temperature regulation. Thus, students know that when it is hot we perspire (i.e. they are aware of the proximate reason leading to the change), but the physiological processes responsible for this result create a "black box" and hence are ignored (Budding 1996).

Dynamism

Hmelo-Silver et al. (2000) and Whitner (1985) define a dynamic system as a coherent whole comprised of components interacting with each other both within single systems and between systems. The mechanism responsible for this interaction is based upon matter transportation between all the levels of a body's hierarchy from the single cells to the entire body. Moreover, Whitner (1985) also raises the importance of synergic properties of a system, which emerge from the system's dynamic nature.

Wilson et al. (2006) suggest that a major obstacle to dynamic thinking is connected to one's ability to follow matter as it is transported through a system. Even college students find it difficult to understand this process in plants, which prevents a basic comprehension of photosynthesis. Additionally, Duncan and Reiser (2007) report a lack of understanding about genetic systems amongst high school students, stemming from their inability to relate to causal/mechanistic explanations.

The goal of this study is to evaluate how Israeli high school students understand the body's systemic nature after completing a full-year's curriculum on this topic. To do this, we identify the extent of students' understanding of the three central elements described here, and analyze it according to its place within the hierarchical stages of the STH model. Thus we ask the following research questions:

(1) What are the students' abilities in identifying the components and processes that exist in the human body system?

(2) What are the students' abilities in identifying dynamic relations within the system?
(3) What are the students' abilities in generalizing and identifying patterns in the system, identifying the hidden and time dimensions of the system?

Methods

This research is not a formal curriculum evaluation, but rather its purpose was to capture the ability of Israeli grade 10 students to perceive the human body as a system after learning the unit *Human Biology*. In other words, we wanted to know which parameters of system thinking, connected specifically to the human body, dominated the subjects' thinking, after exposure to a learning unit. Thus the goal here is not evaluation of a unit but rather a deep exploration of thinking. Thus, we needed a research design that was sufficiently open in order to fully define the limits of our subjects' thinking about human biology.

Based on this demand it was apparent that our design should be qualitative; specifically, it involved a large-scale, one-shot case study (Gall et al. 2002), in which the students were interviewed using Word Associations, Repertory Grids, and Concept Mappings, one week to 10 days after the completion of the unit. It might be added that such qualitative instruments have been utilized in previous research on system thinking and they were found to be valid which also influenced our decision to use them in our research. Obviously, the use of such instruments made it easier to compare our results to others who also used such instruments in their research.

Sample

One hundred and eighty students from 8 tenth-grade (age 16–17) classes in three high schools from southern Israel were examined in this study. The mixed-gender (55% female) sample is homogenous in that all of the subjects are studying for a matriculation diploma, but heterogeneous in that their social-economic background varies from medium to high.

Instruments

Word Associations

The word association tool (**WA**) evaluated the subjects' ($N=180$) ability to identify both components and processes in the human body system. Ideas expressed via **WA** are the participants' spontaneous expressions. They are subject to fewer constraints than are found in semi-structured interviews and thus give less biased results. Moreover, they show high internal reliability (Hovardas and Korfiatis 2006; Wagner et al. 1996; White and Gunstone 1992). The students were asked to write 15 concepts related to the human body system; these concepts were later classified into different categories, as described in the Data Analysis section. The rationale underlying this tool was to differentiate between concepts relating to structures and those relating to processes and to determine for each type the level of complexity of the system being presented by the student.

Repertory Grid

The Repertory Grid (**RG**) method is based on Kelly's Personal Construct Theory (Kelly 1955, in Adams-Webber 1990). Kelly describes how concepts are acquired and organized within a learner's cognitive structure. **RG** is widely applied in education research; examples include: Nicholls (2005) (higher education pedagogy); Bezzi (1999) (perceptions of geoscience university students); and Bencze et al. (2006) (relationships between teachers' conceptions of science and the types of inquiry activities they use). In relation to system thinking, Latta and Swigger (1992) argue that **RG** can be used to assess a subject's conceptual models, and could therefore identify those aspects of a system that are most commonly misunderstood. In addition to the students' ability to identify components and processes, this tool also provided insight about their capacity to identify the system's dynamic relationships, to make generalizations, and to identify the system's hidden dimensions.

The repertory grid method has two components:

1. *Elements:* are the objects of attention within the domain of this investigation. In this research the subjects created a list of 12 elements (such as "breathing," "blood cells" and "oxygen").
2. *Constructs:* are the subjects' interpretations of the elements. A construct is a bipolar dimension that, to some degree, is a property of each element. After writing their elements on cards the subjects placed them in an envelope. They then withdrew 3 cards at random, and were asked to specify aspects in which two of them were alike. Finally, they were asked in which respects the third element differed from the other two. This procedure was repeated 8 times.

The basic assumption of **RG** is that the subjects will use their personal constructs in comparing between elements. For example, students chose the following elements: "Oxygen", "Neuron" and "Alveoli". Using these concepts, it was possible to produce several constructs, such as: (1) Part/Not part of a structure, (2) Process/Not a process (3) Participates/Does not participate (in oxygen absorption). RGs were employed with the entire interview sample (N=180).

Concept Maps

Concept maps (**CMs**) are diagrams indicating interrelationships among concepts and representing conceptual frameworks within a specific domain of knowledge (Novak 1990). Several science education studies have used pre and post instructional CMs to assess students' conceptual understanding (Martin et al. 2000; Rye and Rubba 1998; Songer and Mintzes 1994). Such studies suggest that Concept Mapping is a valid and useful technique for exploring conceptual change. Research also indicates that increases in the number of concepts, connections and diversity in **CMs** are a reliable parameter for gauging students' systemic thinking (Ben-Zvi Assaraf and Orion 2005; Songer and Mintzes 1994). The CMs in this study were produced by 23 students, chosen by their teachers, who had received a final grade of over 80 on the Human Biology unit. We asked these students to produce CMs at three stages of the study:

A. Prior to the unit they designed maps about their favorite television show to give them practice in building CMs.
B. After completing the human body curriculum.
C. Three days after creating the previous map the students were interviewed and their CMs were expanded through their dialog with the researcher. This phase included mediation, during which the subjects were asked whether a relation existed between concepts they

had drawn and other concepts in the map, and/or whether this concept could be connected to a new concept that had not yet been written. Concept mapping was done in two stages because the student designs the maps, rather than just responding to the queries of the interviewer, as was the case with the other two instruments. This places a greater emphasis on the students' creativity and thus they were given a second chance to elaborate on their maps. The advantage of this method is that it also provides a deeper exposure of student thinking which was the main goal of this study.

Data Analysis

Word Association (**WA**)

In the **WA** phase, which was conducted after the learning unit, the students were asked to suggest 12 concepts related to the human body, which were then classified according to the central category—"hierarchy in nature". This category was divided into two sub-categories: "structure" (Table 1) and "process" (Table 2), and these categories were in turn divided into further sub-categories.

The WA data was grouped into the following: (a) Total number of concepts (N=1767); (b) Number of concepts without repeats (N=249); (c) Number of concepts belonging to formal (N=1226) vs. informal knowledge (N=547). In this analysis we adopted Pines' (1984) and Carroll's (1964) differentiation between informal knowledge (naïve, affected by language and culture) and formal (or school) knowledge to further classify the findings (See Tables 1 and 2). Terms and concepts that were detailed within the Ministry of Education's *Israeli High School Biology Curriculum* (2006) were classified as "formal"; those not appearing were classified as "informal".

Repertory Grid (**RG**)

In order to assess students' system thinking abilities, the data analysis of the repertory grids involved two processes. First, we qualitatively analyzed the students' statements for considering the exception and the reason exception for each 3-word game cycle, the elements were analyzed and constructs were derived.

Results from the **RG** were converted into constructs (N=1091) by translating the students' interpretive statements for each chosen element. In the second stage of analysis, all of the constructs were sorted into categories using a content analysis procedure. As in the Word Association analysis, the researchers worked separately and only constructs that elicited a 90% and above agreement between them were included in the research sample. In analyzing the students' **RG** it was necessary to divide many of the primary (N=10) constructs into additional, secondary constructs (N=25). The construct categories and their distribution are summarized in Figs. 1, 2 and 3 (in the Results section).

Concept Maps (**CM**)

Adopting White and Gunstone's (1992) approach, we evaluated the CMs according to the number of concepts, their linkages, and their organization within the map. To assess students' ability to present their understanding of dynamic processes within the system, "dynamism" was classified within two categories: "Matter transportation", (statements that describe the dynamic nature of matter transportation in the system), and "dynamic

Table 1 Student understanding of structures in a system based on the Word Association Task

Organism Level	System Level			Cell Level		
	System	Organs	Tissue	Cell	Sub-Cell	Materials
Complexity	Surface area/volume ratio	Lung alveoli	Tissues	Red blood vessels	Membrane	Carbon dioxide
Living organism	Digestive system	Liver	**Skin**	Thrombocytes	Islets of langerhans	Oxygen
Anatomy	Immune system	Eyes	**Blood**	Germs	Mitochondrion	Water
Female	Nervous system	Kidneys	**Bone**	Cells	Organelle	Air
Male	Conduction system	Lungs	**Muscle**	Erythrocytes	Viruses	Calcium
Freckles	Secretion system	Throat	**Organs**	Nerve cell		Fats
Eye color	Blood vessel system	Pancreas	**Capillaries**	T-cell		Vitamins
Tall	Vascular system	Mouth	**Brain**	White blood cell		Hormones
Tattoos	respiratory system	Spleen	**Thyroid**	Blood cells		Insulin
Piercing	Systems	Bronchi	**Skull**			Cholesterol
External appearance	Reproductive system	Large intestine	**Fingers**			Carbohydrates
Clothing	Lymph system	Arteries	**Legs**			Hemoglobin
Beauty	Renal system	Teeth	**Hands**			Food groups
		Nose	**Head**			Glucose
		Anus	**Ankle**			Protein
		Tongue	**Penis**			Urine
		Veins	**Breasts**			Gasses

Informal knowledge is indicated by bolded words; formal knowledge is un-bolded

Table 2 Understanding of processes in a system based on the Word Association Task

Psychological level	Eco-system level	Organism level	Cell level
Thought	Biology	Homeostasis	Chemical activity
Feelings	Smoking	Heart-lung tolerance	Cell respiration
Curiosity	**Conditions**	Secretions	Chemical decomposition
Nightmare	**Plastic surgery**	Sights	Diffusion
Sensation			Organism Level
Freedom		**Hearing**	**Life and death**
Soul		**Physical fitness**	**Medicine**
Pain		**Health**	**Period**
Enjoyment		**Cancer**	**Growth**
Sense		**Disease**	**Existence**
Love		**Proper diet**	**Life**
Sad		**Energy**	**Function**
Psychology		**Diabetes**	**Death**
Moods		**Body temperature**	**Infection**
Intelligence		**Saliva**	**Arteriosclerosis**
Spirit		**Sweat**	**Pregnancy**
		Blood pressure	**Life and death**

Informal knowledge is indicated by bolded words; formal knowledge is un-bolded

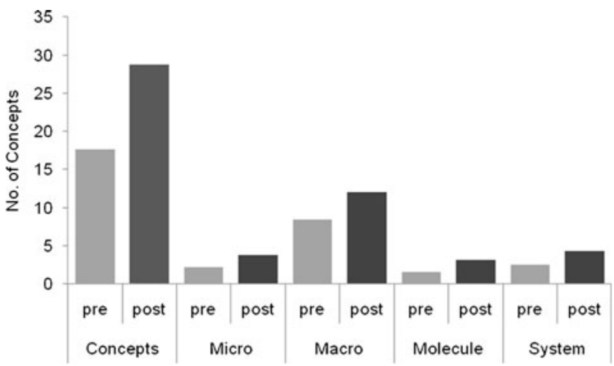
concepts" (concepts connected by a node that described a process). For a step by step description of the concept map analysis and its translation into the STH model of system thinking, see Appendix no.1.

Results

The results are organized around the three research questions, which also reflect the three levels of the STH thinking model.

(1) *What are the students' abilities in identifying the components and processes that exist in the human body system*?

Fig. 1 Distribution of concepts connected to components raised by the students before and after mediation with the concept map task



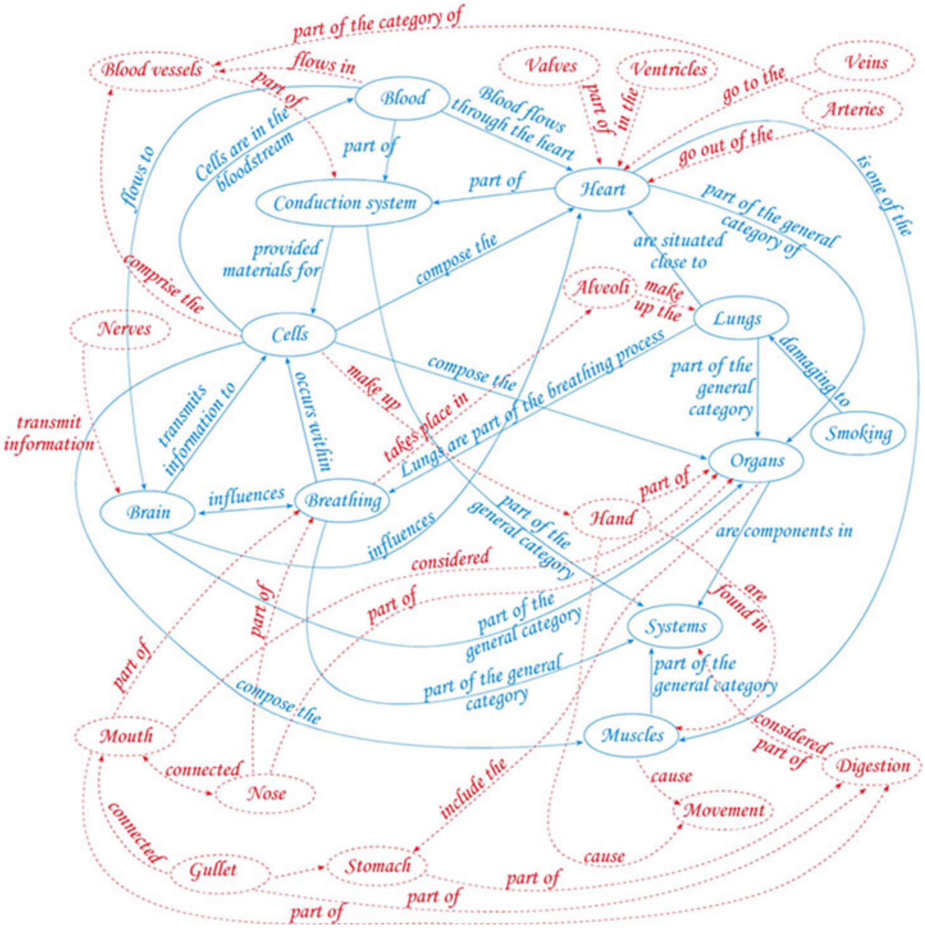
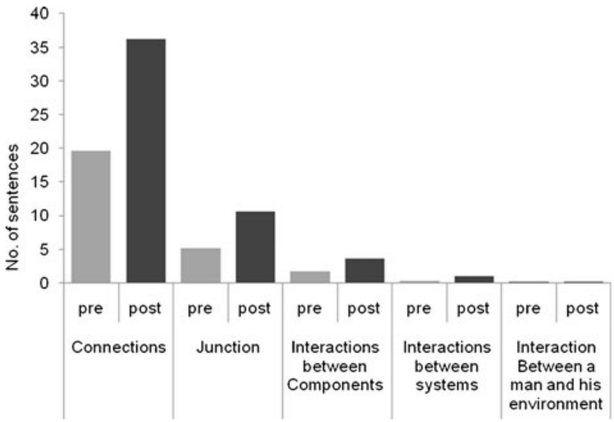


Fig. 2 Eli post-test mediation concept map

Fig. 3 Distribution of the students' ability in synthesizing system components as identified by the concept map task



From the **WA** analysis, students preferred identifying structures (89.64%, Table 3), to identifying processes in the human body (10.36%, Table 3). Examples of structures include “cell nucleus”, “nerves”, and “bones”; process-based concepts include cellular processes such as diffusion, cellular respiration, and organismic processes such as “growth” and “breathing”. The students also referred far more to the systemic level of structures (88.5%) than to the cellular level (10.2%), underlining the emphasis students place on remembering system parts; in contrast, reference to the cellular level was less.

With processes, most of the concepts mentioned were connected to the organismic level, (80.87%), such as “growth” or “reproduction”. Such processes, which are on the level of the whole organism, have a colloquial meaning that the students immediately comprehend. In contrast, very few cellular processes, such as diffusion or respiration, were presented, (2.2%), as they happen on the microscopic level. The students also wrote very few statements (5%) connected to systems processes (such as “absorption” in the digestive system).

The **RG** analysis yielded 1091 statements. These were organized into 35 constructs (including secondary constructs). Level A scores (i.e. identifying a system’s components and processes) account for the largest percentage of the **RG** scores (64.8%), whereas both level B (identifying interactions=16%) and level C scores (creating a web of interactions= 13.7%) require higher levels of system thinking and thus appeared less frequently amongst the statements. There was also a relatively small percentage (5.4%) of “non-scientific” constructs, such as ‘***Lungs** are different from **brain** and **wisdom** because the brain is the source of the body’s wisdom*,’ or ‘***Bones** are different from **blood** and **liver** because the liver and the blood are kind of soft*’.

The frequency of statements in Level A connected to components (79.3%) was almost 4 times higher than the statements connected to processes (20.7%). The results indicate that the statements connected to identifying components tended towards three prominent constructs:

1. Structural connections: a characteristic in which the students attributed certain parts of the body to a certain system (31%); for example, *‘The lungs and trachea are different from the heart because they are both related to the respiration system’.*
2. Structure: a characteristic in which the students addressed a combination of body parts, their organization and design in the human body (31.7%); for example: *‘Intestines and veins are different from ears because they are both vessels’.*
3. Internal/external structural connection: a characteristic in which students refer to a structure emphasizing an internal/external aspect (28.7%); for example: *‘Lungs are different from legs and eyes because legs and eyes are visible, external organs’*. (The remaining 8.6% of the statements are miscellaneous and could not be classified.)

Table 3 Students’ ability to identify structures and processes from the WA analysis

Structures n=1584.	Cell level –			System level			Organism level
Percentage	10.23%			88.5%			1.26%
N	162			1402			20
	Particles	Sub-cellular	Cell	Tissue	Organs	System	
Percentage	59.26%	7.41%	33.33%	11.55%	78.74%	9.7%	
N	96	12	54	162	1104	136	
Processes n=183	Cell level			System level			Organism level
Percentage	2.5%			5%			92.5%
N	4			8			148

The results show that two process types were prominent in the students' personal constructs:

1. Constructs referring to a sequence of actions that show a regular order and act through graded development (43.8%), such as: *'The heart is different from the pancreas and insulin because the pancreas secretes insulin'*.
2. Constructs that refer to the flow of blood within the body (48.6%), like 'A mouth is different from veins and heart because the veins transfer blood from the heart to the body'.

All other constructs accounted for only 7.6% of the statements, even though respiration, digestion, and cellular respiration were central topics of the learning unit.

The **CM**s also support the idea that the students, both prior to and following mediation, focused strongly on macro-level components (citing such components as 'lungs,' or 'heart'), with a lower percentage of concepts addressing micro-level components (such as 'cell' or 'alveoli') (Fig. 1). This favoring of the macro over the micro was also perceptible in the concepts that the students connect to each other. This gap between the micro and macro continued during mediation (interviews). Figure 2, which presents Eli's post-test mediation concept map, suggests that despite the significant growth in the total number of concepts and connections in the concept maps, the micro remained virtually unchanged.

Table 4 presents how Eli's concept maps were analyzed. From this analysis it is possible to indicate the great difficulty she had in presenting interrelationships amongst the components of the system. In her first concept map she raised 24 connections between two concepts, whereas after mediation she increased that number to 33; nevertheless there was little change in the complexity represented in her second map, because the number of junctions (connections between 3 or more concepts) hardly changed. Moreover, the analysis of the sentences within the concept map also shows that she only added one interrelationship.

(2) *What are the students' abilities in identifying dynamic relations within the system*?

Findings from the **RG** indicate that the "simple interaction" level (which refers to the effect of one factor on another) accounts for most of the students' answers (65.7%); for example, *'Hormones are different from the mouth and brain because the brain sends instructions to the mouth'*. The construct "Dynamism", mentioned by 21.7% of the subjects, refers to the ability to identify dynamic interactions in the system, for example, *'the stomach is different from the mouth and head because in the stomach there is digestion of proteins'*. Only 12.6% of the students referred to "Mechanism," which is connected to a cause and effect interaction: *'A cell is different from the pancreas and diabetes because the pancreas secretes insulin, and a deficiency in insulin causes diabetes'*.

The students' ability to recognize relationships between components of the human body was assessed according to the number of connections they made in the **CM**. These too largely pertained to the system's structure; thus 'hand is in the category of organ,' 'blood vessels are a part of the circulatory system,' and 'nose and mouth are connected.' In addition to revealing the students' propensity to favor, once again, structures over processes, these findings also reiterate their continued favoring of the macro over the micro. Furthermore, the data also revealed that the students represent very few interrelationships between different systems, generally limiting themselves to relationships between the components of a single system (See Fig. 3).

Table 4 Examples of STH model characteristics that are identifiable in Eli concept map

STH model	Examples from Eli concept map:								
	CM made before mediation	CM made during mediation							
a. Concepts	Heart, lungs, smoking, organs, systems, muscles, breathing, brain, cells, conduction system blood.	Nerves, hand, nose, gullet, mouth, stomach, veins, arteries, digestion, ventricles, alveoli, valves, movement, blood vessels,							
b. junctions	Heart, lungs, organs, systems, muscles, breathing, brain, cells, conduction system blood.	Digestion, mouth, hand.							
c. Interrelationships	Breathing influences brain, brain influences breathing, brain transmits information to cells conduction system provided materials for Cells.	Nerves transmit information to Brain.							
d. Pattern hierarchy	Cells compose the Organs	Organs are components in systems, air sacs make up the lung cells comprise the blood vessels. cells make up hand.							
d. Hidden dimensions	Breathing occurs within Cells								
Concepts		Connections	Junctions	Interrelationships	Macro organs	Micro cells	molecule	Patterns hierarchy	Hidden dimension
Pre	12	24	10	4	5	2	0	2	1
Post	27	53	13	5	15	3	0	4	1

(3) *What are the students' abilities in identifying both patterns in the system, as well as the hidden dimensions of the system*?

Findings from the **RG** indicate that the construct "hierarchy", which refers to the components' relative positions in the hierarchy of a system, while emphasizing their position in comparison to another, was overwhelmingly mentioned by the students (90.7%). A characteristic statement was: *'The stomach is different from cells and systems because the cells comprise all the systems'*. In contrast, "homeostasis", referring to a general description of the body's inner stability, was mentioned much less frequently (8.7%). A typical account is *'The intestines are different from homeostasis and menstruation because menstruation is part of homeostasis'*. Finally, the temporal dimension was rarely noted (0.7%). The following is a rare example of this construct: *'The esophagus is different from the heart and fat because fat accumulates in the blood vessels and can cause heart disease, even cardiac arrest'*.

The CMs did not yield statements that expressed generalized patterns of homeostasis and dynamism. The only generalized pattern that was expressed was hierarchy. An example of hierarchies, which expresses relative sizes in nature while stressing the size of one object in relation to another, is: '*organs are components of systems*'. Prior to mediation, four statements were mentioned concerning hierarchies; post mediation this number rose to seven. Statements connected to the hidden dimensions of the system were even less frequent, both before (1) and after mediation (3).

Discussion and Conclusions

The goal of this study was to examine how Israeli high school students perceive the human body system after completing a unit on this topic. As it is now conceived, this unit emphasizes a greater level of complexity, which in turn puts greater demands on the students who learn it to think systemically. However, the STH model of Ben-Zvi Assaraf and Orion (2005) shows that students who do not have the ability to do so will remain at the lower levels of the model's hierarchy, and indeed our results show that the vast majority of our subjects did remain at these lower levels. On the other hand, it is worth noting that our subjects never received explicit scaffolding that could support their ability to think systemically. Although their teachers received scientific training that exemplified the systemic nature of the human body, based on our interviews with them it appears that they didn't receive specific support and instruction regarding how systems thinking should be taught. In simple terms, they lacked the PCK needed to build the explicit scaffolds the students needed. Indeed, research has shown that without such "explicit scaffolds" it is very unlikely that the students will develop higher level systems thinking on their own (Liu and Hmelo-Silver 2009; Hmelo-Silver and Pfeffer 2004). In fact, the idea of explicitly scaffolding scientific conceptions extends as far back as the beginnings of the conceptual change movement (Scott, Asoko, and Driver 1991).

Our research focuses on representing the large-scale connections that students make when thinking systemically about the human body from the micro to the macro. Thus, it differs from previous approaches in which smaller, isolated systems were considered. These include studies at the cellular level, for example Verhoeff et al. (2008) work on students' understanding of cell functioning, as well as Duncan and Reiser (2007) research on understanding genetics; it also includes studies at the organ level such as Penner (2000) and Hmelo-Silver et al. (2000) work on the respiratory system, and Hmelo-Silver and

Azevedo's (2006) research on the human circulatory system. This difference in approach dictates that our analysis focuses on students' thinking about the entire human body system, rather than on any specific body system. With this issue in mind, we will use the major levels of the STH model to better understand our subjects' systems thinking after exposure to the Human Biology curriculum.

The subjects of our study emphasized structural components of the system (most at the organ level), over the processes taking place within that system, likely because the latter was more difficult to grasp. This result is similar to both Hmelo-Silver and Azevedo (2006) and Hmelo-Silver and Pfeffer (2004) who also noted students' tendency to concentrate on system parts, with little understanding of the way such parts interact within the system.

Although understanding structures is a necessary prerequisite to perceiving function, knowledge of the former does not guarantee understanding of the latter. This is partly due to the fact that in complex systems, several structures are involved in the same function (Liu and Hmelo-Silver 2009); for example the diaphragm, intercostal muscles, and ribs all participate in respiration. Moreover, the characteristic of a particular structure often affects the behavior of other structures, such as the blood vessels that transport oxygen and nutrients throughout the body. However, for this behavior to occur, the heart must pump blood through the vessels (Liu and Hmelo-Silver 2009). So too, in this research, the subjects were aware of the structural components composing the system, but did not have a broader grasp of how they interacted. On the whole, students identified far more structures and processes on the macro level (organs) than they did on the micro level (cells).

The Ability to Identify Interactions between Components in the Human Body System

The students had considerable difficulty perceiving interactions between system components, as evident from their lack of recognition of the connection that exists between such components. This was specifically seen in the RG results, where amongst the three constructs connected to interaction, the students significantly mentioned the lowest level "interactions" (which signifies a connection without specific details about the process) in comparison to the higher levels of "mechanism" and "dynamism". This is similar to Reiss and Tunnicliffe's (2001) findings that primary, secondary and university education students all regard body components as isolated from each other, without interactions between them. Similarly, Douvdevany et al. (1997) found difficulties amongst Israeli high school students in understanding interactions between the cell and the other hierarchical levels of the body.

Duncan and Reiser (2007) note that no significant efforts have been made to develop pedagogical tools to help students make such connections. Presenting the system as a dynamic entity at the very first stage of learning might improve students' perception of interactions (Verhoeff et al. 2008; Reiss and Tunnicliffe 2001). Students who simply memorize (biological) facts that they perceive as important information without relating them to the totality of their biological knowledge develop erroneous perceptions (Westbrook and Marek 1992).

The Ability to Identify Dynamic Interactions in the Human Body System—The Dynamic Nature of Matter Transportation

Understanding the dynamic nature of matter transportation is even more critical to systemic thinking than understanding a system's components. This is so because this system characteristic is connected towards fulfilling the overall purpose and functions of a system

(Hmelo-Silver et al. 2007). Although understanding the dynamic nature of matter transportation is critical to understanding its function, research shows that most students pay little attention to it (Kesidou and Roseman 2002), and certainly in our study this was the case, especially at the molecular level.

Thus, our results showed that about one-third of the subjects focused on general processes of "matter transportation" without mentioning any specific substances whatsoever. Amongst the remaining two-thirds of the students, the most frequent mention (90%) was CO_2 or O_2 transportation, connected to either the circulatory or respiratory system. However, no other molecular-level substances were mentioned, which means that the students' grasp of the molecular-level was poor.

However, Hmelo-Silver et al. (2000) argue that the dynamic processes that underlie the body's stability are played out on the molecular level, so that without an intimate understanding of such molecular processes it is impossible to understand the body's dynamism. Nevertheless, this dynamic system itself is derived from unseen components, which makes it impossible for the students to connect such components in order to perceive their dynamic interactions. Thus, for example, maintaining the stability of the body is based on mechanisms of hormonal and nervous system feedback that are unseen and therefore remain abstract to the student.

The Ability to Organize Components and Processes within a Web of Interactions

In human biology, phenomena are interconnected at the anatomical, physiological and biochemical levels. This means that systemic thinking must account for these interconnections and the underlying mechanisms that drive a system (Liu and Hmelo-Silver 2009). For example, respiration occurs at a cellular level as well as at the organ system level. There are intricate relationships among the structures (the parts of a system), the behaviors (the "how" or mechanisms of a system), and the functions (the "why" of a system). These levels are interdependent. A disturbance at one level or component of the system can easily affect others. When cells need oxygen, not only does a person breathe more deeply than usual, but also the heart may beat faster to deliver more oxygen to the tissues (Hmelo-Silver et al. 2007, p308).

Our subjects, however, had great difficulty in describing the mechanisms underlying the interactions between body components. Even when they were given specific mediation (during the CM interview) most of the students gave more examples of the same processes, without mentioning mechanisms. Possibly, the emphasis placed on learning structure and processes without explicit connections to mechanisms may create difficulties for students in integrating mechanisms into their conceptual structure (Verhoeff 2003; Verhoeff et al. 2008). Moreover, understanding mechanisms requires that a subject connect at least three components in a web of interaction, unlike processes, which can connect as few as two components.

The Ability to Generalize and Identify Patterns in the Body System

Our subjects had difficulty characterizing the three basic patterns of the human body system: "hierarchy", "homeostasis", and "dynamism". In general, Reiss and Tunnicliffe (2001) discovered that students could not identify patterns in the body, because the way they are taught does not help them to develop an understanding of this system's complexity. This is important since system-level patterns can emerge through the self-organized activity of many interacting elements (Booth Sweeny and Sterman 2007). Moreover, the same system pattern can often be found in diverse domains, and it is useful to describe systems in sufficiently general terms so that these commonalities can be revealed (Goldstone and Wilensky 2008, p 467). In the following section we will discuss how our subjects represented the three basic patterns of the human body system.

1. Hierarchy:

In analyzing the **RGs** we found that the most prominent *pattern* raised by the subjects was “Hierarchy”. While representing hierarchy, the students referred primarily to the macro and much less to the micro level, similar to the results of Chang and Chiu (2004) in their research about the understanding of blood-sugar level.

Hierarchical understanding is affected by a subject’s acquaintance with the molecular components of a system, which in turn requires knowledge from other disciplines, such as chemistry and physics (Nicoll 2001; Banerjee 1991). Moreover, Knipples (2002) suggested that biology teaching has become mechanical—emphasizing content without attending to the relationships amongst organization levels. Finally, Novak (1977) argues that the reason for students’ failure to understand complex concepts in general, is a lack of appropriate cognitive preparation; indeed, Sungur and Tekkaya (2003) found a strong relationship between students’ cognitive abilities and their achievements and when learning about blood circulation.

Our research does not indicate whether the students’ difficulties with hierarchy stem from cognitive difficulties, or from the learning environment itself. We do know that our teachers were not sufficiently aware of the specific patterns connected to the human body system that the students needed to learn. Moreover, they did not use knowledge-organization activities which might have helped their students represent these patterns. In their research on systemic thinking, for example, Booth Sweeny and Sterman (2007) had their subjects explicitly compare different biological systems exhibiting the same patterns at different hierarchical levels; this knowledge-organizing activity was effective in developing a greater understanding of patterns about the human body system amongst their test subjects.

2. Homeostasis

Our subjects barely mentioned “homeostasis” in their explanations, an ironic occurrence given the full name of the curriculum they were learning. This result is in line with other studies, which show that understanding homeostasis is difficult for students from high school to university age, due to its complexity (Barrass 1984; Simpson and Marek 1988; Westbrook and Marek 1992). Simply put, homeostasis requires one to comprehend several processes taking place simultaneously, while relating each to the other. Studies attempting to discover the reason homeostasis poses such a challenge have concluded that understanding the mechanisms that maintain a stable inner environment is beyond an individual’s life experience, and requires abstract thinking. The ability to think abstractly is in turn based on the capacity to achieve a certain level of higher order thinking. Indeed, Westbrook and Marek (1992) found a correlation between students’ cognitive level and the extent to which they were able to comprehend homeostasis. Understanding homeostasis requires several cognitive abilities, such as discerning that multiple phenomena occur simultaneously, as well as comprehending that every process is comprised of several stages.

3. Dynamism

The students had difficulty representing the dynamic nature of the human body, which indicated an inability to represent changes in the size and number of a system’s components, in the interactions between them and in their hierarchic structure. In turn, this difficulty stems from the fact that students are not exposed to the dynamic nature of a system, but mainly to structures (Stern and Roseman 2004). Understanding the dynamism that characterizes a system also requires a high level of abstraction (Jungwirth and Dreyfus 1992; Frank 2000). Even college students find it difficult to understand the process in plants that involves matter transportation, which prevents their full understanding of photosynthesis (Wilson et al. 2006). Finally, in order to comprehend its dynamism, the student must be capable of perceiving the interactions throughout the system as a whole.

The Ability to Identify the Hidden Dimension of the Human Body System

Very few of the subjects were able to identify the hidden dimensions of mechanisms (such as gas exchange in the lungs) connected to the body. This result matches Reiss and Tunnicliffe's (2001) study, which found that 93% of the students they surveyed (when asked to do so) drew external components of the human body while only 6% drew hidden components.

Students tend to believe that there is a linear relationship between the salience of a phenomenon and its corresponding effect, and to ignore the fact that in complex systems, a non-salient phenomenon may act as a significant influence (Banet and Nunez 1997; Liu and Hmelo-Silver 2009; Penner 2000; Ramadas and Nair 1996). For example, individual alveoli have a tiny volume but together create a total surface area of about 70 m^2, which is responsible for the major function of air diffusion. Liu and Hmelo-Silver (2009) suggest that students be explicitly exposed to the hidden molecular dimension when taught about the body's functions.

The Ability to Think Temporally

The subjects rarely referred to how processes developed within time, even though they were exposed to such examples in the program. However, this might be due to the fact that they were not explicitly asked about this element. Indeed, analysis of concept maps in earth science research did in fact indicate use of this skill when the students were openly asked about this element (Ben-Zvi Assaraf and Orion 2005).

Thinking temporally is based on the ability to both predict and look behind (Wilensky and Reisman 2006). For example, one of the problems that the subjects learned in this program was about eating disorders, which requires an ability to think temporally as it connects processes that occurred in the past and at the same time affects the body in the future.

In addition, coping with the human body system involves thinking at the micro and macro level, which is difficult on its own. Understanding the relationships between such organization levels may lead to an improved ability to solve problems in the dimension of time because the interactions between levels are embedded in time (Hmelo-Silver et al. 2000).

In sum, systems thinking is an essential part of biology learning. However, its nature, including lack of linearity, causal relationships, hidden dimensions and its dynamism cause many difficulties for the learner. Our research shows that even after completing a unit dealing with the body system, many of the participating students were left with only a superficial understanding of its nature. This strongly suggests that more effort need be invested in scaffolding systems learning based on the STH model, what Riess and Mischo (2010) call knowledge about complex systems, stressing the importance of declarative knowledge as the basis for procedural knowledge in the development of system thinking skills.

Scaffolding can be differentiated from other forms of educational support in the following ways. First, it refers to performance; other kinds of support that provide information or clarify a concept, but which do not support performance are not considered scaffolds. Second, scaffolding involves the gradual "fading" of conceptual supports. As described by Collins et al. (1989, p.456), fading is explained as the process by which "once the learner has a grasp of the target skill, the master reduces (or fades) his participation, providing only limited hints, refinements, and feedback to the learner, who practices successively approximating smooth execution of the whole skill". This means that via scaffolding students should transition from being regulated by others to being self-regulated (Davis and Miyake 2004). The challenge for the future will be to take a model like Ben-Zvi Assaraf and Orion's STH (2005) or Hmelo-Silver and Azevedo's BSF (2006) and translate its structure into scaffolds that will make systems learning easier in many subjects that demand this skill, including human biology.

Appendix 1: Correlation Between Concept Maps and the STH Model

Below is a step-by-step description of how concept maps can be read as indicators of system thinking, based on the correlation of their contents to the STH model. The description is divided according to the model's three basic levels, and further subdivided into the model's eight individual characteristics. (Note: The fifth characteristic "identifying matter and energy cycles" is *not* featured here, as it is not relevant to human body systems.)

Level A: Analysis of System Components

Characteristic # 1: *Identifying components and processes in the human body system*. Characterizing system thinking at the components and processes level requires the following steps:

a) Selecting a suitable characteristic into which all the concepts written by the population may be pooled. In this study we chose 'hierarchy in nature.'
b) Dividing this 'master-characteristic' into the categories—'Structure' and 'Process'
c) Further dividing each of these into the sub-categories of 'Microscopic' and 'Macroscopic' levels.
d) Sorting the concepts written by the students into each of the categories now present under the master-characteristic 'hierarchy in nature.'
e) Counting all of the concepts provided by the population to arrive at an overall amount of concepts.
f) Counting the number of concepts in each category.
g) Calculating distributions for the estimation of the students' relative ability to represent system components vs. system processes.

For a more thorough insight into the students' treatment of components vs. processes, the maps should also be analyzed according to the connections students made between the concepts. This necessitates the following:

a) Counting all the connections made by the student. A connection is a word describing a connection between two concepts. For instance: *(The veins)* <u>*transfer*</u> *(blood)* <u>*from the*</u>

(heart) to the *(body)'*. The underlined words represent the connections drawn between the concepts.

b) Analyzing the contents of the connections to derive statements. *"Veins transfer blood from the heart to the body"*.
c) Sorting the resulting statements and removing those that are irrelevant to the study topic.
d) Sorting the statements into process/non-process related. A process-related statement refers to a string of actions or changes that are assigned a certain order within a gradual development. On the other hand, a merely descriptive statement would refer statically to an object's state or appearance.
e) Calculating distributions to compare process/non-process-oriented statements.

Level B: Synthesis of System Components

Characteristic # 2: *Identifying simple relationships between system components.* Evidence in concepts maps of relationships between system components can be gathered by identifying both the concepts in the students' body of knowledge, and the manner of their organization into meaningful connections. To do this one must:

a) Analyze the connections and translate them into statements.
b) Identify statements that address relationships between components, i.e. statements that address the effect of element 'x' upon element 'y'.

Characteristic # 3: *Identifying dynamic relationships in systems.* This ability can be measured by the examination of the connection a student has formed between two concepts.

a) Analyze connections and translate them into statements.
b) Identify statements that express dynamism—i.e. statements in which the student refers to the transmission of a certain substance within the human body system.

Characteristic # 4: *Organizing components and processes within a framework of relationships.* Students' ability to connect a single component to a large number of other components can be assessed by examining the number of junctions on their concept map. A 'junction' is a concept that has connections to at least three other concepts on the map. The number of junctions students mark between their concepts provides insight into the level of knowledge integration they have undergone. For this reason, the junctions in each map are to be counted.

Level C: Implementation

Characteristic # 6: *Generalization and identification of patterns.* Concept maps allow us to identify students' understanding of patterns in human body systems by analyzing the contents of their connections. To do this, the statements derived from these connections must be sorted, and those statements that relate to patterns identified. The three patterns to be looked for are: Homeostasis, Hierarchy and Dynamism. **Homeostasis** includes statements that generally describe the body's internal stability ("*the concentration of urea and water in the body is regulated by homeostasis"*). **Hierarchy** includes statements referring to scale in nature, while emphasizing one scale in relation to another ("*the circulatory system includes capillaries"*). **Dynamism** includes statements that address dynamic processes as system characteristics that occur in the human body ("*oxygen enters the body through the lungs"*).

Characteristic # 7: *Identifying hidden dimensions*. To assess this characteristic, the statements derived from the map must be sorted, and those that refer to internal patterns and connections that are invisible on the body's surface must be identified.

Characteristic # 8: *Temporal thinking*. This includes both retrospective thinking (backwards) and projection (forwards). To identify a students' understanding that interactions taking place in the present can bring about and influence future events, those statements from the map in which there are temporal references must be identified.

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