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The 'What is a system' reflection interview as a knowledge integration activity for high school students' understanding of complex systems in human biology

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ABSTRACT

This study examined the reflection interview as a tool for assessing and facilitating the use of 'systems language' amongst 11th grade students who have recently completed their first year of high school biology. Eighty-three students composed two concept maps in the 10th grade—one at the beginning of the school year and one at its end. The first part of the interview is dedicated to guiding the students through comparing their two concept maps and by means of both explicit and non-explicit teaching. Our study showed that the explicit guidance in comparing the two concept maps was more effective than the non-explicit, eliciting a variety of different, more specific, *types* of interactions and patterns (e.g. 'hierarchy', 'dynamism', 'homeostasis') in the students' descriptions of the human body system. The reflection interview as a knowledge integration activity was found to be an effective tool for assessing the subjects' conceptual models of 'system complexity', and for identifying those aspects of a system that are most commonly misunderstood.

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Concept maps; system thinking; reflective interview; biology education

Introduction

Understanding the structural and behavioral aspects of complex systems has become a challenging intellectual endeavor for scientists and science students in light of the increased emphasis on such systems in both research and education (Jacobson, 2001; Jacobson & Wilensky, 2006). The importance of system thinking was stressed in the 2013 Next Generation Science Standards report, which includes a list of seven 'cross-cutting concepts that bridge disciplinary boundaries, uniting core ideas throughout the fields of science and engineering'. All seven of these concepts reflect elements of systems and system thinking: (1. patterns; 2. cause and effect; 3. scale, proportion and quantity; 4. systems and system models; 5. flows, cycles and conservation; 6. structure and function; 7. stability and change).

Previous research has unveiled the difficulties that students of all ages face when dealing with complex systems (e.g. Ben-Zvi Assaraf & Orion, 2005; Hmelo-Silver & Pfeffer, 2004; Plate, 2010). Jacobson and Wilensky (2006) suggest that designing environments for learning about complex systems should include, among other characteristics, a focus on

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methodologies that will foster collaboration, discussion, and reflection. Many reflective learning strategies have been suggested or described as applicable in science classroom or laboratory settings (Fogarty, 1994; Tan, 2005). Meta-cognitive learning of this sort can be explicitly taught through verbalization, through visual and concrete graphs such as flowcharts, and through thought maps, like the concept maps used in this study (Ben-David & Orion, 2012).

This paper presents an examination of the reflection interview that we used both as a knowledge integration activity and as a research tool in our study of systems thinking amongst high school biology students. Previous research has been principally concerned with characterizing students' understanding of the human body as a system, and the reflection interview is a means to that end (Ben-Zvi Assaraf, Dodick and Tripto, 2013; Hmelo-Silver & Pfeffer, 2004; Tripto, Ben-Zvi Assaraf, & Amit, 2013). This paper, however, is concerned rather with an examination of the reflection interview itself, and with the assessment of its efficacy, its strengths, and its weaknesses.

Our interview was based upon a comparative scaffolding strategy. Each of the students we interviewed had composed two concept maps during their first-year of biology studies (10th grade)—one pre-map from the beginning of the year and one post-map from its end. In the interview, which was conducted at the beginning of the following school year, the students were given their two concept maps and asked to compare them, using a short series of interview questions as guidelines for the comparison.

The act of comparing the two maps in the interview served two distinct purposes. The first was pedagogical, using the activity to help students organize their knowledge and to reflect on their own learning process as part of a learning environment that fosters meta-cognitive thinking (Fogarty, 1994). Such activities are designed not just to look for, but to encourage the use of systems thinking and systems language amongst students. The interview's second purpose was to provide us as researchers with a means to assess the extent to which the students understood the human body system. We did this by examining the language the students used while discussing their concept maps in the interview. The term 'systems language' refers to the language intuitively used by students to describe the human body as a system. We as researchers, following the results of previous research done by Ben-Zvi Assaraf, Dodick and Tripto (2013a), can use students' language choices (e.g. references to system characteristics like interactions and patterns) to identify the presence of various systems thinking components and create a model of the system that each of the students had constructed for themselves as they learned.

The interview's questions can be roughly divided into two sections. The first section is dedicated to guiding the students through their concept map comparison. It consists of four questions, two of which employ explicit teaching and two of which do not. The second section consists of two additional questions that are designed to help the students reflect on and think critically about the work they have done. Our examination of this tool is therefore based on two research questions, one for each section of the interview:

(1) How do the results provided by the parts of the interview that employed explicit teaching compare to those provided by the parts that did not? To what extent does the explicit approach help students to make fuller use of systems language?
(2) What does the reflection section of the interview reveal—to the students themselves and to us as researchers—about the students' understanding of the human body as a system?

Literature review

What does it mean to understand 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, it is references to these specific elements (defined below) that we looked for in our analysis of students' understanding of the human body as a system.

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, Holton, & Kolodner, 2000; Knipples, 2002). Such hierarchies have two general relationships: between the macro and micro and between different levels in the hierarchy of the human body (Hmelo-Silver et al., 2000). 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', that is, 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 (Kresh, 2006, p. 6). This means that to understand a bio-system, one must refer to interactions occurring both between the system's parts and between various systems. *Homeostasis*: To identify and analyze a multi-system phenomenon like homeostasis, one must have a systems understanding of the human body. 'Homeostasis is known as a key concept in biology and is well-documented on various levels of biological organization' (Reimann, 1996, p. 1). It has been acknowledged as one of the most important, if not the 'defining', core principle of physiology (Michael, Modell, McFarland, & Cliff, 2009; Michael & McFarland, 2011). The term refers both to the maintenance of a stable internal environment and to the regulatory processes (operating via feedback) leading to that stability, concepts that can be difficult for many students to assimilate. Understanding homeostasis is difficult because some processes are hidden to the eye and/or involve dynamic perception (Westbrook & Marek, 1992). Understanding homeostasis enables a deeper understanding of the complexity of the human body, because homeostasis explains both the interactions between the body and its environment and the processes that occur on its different organizational levels (Tripto, Ben-Zvi Assaraf, & Amit, 2013).

Dynamism: Hmelo-Silver et al. (2000) define a dynamic system as a coherent whole comprising 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. Understanding system dynamics allows you to identify the interaction between events and predict the consequences of changes (Sommer & Lücken, 2010, p. 127). Wilson et al. (2006) suggest that a major obstacle to dynamic thinking is connected to the 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.

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Unsurprisingly, system thinking has been shown to seriously challenge students of different school and college ages (Jacobson & Wilensky, 2006). Understanding complex systems is fundamental to understanding science, but the complexity of such systems makes them very difficult to understand because they are composed of multiple interrelated levels that interact in dynamic ways. Representation of complex systems must therefore be made explicit (Hmelo-Silver, Marathe, & Liu, 2007).

System thinking—what is it and how do we recognize it?

System thinking is a school of thought that focuses on recognizing the interconnections between the parts of a system and synthesizing them into a unified view of the whole (Ben-Zvi Assaraf & Orion, 2005). Moreover, it deals with recognizing patterns and interrelationships, and learning how to structure those interrelationships in more effective, efficient ways (Senge, 1990). The importance of system thinking for a meaningful understanding of science, and consequently for the investigation of school-age students' system thinking, has been a consensus among science education researchers for the past decade (Ben-Zvi Assaraf & Orion, 2005; Brandstädter, Harms, & Großschedl, 2012).

The learning sciences have recently seen substantial growth in research about students' understanding of complex systems (Etkina et al., 2010; Hmelo-Silver & Pfeffer, 2004; Hmelo-Silver et al., 2007; Jacobson & Wilensky, 2006). Wilensky and Reisman (2006) claim 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.

Several models have been put forth as useful means of representing the various forms and levels of system thinking. One promising approach for portraying systems thinking in a way that reflects the system's multiple interacting components and their fates is Structure-Behavior-Function (SBF) thinking (Goel, Rugaber, & Vattam, 2009; Hmelo-Silver et al., 2007). In SBF terms, the *Structure* portion of an SBF model of a complex system specifies the 'what' of the system, meaning the components of the system as well as the connections among them. *Behaviors* specify the 'how' of the complex system, namely the causal processes occurring in it. *Functions* specify an understanding of the 'why' of the system (Goel et al., 2009). For example, the diaphragm is one of the *structures* of the human respiratory system, the contracting and relaxing mechanism is an example of the *behavior* of the diaphragm, and the *function* of the diaphragm is to create an air pressure differential inside the thoracic cavity so that the air can move in and out.

Another form of conceptual representation is the Systems Thinking Hierarchy (STH) model developed by Ben-Zvi Assaraf and Orion (2005). This is the model we intend to use to assess students' understanding of systems, because it is more detailed than the SBF model, and therefore provides us with a more accurate picture. Ben-Zvi Assaraf and Orion (2005) suggest that how people think about and understand a system can be categorized according to eight hierarchical characteristics or abilities, which are evinced by students in an ascending order. These eight characteristics compose the STH model, which was developed following a study of eighth grade students. The model's characteristics are arranged in ascending order of advancement into three sequential levels: (A) analyzing the system components (characteristic 1); (B) synthesizing 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 fifth characteristic 'identifying matter and energy cycles' is not featured here, as it is not relevant to human body systems.

(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 the system (level B).
(4) Organizing the system's components, processes, and interactions, within a framework of relationships (level B).
(5) Identifying matter and energy cycles within a system (level B).
(6) Recognizing hidden dimensions of the system (i.e. understanding phenomena through patterns and interrelationships not readily seen) (level C).
(7) Making generalizations about a system and identifying patterns (i.e. hierarchy, homeostasis and dynamism—matter transitions) (level C).
(8) Thinking temporally (i.e. employing retrospection and prediction) (level C).

Why employ reflection and explicit teaching?

Research indicates that metacognitively aware learners are more strategic and perform better than unaware learners (Pressley, 2006), but not all students engage in metacognitive thinking unless they are explicitly encouraged to do so through carefully designed instructional activities (Lin & Lehman, 1999). Because not all students develop and use metacognition spontaneously, teachers need to provide students with explicit instruction in both metacognitive knowledge and metacognitive strategies (Hartman, 2001). There is robust evidence that indicates the efficacy of explicit instruction in fostering learners' metacognition, especially among lower achieving students (Dignath, Buettner, & Langfeldt, 2008; Zohar & Ben David, 2008; Zohar & Peled, 2008).

Explicit instruction can take the form of many constructivist practices in which the development of metacognitive understandings and skills is an explicit instructional goal (Zohar & Ben David, 2008). It is characterized by a series of supports or scaffolds. Several researchers have claimed that learners benefit more in an explicit scaffolding environment than in an implicit one, since explicit scaffolding requires less effort on the learners' part to manage, monitor, and self-regulate their own learning (Azevedo, Cromley, & Seibert, 2004; Land, 2000; Quintana, Zhang, & Krajcik, 2005). Metacognitive prompts are commonly used in order to remind students to activate their MS during science learning or to provide a scaffold that helps learners follow and internalize scientific processes (see Conner, 2007; Peters & Kitsantas, 2010).

Explicit teaching does not mean lecturing students, but rather raising the issue from every possible angle and directing students to 'see' it from one angle in particular (Clough, 2006). In that sense, it supports the three basic assumptions that Sofie, Loyens, and Gijbels (2008) associate with the constructivist view: first, that understanding is to be found in our interaction with the environment and that certain contents and the way in which they were learned are inseparable; second, that cognitive conflict is the driving force behind learning; third, that knowledge is created through social dialogue (in this case, the dialogue between interviewer and interviewee). Such teaching encourages students to pay conscious attention to explicit knowledge regarding thinking strategies and processes. In other words, the goal of this approach is to deal with metacognitive knowledge in a conscious and explicit way, whilst using constructivist teaching methods that focus on knowledge construction. This would mean promoting students' awareness of the type of cognitive procedures being used by them in various specific instances, since metacognition is 'not generic' (Bransford, Brown, & Cocking, 2000, p. 19) but instead is most effective when it is adapted to reflect the specific learning contexts of a specific topic, course, or discipline (Zohar & Ben David, 2008).

Reflective prompts (also called metacognitive prompts) are more focused questions that provide more directed help with specific aspects of the learning processes. These prompts aim at guiding students toward coherent understanding of the domain tasks at hand and may lead to extensive inference generation (Lin, 2001). Prompting has also been used to stimulate self-explanation for metacognitive development. Eliciting learners' explanations and justifications through prompting can help them to draw conclusions and make inferences that can lead to increased comprehension (Chi, Bassok, Lewis, Reimann, & Glasser, 1989). The most important advantage of these types of explicit prompts is that they focus students' attention on their own thoughts and on understanding the activities they are engaged in during the course of learning (Brown, 1997). Prompting is one type of scaffold that can be used to guide students' metacognitive thinking. In this study, the students' concept maps served as the prompts that helped them reflect on their own knowledge of the human body as a system.

Concept mapping and its uses

Concept mapping was developed by Novak in 1972 to replace interview transcripts as a means of following and understanding changes in children's knowledge of science (Novak & Musonda, 1991). The technique's capacity to externalize understanding can provide researchers with 'a window into students' minds' (Shavelson, Ruiz-Primo, & Wiley, 2005, p. 416) that makes it valuable and popular as an assessment tool (Ingeç, 2009; McClure, Sonak, & Suen, 1999; Novak,1990; Novak & Gowin, 1984; Rice, Ryan, & Samson, 1998; Ruiz-Primo, 2004). In addition to its use in research, concept mapping is also a useful teaching tool. It is a technique that promotes meaningful learning, enables the students to actively participate in the formation of their knowledge, and gives responsibility to the students during their leaning processes (Nakhleh, 1994). Finally, if concept mapping is used repeatedly, it can facilitate learning by encouraging students to engage in self-reflection (Hay, 2008; Hay and Kinchin, 2008) and dialogue (Kinchin, 2003).

Concept mapping has been described as effective in enhancing both cognitive and meta-cognitive processes in students (Angelo & Cross, 1993; Jegede, Alaiyemla, & Okebukola, 1990). Concept maps facilitate meaningful learning by helping students link their prior knowledge with new experiences as well as organizing the accumulated knowledge (Liu, Chen, & Chang, 2010). Henige (2012) reported that concept maps help students organize information into manageable and meaningful chunks, and teach them to recognize patterns in it. Specifically, the use of concept mapping has been shown to promote higher-level thinking on biology topics (Bramwell-Lalor & Rainford, 2014; Gonzalez, Palencia, Umana, Galindo, & Villafrade, 2008).

Concept maps have also been found to be useful assessment tools, for both teachers and students. They provide visual pictures of how students organize their knowledge structure within a particular domain. Edwards and Fraser (1983) noted that concept maps can be as effective as more time-consuming clinical interviews for identifying the relevant knowledge a learner possesses before or after instruction. Concept maps have also been noted as specifically useful for assessing systems thinking. Previous research has shown that increases in the number of concepts, connections, and diversity in CMs are a reliable parameter for gauging students' systems thinking (Ben-Zvi Assaraf & Orion, 2005; Songer & Mintzes, 1994; Sommer & Lücken, 2010). Recent studies have addressed the question of how best to integrate computer-based concept maps into the evaluation of systems thinking (Brandstädter, Harms, & Großschedl, 2012).

Kinchin, Hay, & Adams (2000) adopted a constructivist approach to the analysis of concept maps, showing how analyzing their contents qualitatively can reveal typologies of gross knowledge structures that reflect different patterns of students' knowledge and understanding of systems. This approach does not attempt to measure change in quantitative ways (through change in concept richness or map linkage, for example), as has been done by many (e.g. Cassata, Himangshu, & Iuli, 2004; Novak, 1998). Instead, it shares an epistemological approach with Jarvis, and suggests that 'meaningful change' is any that gives greater potential for the exposition of individual interpretations of a subject. The approach is a significant departure from Novak's original definition of meaningful learning (Novak, 1998), and it implies a focus on individual student approaches to learning rather than change as a process of development toward goals specified by teachers.

Methodology

The research approach

This study, though it is a series of individual case studies, was nevertheless conducted on a relatively large population of 83. We chose to work with a large population so as to get a broader picture of the way students respond to the reflective interview, employing a Multiple Case Narrative methodology (Yin, 2003). Case study research is a qualitative approach in which the investigator explores a case or multiple cases over time through detailed, in-depth data collection involving multiple sources of information and reports a case description and case-based themes (Creswell, 2007). Yin (2003) suggests that the multiple case study design uses the logic of replication, in which the inquirer replicates the procedures for each case. As a general rule, qualitative researchers are reluctant to generalize from one case to another because the contexts of cases differ. To best generalize, however, the inquirer needs to select representative cases for inclusion in the qualitative study.

We proposed first to 'zoom in' on each of the individual students, gathering as much information about each as possible, and then to 'zoom back out'—generalizing from this information to identify their system language when comparing their products (concept maps) in two stages of the learning process. While this methodology is similar to the conventional-quantitative study in that its purpose is to collect data from multiple people, it nevertheless preserves its narrative-qualitative nature and produces narrative-qualitative findings. The duality of this approach (combining a relatively large population with a narrative-qualitative form) is what, according to Shkedi (2005), allows researchers to identify the presence of broad patterns recurring within a wide variety of case narratives. In our study, the Multiple Case Narrative methodology provides us with a comprehensive view of the students' understanding of the human body as a system, and reflects their overall point of view and 'system language' as it emerges from their many individual explanations.

Research population

The research population consisted of 83 11th grade biology students, of whom approximately 60% were girls and 40% were boys. The students were gathered from three schools, taken from two different school districts. All of the students were from similar backgrounds, coming from non-religious Jewish families of mid to high socioeconomic status. The schools were chosen for their willingness to cooperate with the researchers. All of students in the study had chosen biology as their major, and because Israel has a centralized education system all of them studied the same curriculum. The biology syllabus for this age group centers around a curriculum called 'Human Biology'. The students learned about seven human body systems overall (i.e. vascular, nervous, immune, endocrine, respiratory, digestive, and urinary), with an emphasis on homeostasis.

The research tool

Concept map

The students participating in this study created two concept maps during their first year of biology studies (10th grade)—one at the beginning of the school year (pre) and one at the end of the school year (post). Their concept maps served both as a knowledge-integration activity (Bramwell-Lalor & Rainford, 2014) and as an evaluation tool for us as researchers and for the students themselves (Mintzes, Wandersee, & Novak, 2000; Novak & Gowin, 1984). They thus served at once to help the students learn about the human body systems, and to help us assess their understanding and identify possible obstacles to it. The concept maps served as scaffolding for the students, allowing them to see, verbalize, and assess their own thinking as the interview progressed. For an example of a pre and a post concept map, see Figures 1 and 2.

Adopting Ben-Zvi Assaraf, Dodick and Tripto's (2013a) 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 into two categories: 'matter transportation' (statements that describe the dynamic nature of matter transportation in the system) and 'dynamic concepts' (concepts connected by a node that described a process). 'Homeostasis' includes statements that generally describe the body's internal stability, and 'hierarchy' includes statements referring to scale in nature, while emphasizing one scale in relation to another (e.g. 'the circulatory system includes capillaries').

For a step-by-step description of the concept map analysis and its translation into the STH model of system thinking, see Tripto, Ben-Zvi Assaraf, & Amit (2013).

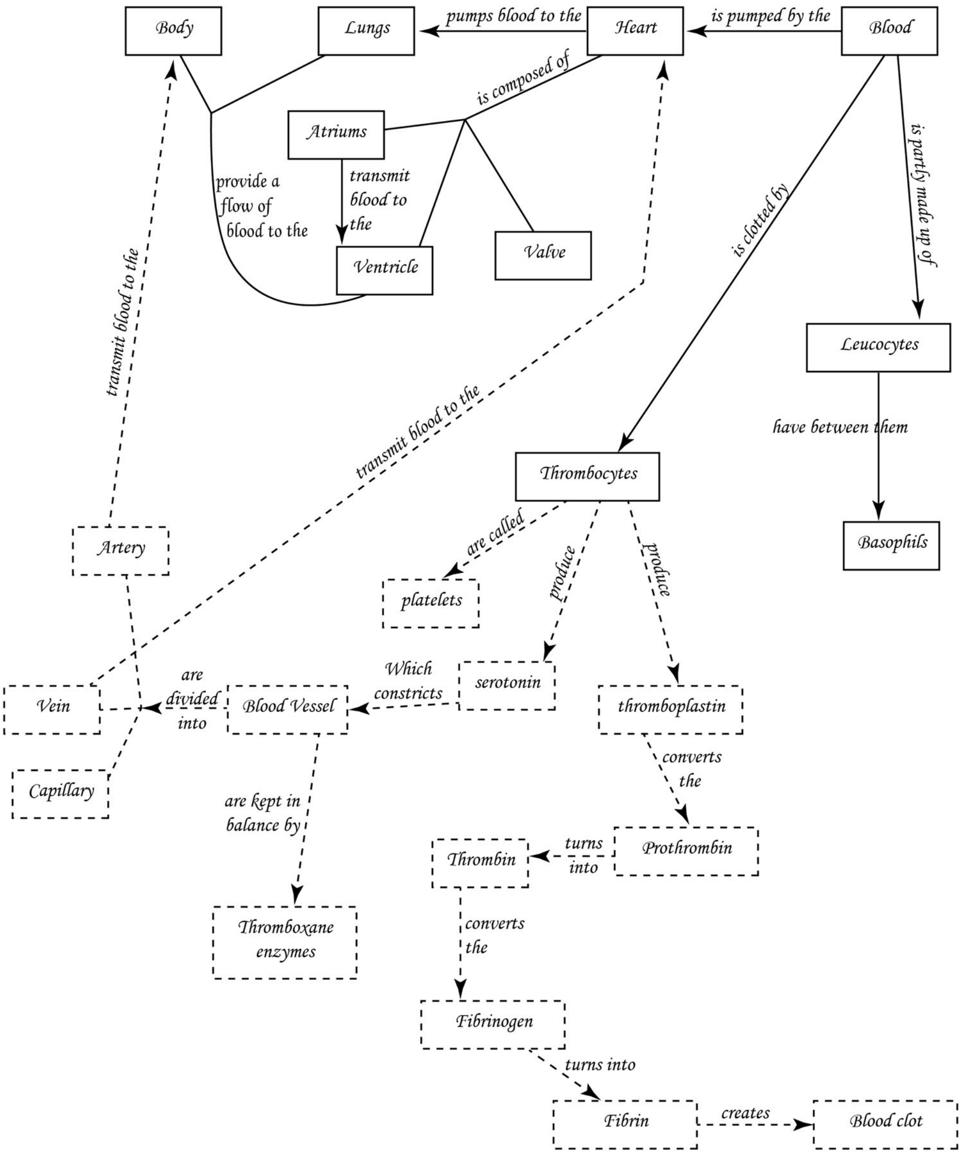

Figure 1. Hagar's concept map from the beginning of the school year (Pre).

Reflective interview

When the students in our study population completed the 10th grade, we conducted a semi-structured reflective interview with those of them who had chosen to continue with the subject in the eleventh grade. The individual interviews took place at the students' schools during class hours and lasted for 30–40 minutes each. According to Denzin and Lincoln (2000), interviews should take place in students' natural environment (school), and be conducted as a conversation. Therefore, they took place in a quiet room and in a relaxed atmosphere, so that the students would feel free to answer the questions. The interviewer also took care to avoid judgmental reactions to students' answers, and not

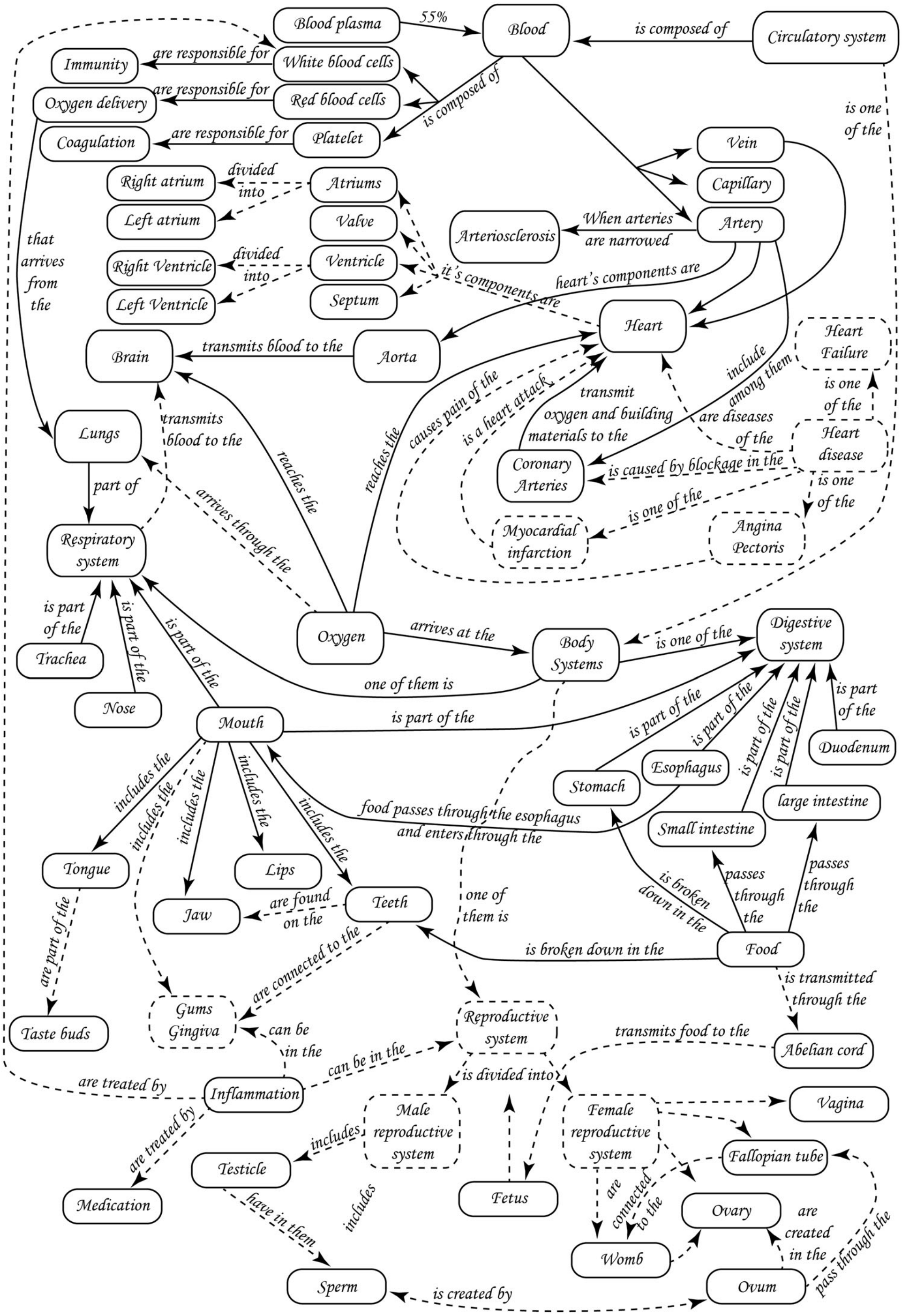

Figure 2. Hagar's concept map from the end of the school year (Post).

to use terms that could influence the students' answers, unless the terms were first brought up by the students. It is also important that the interviewer be flexible, posing further questions and asking for clarification and examples in order to better understand the interviewee's opinions.

The purpose of the interview was to motivate the students to organize the thinking products (CMs) they had produced in the tenth grade. It was also designed to help them reflect upon and assess their own knowledge and understanding of the material. The model of interviewing skills reviewed in this study values a 'reflection on action' (retrospective thinking) approach, in which students are encouraged to reflect on their own 'system language' through use of their products (CM).

The interview consisted of three stages:

(1). *Preliminary definition*:

Before commencing the interview, the interviewer read aloud the following definition of 'system', (based on Ben-Zvi Assaraf et al. 2013) and noted its significance in connection with human body systems:

> Humans, like all living things, are made up of organized, complex systems. Each system contains structures at different levels of organization, in which various processes occur. A system is an entity/body that functions through the mutual interaction of its components, in order to perform a singular function—**homeostasis**. Every component in the system has a role that supports the system's function. The system is made of **components**, and **processes** take place there. The processes in the system make possible the **interactions-the cooperation** between the system components toward the achievement of a common goal.

This basic definition was followed by brief descriptions of the system's three patterns: hierarchy, homeostasis, and dynamism. It is worth noting that this definition was not new to the students, but was a reiteration of the definition they had been given in biology class the year before.

(2). Concept map comparison by means of implicit, then explicit, teaching:

Implicit teaching: At the beginning of the interviews, the students were presented with their pre and post materials from the 10th-grade (i.e. their two concept maps), and asked to compare the two of them in relation to the following two questions, which do *not* make explicit use of systems language:

(a) How would you sort the concepts circled on both maps?
(b) Look at both maps; which map better describes the human body as a system?

These two questions were phrased so as not to point the students in a particular, predetermined direction, nor specifically elicit the use of system-related language.

Explicit teaching: Later, the interviewer read the definition of a system again, noting once again the significance of the definition regarding human body systems. The students were asked to compare their two concept maps again, this time based on these two questions, which *do* make explicit use of systems language:

(c) Do your maps represent interactions between system components?

(d) Do the pre and post concept maps you created express each of the system characteristics: dynamism, hierarchy, and homeostasis?

These questions are designed for a specific purpose, namely to help the students define what a system is, based on how it was represented in their own products, and use systems language in their explanations.

(3). Helping students reflect on their own learning process

At the reflection stage of the interview, the students were asked:

(e) What would you add or improve in the pre and post concept maps to better describe the human body as a system?
(f) What did you learn from the concept maps about your understanding of the human body as a system?

This part of the interview yielded information about the students' perception of their own learning, and about their perception of what a good understanding of human body systems *is*. The fifth and sixth questions in the interview were designed to engage students' metacognitive skills, encouraging them to reflect on their own thinking and on the results of their map comparison. Analysis of their answers to these questions also helped us identify the difficulties that remain for them in understanding the human body as a system.

Several steps were taken to ensure that students used as much systems language as possible during the interview. First, the definition with which the interview began made explicit use of systems language when describing a system and its characteristics. Second, the explicit teaching part of the questionnaire used systems language to present students with specific criteria for comparison—asking first for references to interactions and then for references to the three system characteristics 'hierarchy', 'homeostasis', and 'dynamism'. Third, the reflection sections of the questionnaire asked the students to explain their understanding of what a system is.

Data analysis

The data processing for this study was done according to the narrative approach to qualitative research and data analysis (Denzin, and Lincoln, 2005), through category building and continuous interaction between a conceptual perspective and the data arising from the field (the students' explanations). The most common way of presenting interview data is to organize the transcripts into categories (Seidman, 1998, p.107). The categorization process was conducted in the following stages:

(1) First, all the interviews ($n = 83$) were read and categories were ascribed to each interview separately. Every interview was first processed into categories separately, so as not to force earlier interviews' categorization on those that followed.
(2) Next, links and relations were found between categories and, according to these relations, we built a 'category tree' with a number of categories and sub-categories. The graphic presentation of categories with a 'category tree' allowed a view of all

> relations and hierarchies between categories. The categories were then united under one main category, which directly addressed the study questions, after which the theoretical explanation was constructed, based on quotes from the students (Shkedi, 2005).

Internal validity was established at the mapping stage of the analysis. The primary and sub-categorization was debated and agreed upon by the researcher and two additional science education researchers.

To ensure the trustworthiness of our results, we drafted a comprehensive final report, including contextual information, proper quotations from informants, and an explicit conceptual discussion, so other researchers could review the database evidence. The analysis process was also fully documented and preserved, and the final report offered and maintained a chain of evidence. Finally, the analysis of the different categories was carried out by the researcher and her advisor separately and simultaneously. The advisor was consulted after each stage to further strengthen the reliability of the results. For category trees see Appendix 1.

Findings

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 in our analysis of the students' 'system language'.

The first two sections of the interview (i.e. the preliminary definition and questions 'a' through 'd') assessed the students' use of systems language in describing their concept maps, checking to see whether the use of explicit teaching encouraged that use, and to what extent. The contents of the students' explanations were analyzed and categories were formed from their answers to the non-explicit questions vs. the explicit ones. The final section of the interview (questions 'e' and 'f') engaged the students in a reflective process. The results are presented here according to the two research questions, first addressing the differences in the answers elicited by the explicit vs. non-explicit interview questions, and then addressing the results of the reflective section of the interview.

> Question #1: How do the results provided by the parts of the interview that employed explicit teaching compare to those provided by the parts that did not? To what extent does the explicit approach help students to make fuller use of systems language?

To answer this question, let us first look at the students' responses to the questions that did not explicitly employ systems language, namely:

(a) How would you sort the concepts circled on both maps?
(b) Look at both maps; which map better describes the human body as a system?

The non-explicit questions elicited seven categories of responses from the students, the two most dominant of which were both related to the most basic and easily grasped of the systems characteristics—'hierarchy'. This characteristic describes orders of magnitude in the human body, stressing one order of magnitude vs. another. In the largest category, 80% of the students' answers included the act of merely presenting different structures on the human body (e.g. 'In both maps you can sort the concepts according to system, organs, vessels and cell types'). In the next, 35% of them noted the multiplicity of sub-systems, a reference to the hierarchical nature of systems within the larger human body system (e.g. 'In the first map there are more systems and in the second I focused on one'). Four of the seven categories noted by the students, the two noted above and the less common categories 'multiple components' (20%) and 'describing human body generally' (6%), are related to an understanding of structures in systems, which is the most basic aspect of system complexity.

Higher levels of complexity were also represented in the three remaining categories, but to a lesser degree. While 31% of the students did refer to 'processes' (i.e. a series of actions/changes that occur naturally in stages) as a characteristic of the system's complexity, only 10% addressed the more advanced characteristic of 'interaction', despite the fact that this is a central characteristic involved in understanding systems' complexity. A reference to processes can be a simple statement like 'in the first map I note the chemical breaking down of food, metabolism', while interaction is reflected in statements like 'hemoglobin travels through the red blood cells to the lungs, and they supply oxygen to the body'. The same scarcity (10%) can be seen in the case of the characteristic 'homeostasis', which, like interaction, is central to understanding systems' complexity but more sophisticated than the more basic structural characteristics. It is worth noting that both of these latter categories are scarce despite being specifically noted in the definition read to the students before the comparison began. (Figure 3)

Our comparison between the students' answers to questions 'a' and 'b' and the more explicitly worded questions 'c' and 'd' showed significant differences, as the latter two elicited far more complex representations of the human body system. This is clearly indicated by the fact that the non-explicit questions elicited only 7 categories of student

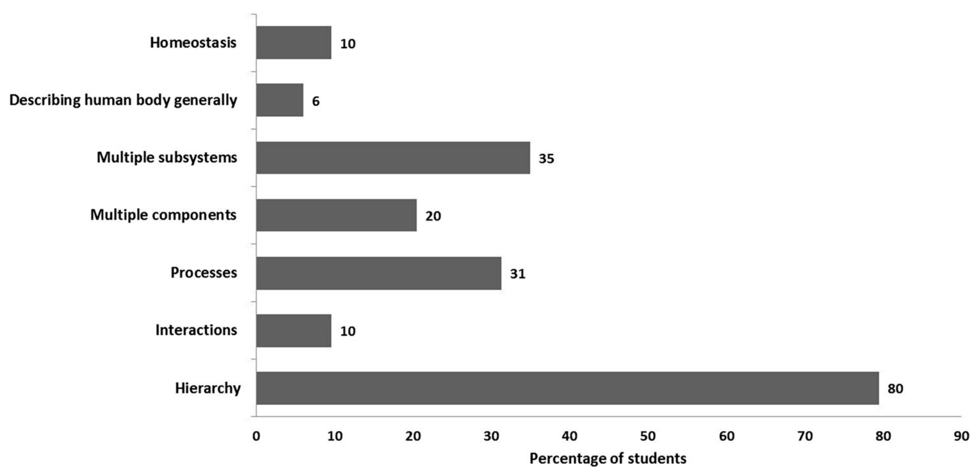

Figure 3. Distribution of categories in relation to the human body system characteristics—no explicit instruction ($N = 83$).

answers, while the explicit ones yielded 25 categories (8 from question 'c' and 17 from question 'd').

Interview question 'c'—'Does your map represent interactions between system components?'—elicited a far less generalized and more detailed comparison from the students than the previous questions had, in terms of their ability to identify different specific types of interaction. 'Interactions' refers generally to the impact that one element has on another in the human body. When asked explicitly to look for interactions, 51% of the students noted general interactions (e.g. 'the brain gives commands to the digestive system'), a substantial increase from the mere 10% noted in response to the non-explicit question. Moreover, the explicit question elicited a variety of different, more specific, *types* of interactions from the students. For example, 27% of them noted interactions between systems, meaning the impact one system has on another (e.g. 'there are interactions between the respiratory and vascular systems'). A further 18% noted matter transfer as a component of interaction—an indication of more advanced thinking because it addresses the system's hidden dimensions (e.g. 'the respiratory system moves oxygen to all parts of the body through the blood'). Only 7% noted interactions at the cellular/molecular level, such as 'protein is influenced by enzymes—that's how it breaks down'. Processes were noted by the students here too (17%), but were described within the context of interaction (e.g. 'there is interaction between the heart and the blood, because the blood vessels carry blood throughout the body through the action of the heart'). Some of the students (17%) also noted phenomena that arise from multiple interactions, indicating a more complex relationship (e.g. 'the hormonal system secretes adrenalin, which increases the heart rate, which raises the blood pressure'). The two smallest categories this question elicited were 'interactions in the time dimension' (6%) and 'interaction as part of

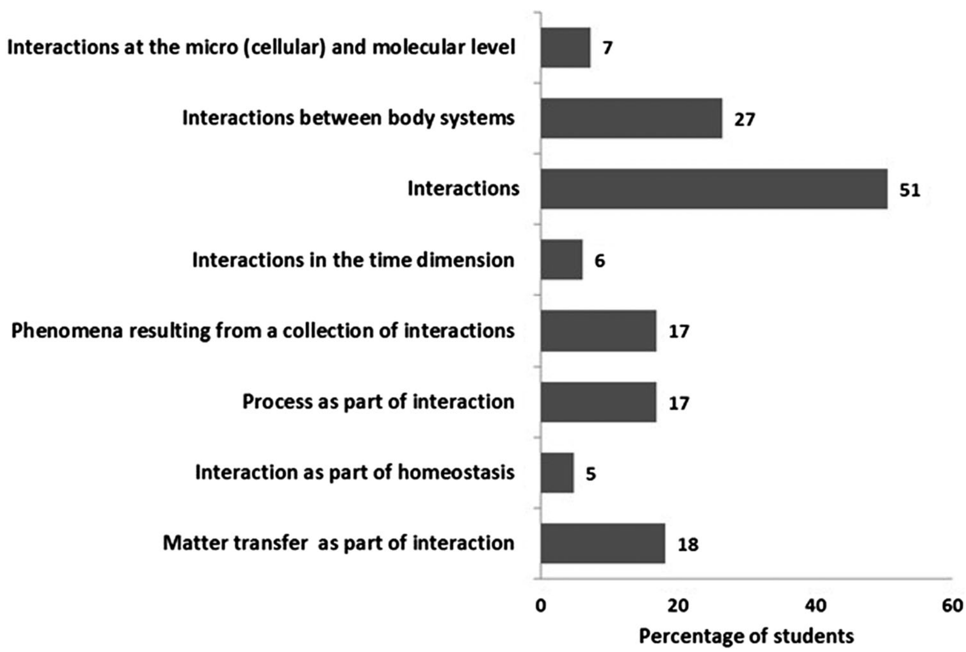

Figure 4. Distribution of categories in relation to interaction—with explicit instruction ($N = 83$).

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homeostasis' (5%), which are the two categories that reflect the highest levels of system complexity (Figure 4).

Interview question 'd' explicitly asked the students whether their pre and post concept maps express the system characteristics 'dynamism', 'hierarchy', and 'homeostasis'. When asked explicitly to look for homeostasis, students found it, even if the term homeostasis was not explicitly written on their concept maps. As Figure 5 shows, the explicit questions elicited a much greater quantity and range of references to homeostasis, which was mentioned by 74 of the 83 students, and which is represented by the top 10 of the 17 categories in the graph.

The division into sub-categories for 'homeostasis' was based on one of two factors. The categories, 'system level control', 'cell level control', 'sickness as disruptor of homeostasis', and 'balance and stability', arose from the characteristics of homeostasis described in the students' explanations. Three additional categories, namely 'concentration of materials' (meaning the concentration of molecules in the body's fluids), 'fluid volume' (the space

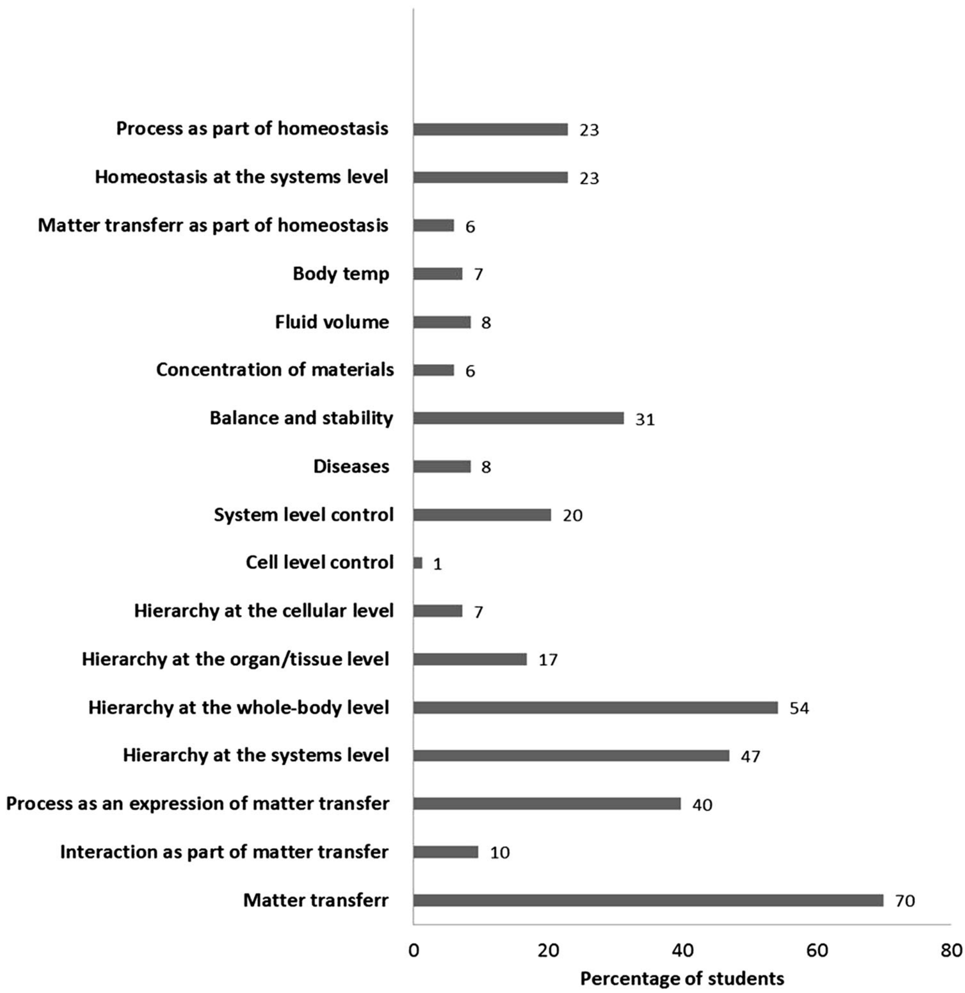

Figure 5. Distribution of categories in relation to patterns—with explicit instruction ($N = 83$).

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taken up by fluid in the body), and 'body temperature', are dimensions of homeostasis noted by the students.

A third of the students (31%) noted homeostasis as maintaining balance and stability in the human body (e.g. 'the blood transfers hormones, sugars and oxygen, and that's how they stay at a constant level in the body'). A further 23% noted homeostasis at the system level (e.g. 'the digestive system allows the transfer of building blocks to the cells and thus maintains homeostasis'). The topic of control was addressed on two levels, with 20% of the students noting it at the system level (e.g. 'the circulatory system maintains homeostasis by moving blood, where there are substances that maintain homeostasis'), and only 1% addressing it at the cellular level.

The pattern 'dynamism', which refers to the transfer of matter in the body, was noted by 74 of the 83 students following the explicit question, while the non-explicit questioning elicited no mention of it at all. Dynamism was expressed by the students in three ways, of which only the latter two are expressions of more advanced systems thinking. The most prominent among them (70% of students) was simply noting the transfer of a particular material (e.g. 'The circulatory system has oxygen that reaches the body's systems'). Another dominant expression, used by 40% of the students, was of processes as an expression of matter transfer (e.g. 'diffusion of gas, meaning oxygen moves into the cells' or 'glycerol and fatty acids are absorbed in the cells'). The third expression, noted by only 10% of the students, was interaction as part of matter transfer—referring to the impact of A on B as part of matter being transferred (e.g. 'In the second map the lungs provide the oxygen to the brain and the heart, that's a process crucial to their function')

> Question #2: What does the reflective section of the interview reveal—to the students themselves and to us as researchers—about the students' understanding of the human body as a system?

The reflection section of the questionnaire (questions 'e' and 'f') required the students to think about what a system is to them, and what it means to understand the human body as a system. Thinking about what they had done (i.e. their two maps) allowed the students to undergo a process of internal assessment through which to improve their own performance and confirm their own ideas. In this process they thought about their own learning whilst checking and mapping the knowledge present in their cognitive system and connecting it to new knowledge, insights, and experiences. This level of assessment, along with the incitement to use metacognitive skills and engage in reflective thinking, helped the students accurately assess their concept maps, and through them their previous knowledge.

In addition to assessing previous knowledge, this part of the interview also encouraged the students to generate new knowledge by identifying the parameters missing from their maps, which meant recognizing the obstacles to their own understanding that such gaps represent and showing a new awareness of system elements like patterns, interactions, and connections between systems. This new awareness was expressed in statements like 'I should have added homeostasis', 'I should have added more connections between the systems I wrote down', 'I should have shown that everything's connected to everything', 'shown more detail'. These statements indicate the students' awareness of their own partial understanding of the systems, and their ability to pinpoint specific contents that they would now improve.

The students' perception of the human body's complexity—as indicated by their answers to the reflection questions—is presented in Figure 6.

The most prominent category that arose from the analysis of the students' answers —'awareness of processes'—shows that for 41% of them the complexity of a system is measured by a range of processes ('I would add more detail about processes [to improve my map], because the map is very generalized'). Nearly as many (38%) also see connections as a key factor in system complexity, both in their awareness of their multiplicity ('I would make more connections between the concepts so they would look connected to everything') and of connections between systems ('I understood that there's a connection between systems, and that each does not work alone'). A third of the students (33%) show awareness of multiplicity of systems, which shows their understanding that the level of detail in a human body system is an indicator of its complexity (e.g. 'let's say the immune system, I could elaborate on that. Start with a general topic and then detail what happens in the heart and then the lungs. Here there's detail missing; and then to diseases and then explain the causes for disease. The map is not detailed

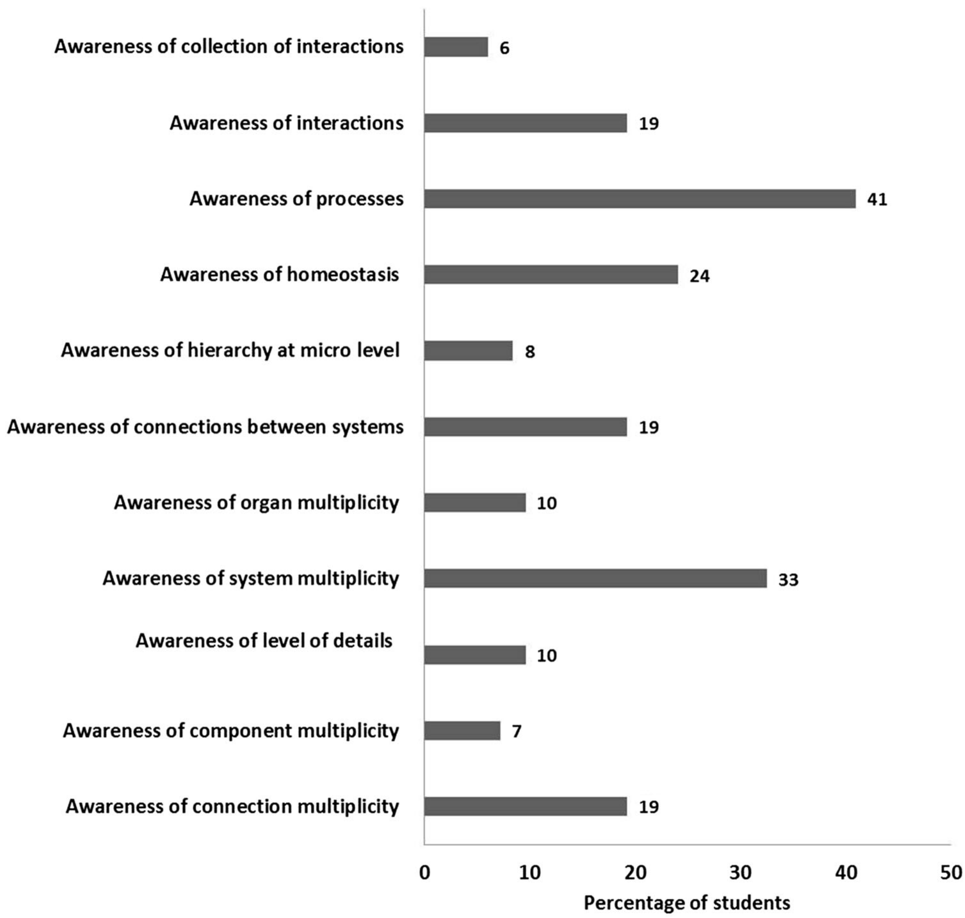

Figure 6. Distribution of categories in relation to reflection on extent of understanding of the human body as a system ($N = 83$).

enough'.). The students' perception of which patterns are relevant as indicators of system complexity is evident in the fact that their explanations referred to the patterns hierarchy and homeostasis (e.g. 'I would add homeostasis as a concept and send arrows to all the systems in which it happens'). Dynamism was not mentioned, suggesting that it does not hold a prominent place in the students' perception of the system.

Discussion and conclusions

This study examined the reflective interview as a tool for developing meta-cognitive thinking and for assessing high school biology students' understanding of the human body system. One of the major issues affecting students' ability to learn about complex systems is their cognitive, meta-cognitive, and self-regulatory process. Therefore, studying the use of meta-cognitive process, scientific reasoning skills, and motivational strategies in understanding complex systems is critical (Hmelo-Silver & Azevedo, 2006). Developing meta-cognitive awareness is critical to helping students learn about complex systems. It is also critical to their understanding of the systemic nature of homeostasis, which is the element most emphasized in the current biology curriculum.

The pedagogical approach applied in this study focused on developing meta-cognition on two different levels. The first level, addressed in the first part of the questionnaire, refers to students' knowledge of their own internal systems model—their metacognitive knowledge. This knowledge includes students' ability to verbalize general characteristics of systems thinking. The second level of meta-cognition addressed here (in the interview's second part) is students' effective control of the cognitive system, which includes elements like reflection, follow-up, regulation, and control (Ben-David & Orion, 2012).

Meta-cognitive knowledge has two primary characteristics. First, it carries a strong verbal component and can be described in words. Second, it is knowledge that must be supported by experience; because it is highly abstract, most students are unlikely to be able to develop it without engaging in a series of practical experiences. This means that helping students learn to apply meta-cognitive skills and reach high levels of thinking means providing them with a variety of concrete situations with which to practice (Zohar & Barzilai, 2013). For example, Cuevas, Fiore, and Oser (2002) demonstrated how computer technologies can potentially be used to transform the learning experience for complex systems into a constructive cognitive and metacognitive activity for different populations of learners.

The verbal and the practical components were both expressed in our study when the students were asked to compare the two concept maps they had created the year before. The explicit teaching of 'what is a system' was designed to encourage the students to engage in active thinking. The interview questions directed the students to examine their own products in an explicit mediation process. The explicit teaching of meta-cognition has been found to be effective in promoting learning and thinking processes (Perssely, 2006), and it was adopted in this study to encourage our students' metacognition. Verbalizing thoughts is one of the key principles of explicit teaching through social interaction (Costa, 1991; Fairclough, 1992; Hogan, 1999; Thomas, 1999, 2002; Tishman, Perkins, & Jay, 1996). Using the task of comparing the two concept maps as a graphic, visual, and tactile tool, the students verbalize their thoughts in their answers to the interview questions. The discussion will address the two components of meta-cognition separately, as they appear in the two research questions.

(1) To what extent does the explicit approach help students to make fuller use of systems language?

This research question refers to the first four questions of the interview, those that encourage students to organize their knowledge, first non-explicitly and then explicitly. The results for this part of the interview indicate a distinct difference in the students' use of systems language, which increased strongly in response to the two interview questions that directed the students explicitly toward the system characteristics 'interactions' and 'patterns'. These results support those of Akerson and Donnelly (2010), who showed that students' attitudes toward NOS (Nature of Science) could be improved through explicit NOS instruction.

Before the explicit phase of the interview, the students presented hierarchy as a structural system characteristic, rather than as a pattern (see Figure 3). This was expressed through references to mostly macro-level components like: system, arteries, lungs, etc. While the students seemed to be aware that processes take place in the human body system, this was not common in their explanations at this point. Moreover, their awareness of interactions, which is crucial to meaningful understanding in biology (Lin & Hu, 2003), was given very little expression. Such a lack in awareness of the characteristic 'interactions' was also found in Authors (2013a). Another study, which examined the SBF model to determine how experts vs. novices understand complex systems, showed that students tend to stress system components rather than interactions (Hmelo-Silver & Pfeffer, 2004). The students' intuitive difficulties with the important concept of system interactions and complexity indicate the need to explicitly develop their understanding and their cognitive skills, and thus help them in the transition from novice to expert (Anderson & Schönborn, 2008). Indeed, in this study the students' transition to the use of complex and varied systems language, which addressed both interactions and patterns, was made possible by the meta-cognitive process elicited in the explicit questions (see Figures 4 and 5).

Another point of difference between the non-explicit and explicit interview questions is the students' reference to dynamism. The pattern 'dynamism', or the expression of some form of matter transition, was not noted at all in the students' answers to the two non-explicit questions. Hmelo-Silver et al. (2000) defined the dynamism of a system as a coherent whole made up of mutually interactive components that work together both within individual systems and between them. The dynamic processes taking place in the human body are hidden in the sense that they cannot be perceived by the senses. Students' concrete knowledge often includes only what their senses can perceive, while knowledge of processes, particularly microscopic ones like those taking place in the cell, is too complex and abstract to be deduced directly from observation. Patterns, particularly homeostasis, are complex and abstract concepts unconnected to students' daily lives, and understanding them requires students to be capable of abstraction (Westbrook & Marek, 1992). The non-explicit questions in our interview elicited references to homeostasis from only 10% of the students.

One question that arises from our findings is—why did the students not make use of the system terminology they were given at the start of the interview until they were asked about it explicitly? All of the systems language used in the explicit questions was also noted in the preliminary definition that was read to the students before the interview began, and yet they did not use it when answering the first two (non-explicit) interview questions. One possible explanation is that the information from the definition was not meaningful to them because it lacked anchors in their cognitive system, that the new information had no useful system of older knowledge to connect to (Ausubel, Novak, & Hanesian, 1978). This has been noted in several studies as a difference between novices and experts, which makes experts better able to access more in-depth and complex knowledge when discussing a given topic because they have an abundance of relevant prior knowledge to draw upon, which has been stored in long-term memory in schemas so that it is organized and easily accessible when needed (Chi, Glaser, & Rees, 1982).

Although a schema can hold a large amount of information, it is processed as a single unit in working memory. Therefore, when relevant prior knowledge is integrated into working memory to facilitate connections between visual and verbal mental models, it is less likely to overburden working memory (Kirschner, 2002). Because experts have well-developed schemas, they attend to different information than novices (Chi, Feltovich, & Glaser, 1981). Experts link their initial visual and verbal representations to underlying principles of the content, and develop a more comprehensive mental model (Snyder, 2000). The results of these studies may be due to a lack of appropriate system thinking assessments in primary and lower secondary school, particularly the assessment of 'forward and backward thinking between concrete objects and system models' (Boersma, Waarlo, & Klaassen, 2011, p. 190).

The explicit part of the concept map comparison elicited an improvement in the students' expression of system understanding. Liu and Hmelo-Silver (2009) showed that without explicit scaffolding, students have difficulty developing systems thinking on their own. However, if they are given an explicit mental framework through intervention that targets thinking about system relations, students are able to see more than one link between the mechanism (the interactions) and the part (the components) (Hmelo-Silver, Jordan, Eberbach, & Goel, 2011; Jordan, Hmelo-Silver, Liu, & Gray, 2013).

The meta-cognitive interview provided the students with scaffolding in the form of comparison, which helped the students use systems language that included complex system characteristics like 'interactions' and 'patterns'. The characteristic 'interactions' was represented by a range of interactions that take place in the human body, including interactions between systems, interactions on the micro-level, and even a few interactions through time. Our explicit intervention led to improved expressions of the system patterns 'homeostasis', 'hierarchy', and 'dynamism'.

The explicit questioning allowed us to reveal the most complex system model that the students were capable of representing. The fact that the students showed more complex systems language at the explicit stage indicates that they were able to employ meta-strategic knowledge in order to further develop their own system thinking skills. These results support those of Garofalo and Lester (1985), who showed that teaching metacognition is important to the development of higher-order thinking skills. The metacognitive process led the students to express aspects of meaningful learning by making connections and presenting mechanisms, both indications that the students are capable of coherent perception. Explicit teaching allowed them to present more complex knowledge in their explanations, and encouraged them to monitor their progress and make new, previously unnoticed, connections between ideas.

Because not all students naturally tend to engage in high cognitive skills like metacognition on their own, the comparison scaffolding strategy we used seems to have improved the students' thought processes, and to have encouraged deep learning (Chin & Brown, 2000). Research has shown that students do better when they are aware of their own learning (Marton & Säljö, 1984), and encouraging the use of metacognition is thus a central aspect of deep learning. Conner (2007) found that asking biology students questions designed to assess their own learning led to an awareness of their own skills that helped the students learn more effectively. It is possible that the explicit questions influenced the students' learning by decreasing their cognitive load as they performed their task (Davis, 2000).

(2) What does the reflection section of the interview reveal—to the students themselves and to us as researchers—about the students' understanding of the human body as a system?

This section of the metacognitive reflective interview proved beneficial on several fronts. The students' answers to the reflection questions in the interview told us as researchers how they perceive their products (the concept maps). By revealing their thought processes and making them explicit, the interview allowed us to assess the individual system models the students had constructed for themselves as they learned. Using the concept maps as a visual model allowed the students' perceptions to show through their explanations of the maps. External models (like the concept map) can often provide insights into students' internal, mental models. The interview made the students' hidden knowledge visible and allowed us to examine it (Schön, 1983). Another vital benefit of this reflective interview is that it elicited specific references from the students to various components of system thinking, giving us a very clear picture of which aspects of system thinking they are aware of and comfortable with, and which they are not. Thirdly, we suggest that devoting time to explicit teaching through this interview did not just review the students' products, but also helped them to further advance their learning. The interview was designed to give the students 'time to think', which, according to Tishman et al. (1996) encourages students to give better, deeper answers. This, combined with the verbal interaction with the interviewer, helped the students generate new meaning and knowledge of the human body systems from their two concept maps. The importance of social interaction to the verbalization of thoughts is a basic assumption of the explicit teaching of metacognition (Ben-David & Orion, 2012).

Reflection is a simple tool through which students can be explicitly 'made' to think retrospectively about how their ideas change (or do not change) (Dewey, 1933). Many researchers have noted the important role reflection can play in students' advancement (Hatton & Smith, 1995; Lin & Lehman, 1999). Davis (2000) found that questions that encourage reflection are significant in helping students integrate knowledge acquired in science projects. Khishfe and Abd-El-Khalick (2002) showed the benefits of reflection to the learning process in a study that examined students' perceptions of the Nature of Science, comparing explicit teaching that makes use of reflection and repeated discussion with implicit teaching based on inquiry tasks with no reflection or discussion. They found that the perceptions of students who were explicitly prompted while engaging in reflection were improved significantly over those of the students who were not, particularly in their ability to distinguish between observation and inference.

Another component that arose during the students' reflective process is their sensitivity about their ability to represent the complexity of the human body system. The students expressed frustration at their difficulties in representing the system's complexity. This embarrassment at their limitation can be associated with the reflective process the students had undergone, and can be read as a sign that learning had occurred and as a stage in the learning process. Efklides (2006) noted that metacognitive experiences occur when students have feelings like embarrassment about cognitive processes as they are conducting them. These feelings have an important role in promoting cognitive processes (Carver, 2003; Efklides, 2006). Such experiences lead to the setting of new thinking strategies or the improvement of old ones. They also influence cognitive knowledge, meaning they add new metacognitive knowledge or lead to the improvement or discarding of old metacognitive knowledge (Papaleontiou-Louca, 2003).

In conclusion, the findings of this study show that in relation to system thinking, using a reflection interview as a knowledge integration activity is an effective method not only for assessing the subjects' conceptual models and identifying those aspects of a system that are most commonly misunderstood, but also for extending the students' learning and broadening their understanding of human body systems. These results can serve as a recommendation for teachers and impact how we choose to help our students improve their achievements in scientific topics, particularly regarding the human body system. We suggest that in order to help students succeed both as learners and in life, teachers must provide explicit teaching for specific ideas that encourage metacognitive thinking processes. We also recommend allowing students time to think and to identify their difficulties. These strategies will help our students succeed and make it easier for them to learn about and understand the human body system.

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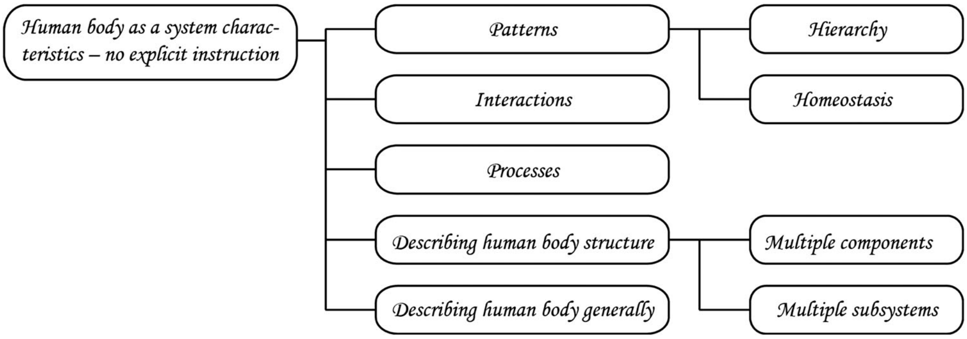
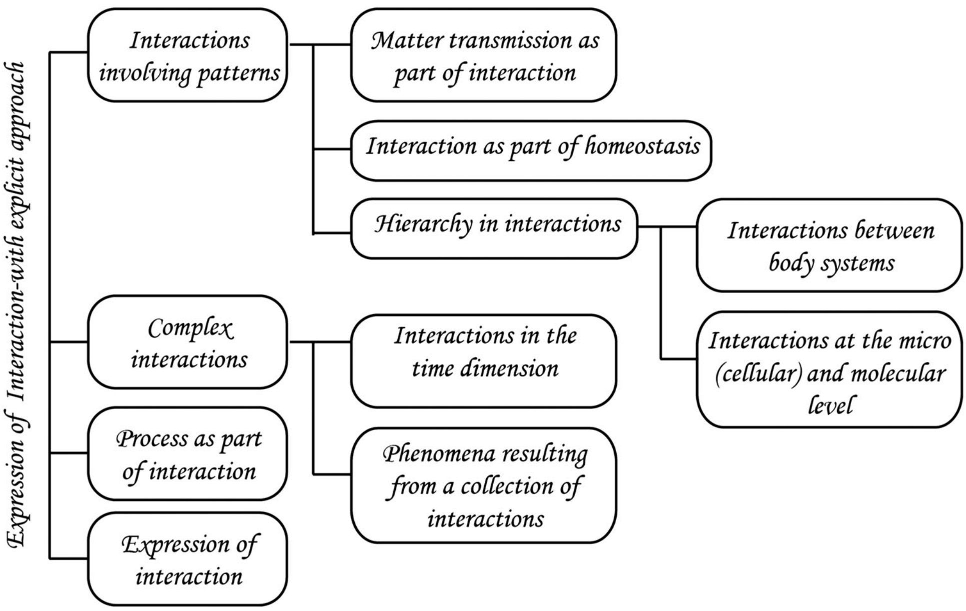
Appendix

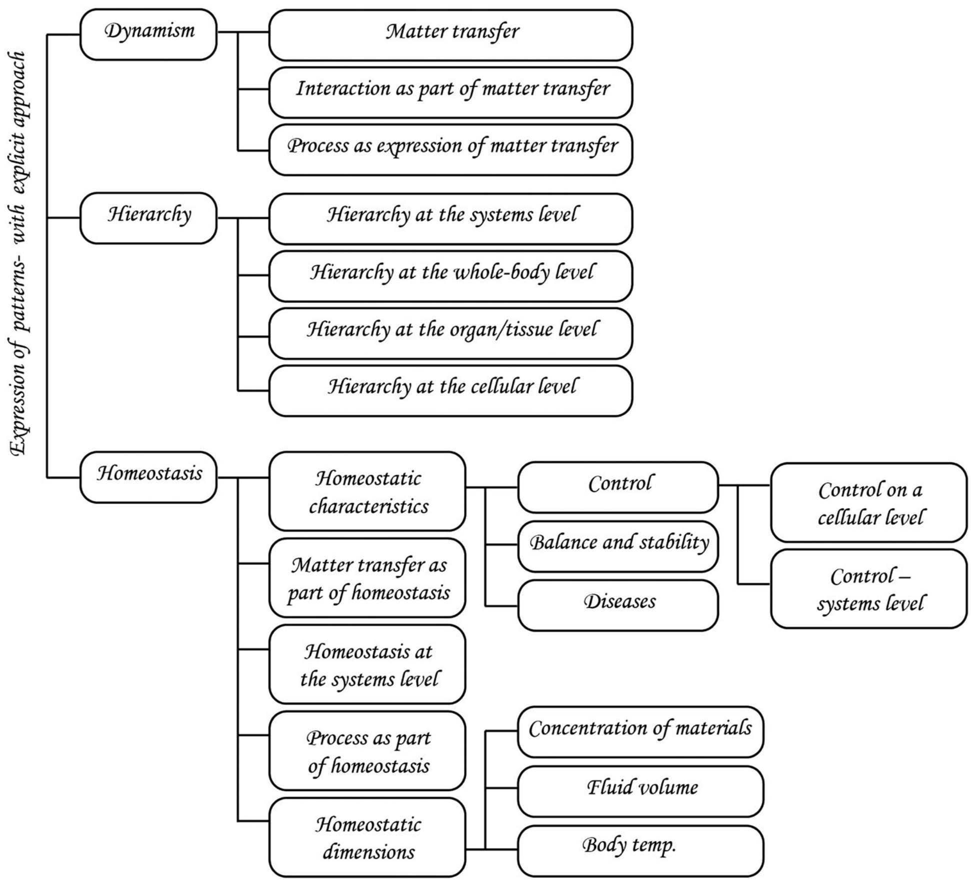
1: Category trees.



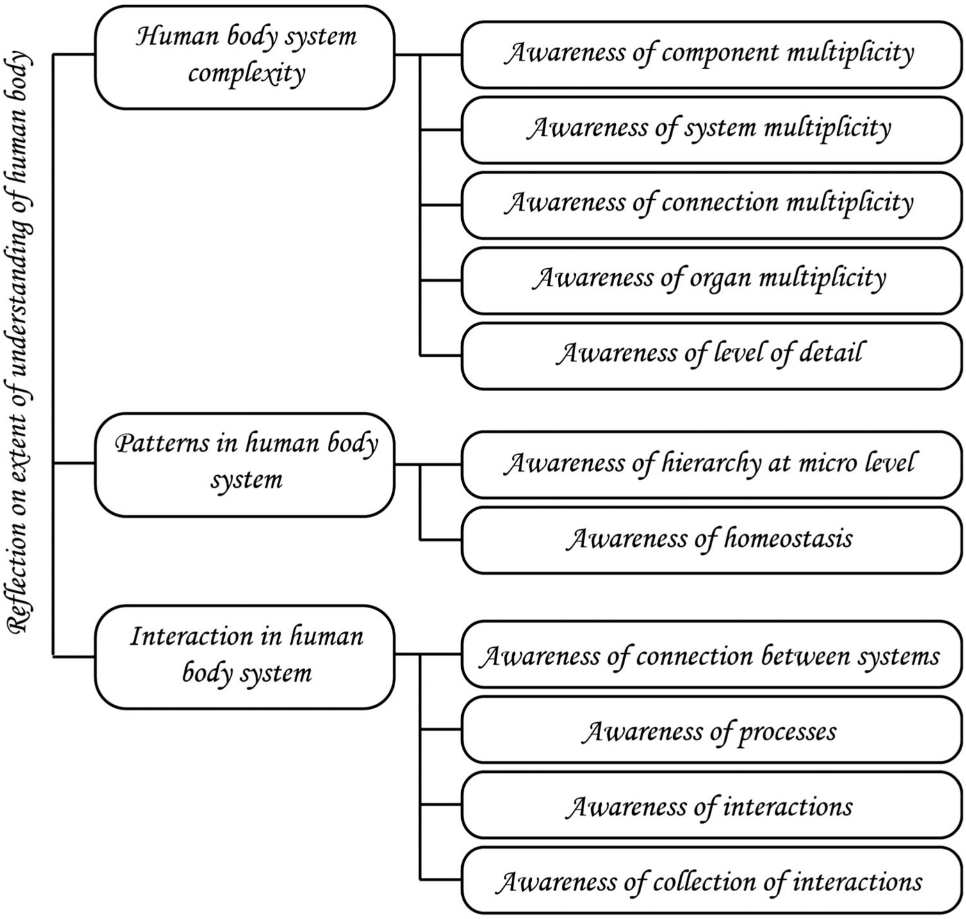
A: Characteristics of human body as a system (*Interview question 'a' 'b'*).



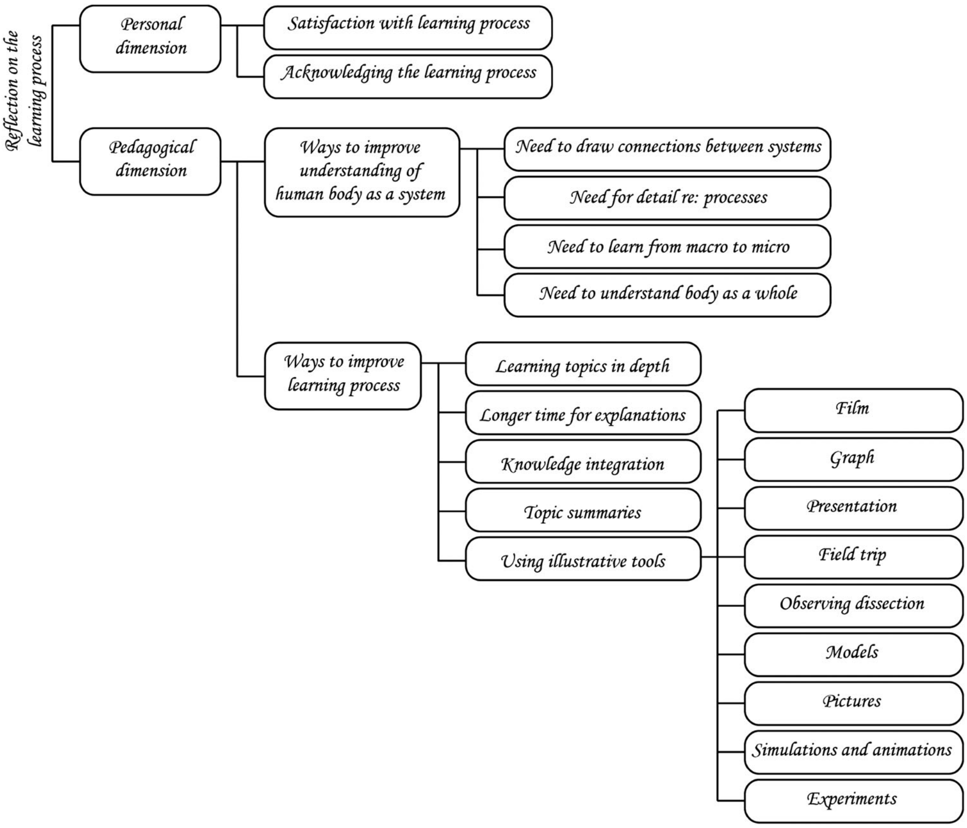
B: Expression of interaction—with explicit instruction (*Interview question 'c'*).



C: Expression of patterns—with explicit instruction (*Interview question 'd'*).



D: Reflection on extent of understanding of the human body (*Interview question 'e'*).



E: Reflection in the learning process (*Interview question 'f'*).