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‘The brain needs nutrition’: pupils’ connections between organizational levels

Abstract

Previous research suggests that connecting organizational levels of biological systems is challenging for pupils. In the present study we investigated 122 pupils’ written responses to a question in a national biology test concerning how nutrient molecules are adsorbed by the small intestine and transported to the brain. We aimed to investigate what awareness the pupils have of the connection between the digestive and circulatory systems. We mapped the pupil’s expressed knowledge by using content analysis which was performed in five steps including connection between the systems, organizational levels and scientific explanations. We found that the most correct descriptions contained the highest number of connections between the digestive and the circulatory systems and linking of the different organizational levels. The most correct descriptions included the highest proportion of the meso level. Therefore, knowledge at the meso level seems to be essential for grasping connections between macro- and submicro-level processes, and connections of digestion and circulation systems.

BACKGROUND

In Sweden (and many other countries), teaching about the human body and its organs, including the digestive organs and brain (of primary concern here) starts in elementary school and continues

throughout school education (Swedish National Agency of Education, 2018). In particular the Swedish chemistry curriculum have formulations concerning food content, digestion and the importance of nutrients for the human health. Previous research suggests that pupils have difficulties in understanding the chemical processes involved in nutrient uptake and distribution (Carvalho, Silva, Lima, Coquet, & Clément, 2004; Clément, 2003). A study of Spanish 4- to 7-year-old pupils’ knowledge of the systems found that it improves with age, and that the pupils appear to understand the digestive system better than most others systems in the human body (García-Barros, Martínez-Losada, and Garrido, 2011). Nevertheless, instead of describing digestion as a system involving several connected processes, many pupils aged 6-13 years describe digestion without mentioning the chemical breakdown, instead they mentioned food being converted to ‘liquid food’ (Cakici, 2005; Carvalho et al., 2004; Rowlands, 2004; Teixeira, 2000). Thus, previous research suggest that pupils may lack knowledge of chemical steps of digestion, but understand that the circulatory system is involved in some way (Granklint Enochson & Redfors, 2012; Mason, 1993; Rowlands, 2004). For instance, Mason (1993, p. 167) quotes a statement that blood ‘gives us vitamins’. For such reasons, pupils’ difficulties in connecting the digestive and circulatory systems may be due to lack of understanding that ingested food is broken down into nutrients (Reiss & Tunnicliffe, 2001).

The interface between the digestive and the circulatory systems is the lining of the small intestine and connecting blood vessels. It is here the nutrient molecules are taken up and their distribution to the body begins. These systems consist of a number of different multi- (macro-, micro-, meso- and sub-micro) organizational level processes (see *Levels of organisation*). Chemical digestive processes change macroscopic pieces of food (e.g. sausage and potato) to microscopic pieces and finally sub-micro level substances such as nutrient molecules (fat, glucose, vitamins, proteins etc.). These nutrient molecules are selectively taken up by endothelial cells and then absorbed from the small intestine into the blood by the microvilli (micro- and meso-level processes, respectively) and distributed in the body via the blood circulation, while substances that the body cannot absorb are excreted (micro- and macro-level processes).

Several studies have characterized pupils’ understanding of the function of the digestive system across various age groups, for example pupils aged 7 or 15 years (Reiss et al., 2002; Teixeira, 2000) and pupils aged 3-7 years (García-Barros et al., 2011). We suggest that some of the mentioned difficulties are rooted in pupils’ difficulties in connecting different organizational levels of biological systems. Thus, in this study, which is based on pupils written responses in a Swedish national biology test given in grade 6 (pupils aged 12-13 years), we analyse pupils’ understanding of connections in the digestive system and the brain’s nutrient supplies.

Levels of organization in nutrient uptake

We cannot perceive chemical and biological processes that occur in the body with our senses (Tripto, Ben-Zvi Assaraf, Snapir, & Amit, 2016). Making sense of processes such as digestion is difficult to conceptualize, hence, we need ways to visualise the invisible, which can be considered at multiple organizational levels (Tripto et al., 2016; Niebert and Gropengiesser, 2015; Meijer, 2011). Different science subjects emphasize different organizational levels (Schneeweiss & Gropengiesser, 2019). Based on findings by Johnstone (1982), Talanquer (2011) recognized a “chemical knowledge triplet”, of three levels of organization: *macro*, *submicro* and *symbolic*. Johnstone (1991) argued that the macro, sub-micro and symbolic levels can be equally applied to an understanding of biological concepts. However, according to Tsui and Treagust (2013), four levels (the three mentioned and a micro level) must be considered to fully understand biological phenomena. In addition, Knippels (2002) argues that molecular-level organization should be explored and taught, as molecules play key roles in complex higher-level systems, such as cells. Digestive and other physiological processes are also intrinsically linked to (bio-)chemistry (Kozma and Russell, 1997). Hence, there is a need to connect chemical (molecular and macromolecular) levels of organization to the higher (cell, organ, organism, and population) levels of biological organization (Knippels & Waarlo, 2018). In the context of the human body, the *macro level* includes tissues, organs and organ systems. Note that many of these structures are not visible but rather contained within the body. The function of organs involves complex *micro-level*

processes in cells and tissues (Tsui & Treagust, 2013), and *submicro-level* chemical reactions (Bucat & Mocerino, 2009). Thus, learning about the human body requires the establishment of relations of phenomena at levels ranging from molecular to macro, which is challenging for the students, as the steps between these levels are huge (Meijer, Bulte, & Pilot, 2013). Fortunately, teaching and learning about connections between macro- and micro-level phenomena can be potentially facilitated by introducing the intermediate *meso-level* (Meijer, Bulte, & Pilot, 2009). However, Meijer et al. use the term macro-micro thinking for this, although submicro-level processes are involved in the phenomena. Further, they identify no fixed number or order of meso levels, and Meijer (2011) argues that some tasks in science education need a focus on connections between macro- and submicro-levels, while others require establishment of relations between different levels.

The meso level is defined in various ways depending on the context. Here, we define it in accordance with Alberts (1998) and Hartwell et al. (1999) as the scale of cellular biochemical processes. Similarly, Johnson (2015) and Goodsell, Franzen, and Herman (2018) define it as a level bridging the micro- and molecular submicro-levels. In absolute terms, it could be defined roughly as the nanometre to micrometre scale. According to Goodsell et. el (2018), understanding meso-level processes is crucial for grasping key concepts in cell biology as they link molecular (submicro-) phenomena in cells to macromolecular systems. Snapir et al. (2017) also argue that pupils’ difficulties in making connections between organizational levels might be correlated to previously demonstrated difficulties in transferring knowledge of, and making connections between, the digestive and circulatory systems (Carvalho et al., 2004; Clément, 2003; Cuthbert, 2000; Cakici, 2005; Teixeira, 2000; Rowlands, 2004 and Gripshover and Markman, 2013). This is a key element of our rationale for focusing on pupils’ understanding of these connections, and the potential utility of meso-level understanding.

Making connections between the organizational levels

Reiss and Tunnicliffe (2001) found that most pupils do not recognize that macroscopic food must be broken down into sub-microscopic molecules to be taken up into the bloodstream, which is a lack of reasoning across different levels of organization. Further, Granklint, Enochson and Redfors (2012) found that most pupils do not use concepts connected with the microscopic level at all when explaining digestion. Hence, they do not make connections at the same level of organization between different organ systems, for instance digestion and circulation (macro-macro). Other researchers have also detected gaps in pupils’ understanding of connections between different levels of organization (Knippels, 2002; van Mil, Postma, Boerwinkel, Klaassen, and Waarlo, 2016 and Meijer, 2011), and macro-micro teaching has been proposed to provide support for pupils to bridge the gaps (Meijer et al., 2009; Talanquer, 2011). We have explored pupils’ use of the meso level for bridging multi-level phenomena in responses to a question in a national test on digestion. Thus, we applied a higher-resolution scale of organizational levels (Figure 1) than the previous researcher (Meijer, 2011) in an effort to in more detail capture what characterizes pupils’ responses. The test did not have this purpose, but provided possibilities for detailed analysis of pupils’ explanations in terms of how students relate phenomena at different organizational levels (Van Mil, 2013), and possible pedagogical strategies to address associated shortcomings.

Figure 1. The scale (in metres) of the organizational levels in biological systems recognized in this article.

AIM AND RESEARCH QUESTIONS

The aim of our study is to describe pupils’ explanations of the transfer between the digestive system and the circulatory system, based on responses to a question about nutrition in the context of a Swedish national biology test. Making connections of organ systems is recognized to be challenging. In an effort to obtain a detailed description of Swedish pupils’ written responses in grade 6 (pupils aged 12–13 years), we analyse the pupils’ responses with a high-resolution tool of organizational levels.

We specifically addressed the following research questions:

1. What awareness of the connection between the digestive and circulatory systems in nutrient uptake and distribution do the pupils indicate?
2. Are references and connections found to organizational levels in pupils’ responses, and if so, which ones?
3. What are the relations between correct scientific explanations and the number of organizational levels used in the responses?

METHODS

Data and context

This study is based on a mandatory national biology test for all grade six (12–13-year-old) pupils in Sweden. One of the questions in the test was: *The brain needs nutrition to function. Explain how nutrient molecules it needs are taken up and transported from the small intestine to the brain.* Please note, we had no opportunity to influence the formulation of the test question since the test had already been performed, and the responses had already been collected. Nevertheless, this question was of interest to us since it opens the possibility to study how the pupils’ express the connection between nutrient uptake (by the small intestine) and nutrient distribution (via the circulatory system). Note, the pupils did not have to explain how food became nutrient molecules but were rather asked how the transfer between systems take place.

The number of responses that we had access to is based on teachers who sent samples (for comparative reasons) to the university who developed the test. In total, 304 pupils responded to the question that is in focus in this paper. A substantial proportion of these (182) simply used single terms mentioned in the question, for example ‘Nutrient – brain’. Some also responded ‘I don’t know’ or ‘Should I know?’, or referred to a pathway using 3–5 words, such as ‘Mouth-stomach-intestine’, with no explanation of nutrient uptake or distribution. The remaining 122 interpretable responses, including both scientifically correct and incorrect explanations of the processes of nutrient uptake and/or distribution, were analysed.

Data analysis

The 122 responses were subject to systematic content analysis (Krippendorff, 2012) which was performed in five steps. In the analysis, we considered the entire answer, although they sometimes included aspects of the digestion process that were not requested. The first two steps of the content analysis were the following:

1. As a first step we analysed whether the pupils described the two different systems (digestion and circulatory system), and also if they connected them.
2. In the second step, the distribution of references to each organizational level between descriptions associated with digestive system (nutrient uptake) and circulatory system (nutrient distribution) was evaluated (Table 1).

By analysing the responses at different levels of organization we were able to indicate how the pupils connect the systems in more detail. In his study, Cakici (2005) focused on whether pupils described the digestive process scientifically correctly, generally considering metaphoric expressions as non-scientific. In contrast, we considered some pupils’ metaphorical expressions as correct, depending on

the context, because they provide valuable indications of pupils' knowledge (Pettersson, Danielsson & Rundgren, 2020), and the organizational levels where deficiencies lie. We therefore incorporated these expressions into our analytical tool when their meaning was clearly stated (Table 1). Terms and every-day expressions connected to each organizational level in Table 1 are highlighted in bold in the *Results* section to facilitate recognition of references to organizational levels in the pupils' responses.

Table 1. Coding tool of pupils' descriptions, based on authentic responses, of nutrient uptake (digestive system) and distribution (circulatory system), related to the levels of organization.

	Macro	Micro	Meso	Submicro
Scale (metre)	10⁰ – 10⁴	10⁴ – 10⁶	10⁶ – 10⁸	10⁸ – 10¹⁰
Nutrient uptake (digestive system)	Organs	Cells	Microvilli	Nutrient molecules
	Food	Cell walls	'Threads'	Glucose
	Liquid	Villi	'Small thin hair'	Carbohydrates
	Nutrition/ nutrients	'Small fingers'	'Intestinal lint*'	Proteins
		'Crumpled and shaggy walls'		Fatty acids Enzymes
Nutrient distribution (circulatory system)	Veins	Capillaries	'Small openings'	Nutrient molecules
	'Channels'	Blood cells	'Small holes'	Carbohydrate
	'Tubes'	Cells		Proteins
	'Pipes'			Fatty acids
	Blood			
	Blood vessels			
	Nutrition/ nutrients			

*'Intestinal lint' is a translation of a Swedish semi-scientific expression (tarmludd), referring to microvilli.

Expressions we interpreted as referring to food, body organs and blood were classified as 'macro level'. References to bodily tissues or cellular level phenomena (for instance descriptions of villi in the small intestine as "looking like fingers") were classified as 'micro level'. Descriptions of the structure of the microvilli (or for instance 'intestinal lint'), were classified as meso level. References to nutrient molecules, such as (nutrient molecules, sugar molecules and proteins) were classified as submicro level, if they were used in a submicroscopic context. Some responses included terms such as 'channels', which were classified as micro- or meso-level, depending on how specifically the channels and their functions were described. After these initial analyses, the content analysis included the following three steps:

3. As a third step we identified (then counted) connections between organizational levels, as illustrated in Table 2, where terms referring to organisation levels (Table 1) are in bold.

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Table 2. Coding tool of pupils’ descriptions, based on authentic responses of connections between one to four organizational levels (macro, micro, meso and submicro)¹.

Connections between organizational levels	Pupils’ responses
Four levels of organization (macro, micro, meso and submicro)	<i>The walls of the small intestine are crumpled and shaggy [villi]. There are small holes in the walls. Some nutrient molecules go into the holes and are transported up into the brain by the blood.</i>
Three levels of organization (macro, micro and submicro)	<i>In the small intestine there is lint, which is called villi. In the villi are blood vessels that collect all nutrient molecules the body wants and transports it through the blood circulation to the brain.</i>
Two levels of organization (macro and submicro)	<i>All nutrient molecules that the small intestine takes up become blood which is pumped by the heart to the brain.</i>
One level of organization (macro)	<i>In the small intestine there are blood vessels that take up all the important substances. Then the blood goes to the kidneys to get clean. Then the pure blood goes into the heart in the body and then to the brain. Then all nutrition has been transported to the brain.</i>

4. As a fourth step, each of the 122 responses were examined to identify relationships between the pupils’ expressed ideas (including metaphorical expressions) about digestive processes, classified in terms of four grades of scientific accuracy of the explanations. These four grades are: scientifically incorrect, some traces of science, partly consistent with a scientifically accurate explanation, and mostly consistent with a scientifically accurate explanation. Illustrative examples are shown in Table 3.

Table 3. Coding tool, based on authentic responses, of the four grades of scientific explanation (underlined) in pupils’ responses

Grade of scientific explanation	Pupils’ responses
Scientifically incorrect	<i><u>Through the joints</u> into the body.</i>
Traces of science	<i><u>It (the nutrients) has become a fluid</u> and goes up to the brain. 9% of food goes to the brain.</i>
Partly scientific	<i><u>Nutrients are absorbed by something that looks like fingers</u> and taken to the brain.</i> <i><u>When you eat, the food comes to the small intestine, food is converted into energy</u> and nutrients that you need to think and much more.</i>
Scientifically correct	<i><u>When you have eaten the food and it has gone down the small intestine the nutrient molecules go into small passages</u> up to the brain. During that time, the body takes up other things that do not go to the brain.</i>

¹ Bold style marks organization levels

5. As a fifth, and last analytical step, we assessed frequencies of links between grades of pupils' explanations, references to organizational levels and numbers of connections between them (mentioning all four organizational levels leads to a maximum of three connections i.e. between macro-micro; micro-meso and meso-submicro). For example, a scientifically accurate response (for a pupil of this age) could include descriptions of food (macro level) being degraded to molecules (submicro level) that are taken up through cell walls in the small intestine (micro level), resulting in two connections (macro-submicro and submicro-micro). Molecules being transferred to blood vessels in the microvilli (meso level) were also described. If all organisational levels were included it resulted in totally three connections (between macro-micro-meso-submicro).

To ensure validity and inter-rater reliability, interpretations were discussed at every step until consensus was reached. Responses were translated into English by the authors and professional bilingual reviewers.

RESULTS

Awareness of the connection between the digestive and circulatory systems

As the question on the national test specifically concerned uptake of nutrients from food in the small intestine and their transport to the brain, it invited explanations of the connections between the digestive and circulatory systems (Table 4). According to Table 4, 27% of the 122 pupils' responses contain both nutrient uptake and nutrient distribution, as for instance *"The intestine takes up the nutrients and the blood transports it to the brain so it [the brain]² gets the nutrients"*. In total, 12% of the responses describe both nutrient uptake and distribution, with connections between them, e.g. *The walls of the small intestine are crumpled and shaggy. In the walls are small holes; The nutrition molecules go into the holes and is transported up to the brain by the blood.* However, 15% of the pupils described both nutrient uptake and distribution, but without any connections e.g. *All the nutrient molecules that the small intestine takes up becomes blood. And the heart pumps it up to the brain.* Instead expressions like 'goes', 'is sent to' or 'taken up' were used, without describing this process.

Table 4. Number (n) and percentages (%) of the 122 pupils' eventual connections between nutrient uptake and nutrient distribution

Connections between nutrient uptake and nutrient distribution	n	% of 122 responses
Both nutrient uptake and distribution, <i>with connections</i>	15	12
Both nutrient uptake and distribution, <i>without connections</i>	18	15
Mixed scientific and non-scientific explanations	49	40
Incorrect	12	10
Not answering the question	28	23

Out of the 122 responses, 40% mix correct scientific explanations with scientifically incorrect parts, for instance, *From the small intestine it [nutrient molecules] enters the blood and is then transported through the neck to the head and brain;* or *The nutrient molecules goes from the small intestine to the rectum and then there is blood cells that carry all the nutrient molecules.* About 10% of the 122 responses were incorrect, for instance *From the small intestine you breathe in the nutrient molecules, which then goes up to the sinus and then to the brain.* Further, 23% of the 122 pupils were not answering the question with their responses, for example, *The brain has thin threads that work*

² Text in square brackets indicates the presumed intended meaning.

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like the internet; If it does hurt in the foot, signals come to the brain that say it hurts the foot, or The brain gives us reflexes that spread to the small intestine and further down. In most cases the incorrect response describes some function of the brain.

In summary, 67% (12+15+40) of the pupils appeared to have some correct idea about the nutrient molecules' path from the small intestine to the brain. Out of these, 27% (12+15) mention both systems, while 12 % of these also managed to describe the connecting mechanism. Note, that pupils generally did not use scientific concepts in their responses but rather describe the structures and the processes with everyday language.

Organizational levels in conjunction with nutrient uptake and distribution

The formulation of the question indicates that responses should focus on submicro- or meso-level phenomena. However, macro-level phenomena were described by 88% of the pupils. But, if we divide the mentioning of organizational levels into nutritional uptake and nutritional distribution, it results in a different picture (Figure 2). Macro-level processes were referred to slightly more frequently in descriptions of nutrient uptake than in descriptions of nutrient distribution (48% and 40%, respectively). In contrast, submicro-level processes were referred to far more frequently in descriptions of nutrient distribution (45% and 5%, respectively). Overall frequencies of references to micro- and meso-level phenomena were low, but the micro-level was most frequent in descriptions of nutrient distribution while the meso-level more often were connected to nutrient uptake.

Figure 2. Percentages of references to phenomena associated with each of the organizational levels in the 122 pupil's descriptions of nutrient uptake and distribution.

Frequencies of connections between organizational levels in the digestive and circulatory systems

To measure the extent to which the pupil's express connections between the four levels of organization in digestive and circulatory system in more detail, we counted their frequencies of connections between organizational levels at nutrient uptake and nutrient distribution. The results are summarized in Table 5, and in the following text, with illustrative examples (indicating references to organizational levels in bold).

Table 5. Number (n) and percentages (%) of the 122 pupils' responses indicated connections between organizational levels at nutrient uptake and nutrient distribution

	Macro-Micro-Meso-Sub-micro	Macro-Micro-Sub-micro	Macro-Meso-Sub-micro	Macro-Micro	Macro-Sub-micro	Two other levels *	Macro - Macro	Levels but no connections	No answer
%	2	7	10	6	24	2	29	14	8
n	2	8	12	7	29	2	35	17	10

* This category consists of a few responses that include connections to two organizational levels other than pairs mentioned elsewhere in the table, e.g. macro-meso.

About (2%) of the pupils connected all four organizational levels (example 1), 10% connected the three levels *macro*, *meso* and *submicro* (see example 2 and 3), and 7% connected *macro*, *micro* and *submicro* levels (see example 4 and 5). The numbered examples below show the organization levels marked in bold (Table 2 provides descriptions of the organization levels associated with identified concepts).

1. The **small intestine** sucks up water from the **food** and **nutrient molecules** in the food. The small intestine has something called **lint**. With the help of the **lint** and **small blood vessels** [capillaries] in the **small intestine** all useful [substances are] sucked up through the **small intestine** and goes to the **brain** (macro – micro – meso – submicro).
2. The **small intestine** is like **small straws** that are soft so when the food comes to the **small intestine** it is squeezed together so that all the **nutrient molecules** in the food passes through the **soft straws** up to the **brain** (macro – meso – submicro).
3. In the **small intestine** is lint called **villi**. In the **villi** are **blood vessels** that collect all **nutrient molecules** the body wants and transport them through the **blood circulation** to the **brain** (macro – meso – submicro).
4. When the **food** leaves the **small intestine**, there is only **goo/grunge** left because the **small intestine** has picked up all the **proteins** and all the **nutrient molecules** in the food. The **nutrient molecules** are then transported from the **small intestine** to the **heart**, which pumps the **blood** to the **brain** and other **cells and organs** in the body (macro – micro – submicro).
5. The **small intestine** sucks up the **nutrient molecules**, which then go into the **blood**. **Nutrient molecules** are transported with the **red blood cells**. The **blood** then goes to the **heart** and is pumped through the **blood vessels** again, to the **brain** among other places, where the **nutrient molecules** are delivered (macro – micro – submicro).

Each organisational level was associated with a set of terms. For instance, the macro level was associated with terms like small intestine, blood vessels, brain, heart and other organs. References to micro- and submicro-level phenomena most commonly concerned the supposed involvement of blood cells in nutrient distribution (see example 8) and nutrient molecules, respectively. Nutrient molecules were sometimes incorrectly described as being transported on blood cells to the brain (see example 5). Although this is not a scientifically correct explanation, it does convey the correct idea that the blood mediates the macro-level transport of nutrients.

The most common connections are between two organizational levels, *macro-macro*, which is done in 29% of the 122 responses. In these, both the digestive system (roles of food and intestines in nutrient uptake) and circulatory system (roles of the heart and/or blood in nutrient distribution) are taken in consideration (Table 5). This result indicates that almost a third of the pupils connected the two macro-level systems, for example:

6. The **blood** that passes through the **small intestine** to the **brain** helps the brain function and so it circulates throughout **the whole body** (macro – macro).

However, connections between *macro* and *submicro* levels were the next most common, appearing in 24% of the responses, especially those that mentioned nutrition, for example:

7. All **nutrient molecules** that the **small intestine** take up become **blood**, which is pumped by the heart to the brain (macro – submicro).

Connections between *macro* and *micro* organizational levels were detected in 6% of the responses, as in example 8.

8. The **red blood cells** take the **food** and take it to the **brain** (macro – micro).

Other connections between two levels, such as between the *micro* and *submicro* levels were rare, even though we found some examples, such as:

9. The **nutrient molecules** travel with **red blood cells** (micro – submicro).

As already mentioned, several pupils referred to a micro-level conception that red blood cells transport nutrients, which is not correct, but indicates awareness that blood is involved in the process. A similar idea was apparent when *meso*- and *submicro*-level phenomena were connected, as in the following example:

10. The **nutrient molecules** are transported with the help of, among other things, **haemoglobin** (meso – submicro).

A few pupils made connections between *macro*- and *meso*-level phenomena, but omitted references to other levels, for instance:

11. It (food) goes to the **small intestine**, where there are **small holes** so it can come to the **brain** (macro – meso).

In addition, 14% of the pupils described one organizational level, but did not connect it to anything, and 8% of the pupils did not answer the asked question at all.

Characteristics of scientific explanations in the pupils’ responses

To obtain insights into the nature of the challenges in describing digestive and circulatory processes, the 122 pupils’ responses were first categorised using a four-step scale of the scientific accuracy of the explanations of nutrition uptake and distribution and the frequencies of the categories were calculated. Of those who responded, 18% either did not answer the asked question or gave scientifically incorrect responses, as illustrated by the following examples:

12. The body sorts good and bad.
13. It takes a second for the brain to understand.
14. The brain has thin threads that work like the internet. If the foot is hurt, signals come to the brain saying that the foot hurts.

However, 12 % of the pupils included scientifically correct responses, and almost 70% were categorised as either partly scientific or with traces of science. This is far more than reported in previous research. The pupils’ explanations were related to the four-grade scale of scientific explanations and number of organizational levels (Table 6). About 50% of the pupils’ responses were assigned to the category’s *traces of science* and *scientifically incorrect*. These pupils mainly referred to macro-level phenomena in their explanations and did not connect them to other organizational levels (Table 6), for instance stating something like “*through the joints into the body*”-

Table 6. Percentage of organizational levels at each of the four-grade scales of scientific explanation and average number of connections between organizational levels.

Grade of scientific explanation	Macro	Micro	Meso	Submicro	Average number of connections between organizational levels*
Scientifically incorrect	26	2	0	10	0.95
Traces of science	89	13	5	26	1.37
Partly scientific	91	21	6	64	1.85
Scientifically correct	100	27	53	100	2.6

*The maximum number of connections was 3, including connections between all four organizational levels

As shown in Table 6, *partly scientific correct* explanations were associated with references to macro-, submicro-, and to a lesser extent micro-level phenomenon (in 91%, 64% and 21% of the responses, respectively). Explanations categorized in *partly scientific correct* explanations included nearly 2 (1.85) connections between levels of organization, on average, as illustrated by the following example with macro-meso-submicro-level connections.

15. When you have eaten the **food** and it has gone down the **small intestine** the **nutrient molecules** go into **small passages** up to the **brain**. During that time, the body takes up other things that are not going to the brain (macro – meso – submicro).

Responses with explanations categorised as scientifically correct (12% of the 122 responses) all included references to macro- and submicro-level phenomena. However, the most notable finding is that more than half of the scientifically correct responses (53%) included references to the meso level (in bold in Table 6). References to micro-level phenomena were least frequent in these responses (appearing in 27% of them), which included 2.6 connections between organizational levels, on average (in bold in Table 6). As mentioned, the maximum number of connections was 3, including connections between all four organizational levels, as illustrated by the following example:

16. The walls of the **small intestine** are **crumpled and shaggy** [villi]. There are **small holes** in the walls. Some of the **nutrient molecules** goes into the **holes** and are transported up to the **brain** by the **blood** (macro – micro – meso – submicro).

DISCUSSION

Biology is a complex subject. Different systems are interacting, and many are operating at several organizational levels at the same time. Digestion is such an example. Besides the digestion processes at different organizational level there is also interaction with the circulatory system. This study is based on responses to a test question that is pinpointing the connection between the digestion and the circulatory system. The prerequisite for the question was that the nutrient molecules were already in the small intestine. The purpose of this study was to investigate whether pupils were able to describe the connection between the nutrient uptake (digestive system) and distribution (circulatory system). Our analyses show that pupils have a better understanding than previous research suggests. The difference between our study and earlier studies concerning methodological approach are two folded;

1) Earlier studies are mainly based on interviews (Rowlands, 2004; Granklint Enochson & Redfors, 2012) while our data are written responses to a national test that is expected to correspond to the curriculum. 2) Unlike e.g. Cakici (2005) we consider content in metaphors instead of seeing such answers as incorrect. The main results regarding our specific research questions are discussed under the subheadings below.

Connecting digestive and circulatory systems

In our study, the role of the small intestine as the main site of nutrient uptake appeared to be relatively well rooted among the pupils. Furthermore, the role of blood as the mediator of nutrient distribution in the circulatory system seemed to be understood by more than half of the 122 pupils, and about a third of their responses included the word 'blood'. This is consistent with previous findings, indicating that the relevant age group generally understand that the circulatory system is involved in nutrient uptake (Mason, 1993; Rowlands, 2004; Granklint Enochson & Redfors, 2012). However, other authors have reported lower frequencies of understanding (Cakici, 2005; Carvalho et al., 2004; Clément, 2003; Cuthbert, 2000).

About a one third of the responses to the question included both the digestive and circulatory systems and of these 12% of the responses included explicit links between the systems (Table 4). This result is in conflict with previous findings that pupils find it challenging to make connections between the digestive and circulatory systems (Carvalho et al., 2004; Clément, 2003; Cuthbert, 2000; Reiss & Tunnicliffe, 2001).

Organizational levels in nutrient uptake

In order to describe the pupils' knowledge, we assessed their references to phenomena associated with nutrient uptake by the digestive system and nutrient distribution by the circulatory system at four organizational levels. We also assessed the extent to which explicit links between the systems were made. Our findings indicate that the pupils had more knowledge of nutrient distribution than nutrient uptake. Around half of the pupils' responses included references to submicro-level phenomena, mostly to nutrient molecules, proteins, carbohydrates, and fat. This is a much higher proportion than found in previous studies (Rowlands, 2004). However, this is in accordance with the analysis of pupils' understanding of physics (Lee, Eichinger, Anderson, Berkheimer, and Blakeslee, 1993) and ecological processes (Hogan and Fisherkeller, 1996). As a conclusion, the molecular realm is not beyond the intellectual reach of 5th and 6th graders even though they are not expected according to the curriculum to formulate explanations at this level (Swedish National Agency of Education, 2018). Furthermore, many responses in our study did not mention micro- and meso-level phenomena. This partly confirms a previous report of deficiencies in pupils' descriptions of nutrient uptake (Cakici, 2005). However, our analyses revealed a difference between the pupils' descriptions of nutrient uptake and nutrient distribution. The meso-level phenomena were barely mentioned at all in relation to nutrient distribution but were included in 12 % of the 122 responses in association with nutrient uptake (Figure 2). Nutritional uptake might be relatively easy to associate with capillaries and (incorrectly) to blood cells. However, the relatively high level of explanations of nutrient uptake at the meso level is more surprising since it is rarely addressed in school science. This knowledge might be explained by "out of school" learning. Furthermore, the relatively common submicro level (45%) in pupils' explanations of nutrient distribution, might be explained by information of proteins, fat, carbohydrates and nutrition in school, sport contexts and health information.

Connection between organizational levels

Not only the presence of different organizational levels is of importance, but also connecting organizational levels has importance on how pupils describe relationships between organ systems in the human body (Hmelo, Holton & Kolodner, 2000; Kresh, 2006) such as between the digestive and circulatory systems. Since 80% of the 122 pupils made some connections between organizational levels our results show that these pupils, who can be expected to be representative for their age group (see aim and research question at p. 5) can grasp different organizational levels (Table 5). Our results show

that macro-macro connections between the digestive and circulatory system occurred most commonly (29%). This might be expected since the perceptual level of both the food and organs (nutrient uptake), and blood and heart (nutrient distribution) are experienced and perceptual. However, this partly conflicts with findings by Cakici (2005), Carvalho et al. (2004), Teixeira (2000) and Granklint, Enochson and Redfors (2012). However, linking different levels of organization is considered to be challenging, and moving between the levels is even more challenging (de Jong & van Driel, 2004). Many of the pupils in our study indicated that food degrades to molecules. These findings suggest that they were able to link the macro- and the submicro levels. In about 17% of the responses, connections were made between three levels: macro, micro and submicro, or between macro, meso and submicro.

Characteristics of scientific explanations

When correlating pupils' references to organizational levels and the scientific quality of their responses, our results show that 'incorrect responses' and responses containing 'traces of science' were dominated by macro-level descriptions, while descriptions of both micro- and sub-micro levels increase in the 'partly scientific explanations'. Most notable is, however, the strong correlation between 'scientifically correct' responses and number and correct references to organizational levels. Firstly, the number of connections to organizational levels were high (2.6 of three possible links) in these responses. Secondly, the meso level appears to be highly important, since about half of the pupils (53%) who provided the most correct descriptions of nutrient uptake and distribution also referred to meso-level phenomena most frequently (Table 6).

Summary

In accordance with previous research, our study shows that many pupils know that the small intestine is involved in nutrient uptake and that the blood transports the nutrients to the brain. Most pupils have difficulties in describing the connection between the process of nutrient uptake and nutrient distribution. However, in contradiction to earlier research we show that quite a few pupils can describe parts of nutrient uptake and distribution processes. Some are in fact is capable to describe the whole process. By using multi-level analysis tool (macro-micro-meso-submicro), we can show that increasing scientific correctness and linking of the digestive and circulatory systems are associated to the number of connections between organizational levels, and the use of the meso level in the descriptions. Since our data comes from a random selection of all Swedish sixth graders it can be expected to be representative for their age group.

Educational implications

Pupils' in grade 6 are not expected to formulate explanations at a cellular level since this is not stated in the curriculum (Swedish National Agency of Education, 2018). Further, nutritional uptake might be a mystery to many pupils, partly because it involves events that cannot be observed or experienced. Furthermore, events described at micro, meso and submicro levels, might be considered too difficult to explain to pupils in grade 5 or 6. However, our results suggest that this is not necessarily the case. One way to nurture reasoning about organ systems might be to emphasize that processes such as nutrient uptake and distribution involve both 'chemical' and 'biological' processes at multiple organizational levels in the digestive and circulatory systems. We hope that the results of our study will inspire teachers to teach about connections between organ systems and the different organization levels. It would also be in line with the results of a project showing that pupils in grade three (about 10 years old) in fact can create scientifically valid explanations of chemical phenomena including the particle level (Cheng, Danielsson, Lin, in press). We hope that the detailed scale of organizational levels (macro-micro-meso-submicro) can be used as a tool for teachers, both as a way of assessing pupils' knowledge, and as a teaching tool to clarify at what level the biochemical processes are happening and thus the connection between the organ systems.

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