# Visualising structure and function of the digestive system

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## 1. Introduction and motivation

Visuals play a key role in the communication and comprehension of knowledge about human physiology. This knowledge namely, the internal structure and working of the human body, is basically visual in nature, yet it remains hidden to observation in the course of learning. Advanced textbooks of human physiology make extensive use of visual descriptions and diagrams to communicate both structure and function (e.g. Guyton, 1977). School textbooks try to simplify such diagrams to the appropriate level, and teachers are expected to transmit to students the skills of understanding and expressing their knowledge through diagrams. The effort is not always successful: the reason might be that the cognitive and pedagogical processes in this context remain very little studied or understood. In our research we address this gap by studying how students understand and express their ideas about human body systems through words and through diagrams.

Understanding of human body systems requires correlation of anatomy with physiology, i.e. of structure with function. Structural and functional levels of organization provide a standard way of analysing systems; in earlier research general systems concepts, including structure and function, were used in understanding students' conceptions of body systems (Ramadas and Nair, 1996).

In general, structure is easily conveyed through visual depictions, while function is better expressed through text or propositions, and occasionally through highly schematised diagrams. Heiser and Tversky (2006) have studied understanding of mechanical systems (car brake and multiple pulley systems) by looking at interpretation and production of diagrams from structure and function descriptions. In biology, unlike mechanical systems, structure and function concepts are integrated in a highly complex manner. A one-to-one correspondence between form and function is not immediately obvious. For example, at the school level, while structure of the digestive system is understood at a gross macroscopic level, significant aspects of function involve chemical reactions which occur between molecules - a level of structure that is not accessible to students. It is interesting however to see how far the methodologies that have been used for studying cognition of mechanical systems are applicable to a basic level understanding of systems of far higher complexity.

## 2. Phase one of the research

In Phase one of this research we tested twelve students of Grades 6, 7 and 8 in Mumbai, India, for their knowledge of the digestive, respiratory and circulatory systems. We found that the majority of the students showed a strong preference towards verbal descriptions rather than towards diagrams. We also found (consistent with results of Heiser and Tversky (2006) with mechanical systems) that more function than structure concepts were communicated by students in their descriptions. The higher achieving students were distinguished by their ability to integrate structure with function concepts through use of diagrams together with verbal descriptions (Mathai and Ramadas, 2006).

## 3. Phase two of the research

In Phase two of the research we studied students' understanding of the digestive and respiratory systems in further depth.

This study was carried out on eighty seven students of Grade 8 alone in five English medium schools in Mumbai, India. This phase consisted of testing in three parts.

Part 1 of the second Phase was in part a repetition of Phase 1 but in addition we had some questions which explicitly encouraged visualisation. For instance we asked students to imagine the structure being manipulated in some way (e.g. "What if the stomach was in the shape of a pipe?") and to predict its effect on function. Students were free to respond with either diagrams or text.

Part 2 of Phase 1 was inspired by the method of Heiser and Tversky (2006). Text passages were prepared which described in some detail either only structure (Part 2a) or only function (Part 2b) of a particular portion of the digestive system. These passages were prepared specifically for situations where the mechanical or macroscopic processes predominated over the chemical ones: for example, in the chewing of food, in swallowing, in peristalsis and in absorption of food. Parts 2a and 2b were parallel in the sense of content and questions asked, except that one conveyed structure and the other, function. Students were asked to read the passages and respond to questions in drawings and words. We thus tested their comprehension of complex structure from a verbal description (Part 2a) and similarly complex function (Part 2b). They had to infer function from a description of structure and structure from a description of function. They were also asked to manipulate structure and infer its effects on function and vice versa.

Part 3 of Phase 2 consisted of questions calling for comprehension via diagrams. Again there were two types of tests, one in which the diagrams conveyed structure (Part 3a) and one conveyed function (Part 3b). However unlike the text passages, Part 3a and 3b did not test for equivalent content areas, (though pertaining to structure and function). The diagrams presented were from different topics for both parts. This was done mainly because of the ease in designing and finding appropriate questions. All questions were specific asking students to either write, or draw or do both. In Part 3 students had to go beyond comprehending structure and function from diagrams. They had to infer function

from diagrams of structure and structure from diagrams of function. Further they had to manipulate structure in a diagram and see its effects on function, and similarly manipulate function and predict effects on structure.

Each question in Parts 2 and 3 probed a structure concept, a function concept or a structure-function relationship.

### 3.1 Analysis of data from phase two

Students' responses were divided into 'verbal' and 'drawn', and were analysed separately. For Part 1, both verbal and drawn responses were analysed for basic knowledge and visualisation. Basic knowledge consists of knowledge of structure and of function. Knowledge of structure refers to conceptions about the organs of the system (or 'segmentation' in the case of diagrams), and the order of location of organs. Knowledge of function consists of order of action of the organs as well as understanding of hierarchy. 'Order of action' indicates how organs function together in a system. Functional hierarchy refers to the levels in *understanding* function. For example in the case of the digestive system, there are two levels of hierarchy: the alimentary canal and the liver and pancreas. The alimentary canal is introduced first in the curriculum followed by the liver and pancreas. Therefore students have to incorporate the role of accessory organs (liver and pancreas) into an understanding of the alimentary canal (which follows a linear order). Further, standard propositions from school textbooks were used to evaluate propositions from students' verbal responses. Questions which required visualisation were coded separately. All scores were assigned as proportions, and were between 0 and 1. Average scores were determined for each student and across all students for text responses, diagrammatic responses, structure, function and visualisation.

Questions in parts 2 and 3 were scored for structure (S), function (F) and structure-function relationships (S-F). Scores were obtained separately for each questionnaire and averages were determined for each student as before. The Pearson's correlation coefficient was determined for various scores. An Analysis of Variance (ANOVA) was carried out to check for differences among the means obtained for the different categories of questions presented to students. The scheme of analysis could be broadly summarised as:

**Table 1: Analysis of Part 1 responses**

| **S. No.** | **Text / Verbal responses** | | **Drawn responses** | | **Text and drawings** |
|---|---|---|---|---|---|
| | **Basic knowledge** | | | | Visualisation |
| | **Structure** | **Function** | **Structure** | **Function** | |
| 1. | Organs of the system | Order of action | Segmentation (organs) | Order of action | |
| 2. | Order (location of organs) | Hierarchy | Order (location of organs) | Hierarchy | |

**Table 2: Analysis of responses from Parts 2 and 3**

| Questionnaire | Function (F) from Structure (S) | | | Structure (S) from Function (F) | | |
|---|---|---|---|---|---|---|
| | Scores were given for the following attributes | | | | | |
| **Comprehension of text** | S | F | S-F | - | F | S-F |
| **Comprehension of diagrams** | S | - | S-F | S | F | S-F |

### 3.2 Results

We present here some key results after analysis of data from phase 2, for the digestive system alone.

#### 3.2.1 Basic knowledge and visualisation

We found from part 1 of the questionnaire that the majority of students possessed a reasonably good basic knowledge of the digestive system. They were able to express this knowledge through a combination of text and diagrams. In this case the diagrams were close to those that they had learnt during prior teaching. There was a significant correspondence (i.e. high correlation and no significant difference in means) between their scores (on structure and function as well as function) expressed through text and through diagrams. However scores on structure were significantly higher than those on function, and when it came to manipulating structure to predict effects on function, these students performed poorly.

Thus when students responded from recall of learnt material they showed good performance. Diagrams showing structure, and the sequence of organs in the digestive tract were well remembered by them. Recall of function was less perfect: at a gross level, movement of food along the alimentary canal was described, but chemical transformation of food was not understood. Questions involving application to new problem situations, and explicit visualisation, were not answered properly.

#### 3.2.2 Comprehension of structure and function from text passages

Scores of students on Part 2 (comprehension from text passages) were significantly lower than their scores on Part 1. In this case however their scores on structure were not significantly different from their scores on function. Thus although they had understood structure at a gross level, this advantage did not carry through when more detailed questions were asked on structure (even though the information necessary for answering the questions was provided in the passage, or could be inferred from it).

As for comprehension of structure and function from the two passages one describing structure and the other function, we found that performance (from means of scores) was

approximately the same for both forms. Most students did not distinguish between a structure and function diagram. Function was often represented as functional description or annotation (sometimes extensive) accompanying a typical structure diagram showing the organs of a system. Another way of depicting function was to divide the organs of a system into a sequence of parts and describe the role of each using a verbal description near the diagram. Some students used arrows, but not a significant number, and a few others used schematic flow diagrams.

### 3.2.3 Comprehension of structure and function from diagrams and comparison of results from the three parts

Students' scores on Part 3 were further lower than they were on Part 2. As in Part 2 however, their scores on structure and function were equivalent. There was a significant difference between the scores for comprehension of text and of diagrams. Also, structure scores for comprehension of structure passages were significantly higher than those for function diagrams. Also, it was found that S-F scores from function passages were significantly higher than scores from structure diagrams. Structure, function and structure-function relationships seemed to be comprehended better through text as compared to diagrams.

Understanding of structure, function and structure-function relationships were correlated for comprehension through text and diagrams. About 32% of the students had similar scores across Parts 1, 2 and 3. A minority (5%) had all high scores: these were students who most successfully integrated structure with function through text and diagrams, in familiar as well as in new situations. About 11% students had all low scores while another 11% had high scores in Part 1 but low in Parts 2 and 3.

Surprisingly there were some students (7%) who scored low in Part 1 but high in Parts 2 and 3. Perhaps these students were not good with their school learning, but given new content, they could work with it. It is also possible that some of these students worked with diagrams at a perceptual level without relating them to their conceptual understanding.

Five percent of the students had high verbal scores but relatively low drawing scores. These students showed a clearly higher ability for working with text over diagrams. They might be "verbal" in their cognitive style. No corresponding group was found with a predominantly "visual" style, i.e. good at diagrams rather than text.

### 3.2.4 Alternative conceptions

Problems in visualisation led to some common alternative conceptions:

1. Students inferred that food moves into the liver and pancreas after it passes through the stomach. In general the role of the accessory organs, and the fate of food after digestion in the stomach, is improperly understood.

2. The nature of peristalsis, which is a macroscopic aspect of function and thus easily demonstrable, is still incompletely understood.

3. The connection between the small and large intestine is not clearly understood. This is probably a result of an ambiguous textbook diagram and lack of integration between text and diagrams.

## 4. Conclusions

The preliminary results cited here lead us to a few tentative conclusions.

Dealing with diagrams, especially comprehending new diagrams, is difficult for students, most likely since it is a mode that is relatively unfamiliar and infrequently used in the school curriculum and in classroom transactions.

Students are not comfortable with spatial manipulations using diagrams. Comprehension of text is significantly better than comprehension of diagrams.

There are clearly high scores for Part 1 of the questionnaire. Part 1 consisted of open-ended questions and spontaneous expression (using diagrams or words as students wished). Students were able to understand and respond quite effortlessly to these questions. Part 2 and 3 required deeper understanding and students may not have the requisite training to work out such questions. Students found questions which required visualisation to be difficult perhaps because of their unfamiliarity with handling new situations.

For the digestive system, expression of structure was significantly better than that of function. However this was not true for comprehension scores where structure and function scores were not significantly different. Also text was comprehended better than diagrams. Even structure was better understood through text than through diagrams (this is contrary to the result of Heiser and Tversky with mechanical systems).

The results suggest quite overwhelmingly, the lack of visual or diagrammatic literacy among the large majority of students with a few exceptions. Good understanding of the body system follows from an integrated knowledge of visual and propositional content as the high scorers in this study were able to achieve.

Pedagogical practices need to be developed that take an integrated approach to structure and function using text and diagrams. These would enable students to transfer easily between the two modes of understanding and expression, and facilitate the formation of a coherent mental model of body systems.

## References

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