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The system idea as a tool in understanding conceptions about the digestive system

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The general concept of a 'system' is used to propose a framework for modelling knowledge about physiological systems. 'Systems' criteria are assumed to be closely related to cognition about systems, as follows: the mental organization of knowledge about any system must depend on perceiving a collection of objects as an organized whole, which in turn ought to be based on what are essentially intuitive criteria for organization in systems. With this approach, the understanding of the digestive system by school students is studied. General systems criteria help to frame questions dealing with the structural/functional and purposive/non-purposive aspects, organismic or mechanistic nature of the system, and ideas of feedback and central control.

The system concept as a tool for mental modelling

Bodily functions are a major concern of young children. The digestive system contributes to our experiences through feelings of hunger and satiation, and the periodic discomforts of digestive disorders. Thus, it is likely that even very young children have some spontaneous notions about the working of the digestive system. The aim of this paper is to see how these notions are organized in students' minds, i.e., what are the mental models that they hold of the digestive system.

Systems criteria can be used as a basis for this conceptualization of students' mental models. These criteria provide a research tool, a source of concepts that help us to understand students' understanding and also to model developmental trends. There is some support from general systems study for this approach. Jordan (1973) gives a cognitive interpretation of the system concept, as follows:

> Whenever one person can point to or explain a set of elements and the nature of the connectivity between these elements to another person, then the other person will perceive/conceive of the set as an entity, a thing. The word 'system' will then spontaneously emerge as the adequate expression, the proper name for this thing. A system is therefore an interaction between what is 'out there' and how we organize it 'in here'. 'System' denotes an interaction between the objective world and how it is looked at or thought about; it denotes a mode of *perceptuo/cognito* organization. (p. 61)

Much of contemporary cognitive development research is guided by a similar idea, which Gelman (1990) makes explicit:

> The thesis is that the mind brings domain-specific organizing principles to bear on the assimilation and structuring of facts and concepts, that learners can narrow the range of possible interpretations of the environment because they have implicit assumptions that guide their search for relevant data.

In this paper, the systems idea offers an organizing principle for knowledge representation. Specifically, the theory provides a way of defining the range of questions that are asked to students. If this conceptual model can help learners make explicit their own understanding about body systems, then it might have considerable educational significance. For example, organizing one's knowledge of body systems according to systems criteria could be a significant step towards metaconceptual understanding and intelligent self-regulation of cognition.

Systems criteria and the digestive system

Systems may be classified according to the type of connectivity between their constituent elements, according to the nature of processes, or of the control. Jordan (1973) proposes three bipolar classifications based on the types of connectivities between the elements of a system:

Structural-functional or static-dynamic

Aspects of phenomena that do not change within a given time-span are structural or static, otherwise they are said to be functional or dynamic. When the processes in any system occur over a comparatively short time-span, then the dynamic nature of that system is apparent. The body, and the digestive system in particular, is a dynamic system. This point was tested by asking students questions about the existence and nature of digestive processes, and whether these processes continue when we are sleeping. Students' ability to relate structure with function in specific instances was studied by posing questions like, 'What would happen if the intestines were a straight tube?'.

The alimentary canal is an enclosed structure bound by walls, but capable of exchanging matter with other systems. Food passes unidirectionally from one end of the alimentary canal to the other. Students' idea of an enclosed structure, and of sequential passage of food, was tested, as was their notion of modification of this structure to include auxiliary organs: the liver, gall bladder and pancreas. Distribution of food through the body was probed directly by a question about what happens to the food we eat, and indirectly by asking how medicine swallowed into the stomach can cure a headache.

The dynamic nature of the digestive system implies a certain time-scale over which processes are carried out. Students were asked whether the process of digestion was instantaneous, continuous, or occurring in a fixed interval of time (How much time?).

Purposive–non purposive

'Purpose' denotes a pattern of action characterized by convergence to a terminal state or 'goal'. This convergence is, to a considerable degree, independent of the effects of the external environment. Purposive behaviour may be directed towards the environment or towards the system itself. The purposive property of a system is reflected in the phenomenon of 'adaptation'. One consequence of adaptation is to produce a 'stable system', in which certain variables, required for favourable operation of the system, remain within well-defined limits.

The analysis in terms of 'purpose' seems to hark back to Aristotelean teleology. But in the biological sciences, such apparently teleological explanations often

provide shorthand expressions for the functional aspects of adapted systems (Nagel 1961). In research, the teleological approach is useful because it helps in the framing of 'why?' questions in relation to adapted systems (Mayr 1982). For example, it makes sense for a physiologist to ask what is the 'aim' of a particular reflex. In pedagogy too, the teleological approach is fruitful (Tamir and Zohar 1991). When one says that the function of the stomach is to digest protein, this goal-directed behaviour is a natural way of conceptualizing a phenomenon that is actually the result of millions of years of natural selection. Whether students realize this distinction is an important issue, but it is not addressed here. Cobern (1991) points out that when purpose is of importance in the student's world view, there can be a significant mismatch between the presupposition of students and that of classroom instruction.

The idea in this paper is to see whether students think of body systems as purposive in their behaviour, and whether they are aware of the optimal nature of the functioning of the digestive system. This was done by a direct question on whether eating serves a purpose, and also indirect questions on the consequences of over-eating (Would extra food give extra energy indefinitely?) and of eating spoiled food (Is it true that our body 'tries' to get rid of harmful substances?).

Mechanistic–organismic

The systems-theory definition of a mechanistic system (Jordan 1973) is that when any of the elements of that system is changed or removed, the other elements and their connections remain unaltered. If they do not, then the system is said to be organismic. Organismic systems have central and peripheral properties and elements. Removal of peripheral elements leaves the essence of the system unaltered.

Biology cannot dispense with the idea of an organic whole, as living things are not additive systems of independent parts. Biological processes cannot be understood if they are regarded as isolable mechanisms (Nagel 1961, Mayr 1982). On the other hand, reductionist science calls for separating the body system into separate sub-systems, in turn studying the sub-system by analysing it into constituent organs, and so on till the molecular level. This approach has its limitations, as Szent-Györgi (1969) and other biologists have pointed out.

In the classroom situation, where intricacies and inter-dependencies in mechanisms are often glossed over, the significance of the organismic view can be lost. In the absence of a clear understanding of mechanisms, only a naïve mechanistic credo might be conveyed to students. It is therefore of interest to see in what way students' ideas can be described as either mechanistic or organismic. These ideas were probed, first indirectly, by asking students to compare the digestive system with a food-processor, and then, by asking them to guess the effects of removal of specific organs.

Self-regulation

Apart from these three bi-polar classifications, there is another characteristic, that of self-regulation in systems, whose two aspects are feedback and central control. Feedback can be external or internal, that is, arising from the environment or from within the system. In the operation of the centralized system, one particular sub-system plays an important role. In the human body, the brain is thought to be the controlling and unifying organ. Digestive functions like peristalsis, secretion of

enzymes, absorption, feelings of hunger and satiation, are controlled by the brain by means of feedback mechanisms.

Questions were framed to test whether students were aware of the existence of central control and feedback in situations involving hunger and secretion of digestive juices. There were also direct questions about which organs control digestion, and how digestive functions could be modelled in a robot.

Research on children's conceptions of bodily functions

Early work in this area was motivated by the concept of 'body image', particularly its affective and psychoanalytic aspects, such as differentiation of the self from the outer world. Nagy (1953) and Gellert (1962) cite this early research, stating that their own concern was with children's conceptions of the structural and functional aspects of the body.

Nagy found 4 to 12-year-old students holding a static conception of the body, with each system being reduced to one organ with its assigned 'role' e.g. 'The stomach is for food'. The process of digestion as transformation of food was generally not understood. Gellert found the stomach to be a prominent organ in the children's conceptions. In Contento's (1981) study, 11-year-old children understood that eaten food is transformed in some way, but not how the food brings about any effects on the body.

Mintzes' (1984) review concluded that naïve theories of human anatomy and physiology develop rapidly during the school years. Carey (1985) suggested that young children's concepts about the body are embedded in an intuitive psychology, which evolves into a biological theory by age ten years. Thus, their explanations progress from intentional causality to mechanical causality. Hatano and Inagaki (1987) argued that children's naïve theories about their bodies rely on a version of causality that is not intentional but vitalistic.

Wellman and Gelman (1992) reviewed research on naïve biology to conclude that, although children may not have very well-developed biological theories, they do possess distinct biologically specific causal beliefs. Bloom (1990) made a case for understanding the contexts–such as experiences, beliefs, emotions and values–within which children's biological reasoning develops.

Research on children's conceptions about the brain (Johnson and Wellman 1982) indicates ideas about central control. These fifth-grade children attributed higher cognitive functions (such as thinking, dreaming and remembering) to the brain but thought the brain irrelevant to walking, sneezing, sensing, and control of involuntary functions. On the other hand, when pressed to give an explanation for observed regularities in behaviour, perhaps the idea of central control is natural. Resnick (1991), studying children's reactions to simulations of self-organizing systems (systems showing emergent behaviours due to a very large number of locally interacting components), found a 'centralized mindset', a tendency to give explanations which assumed central control.

Diagnostic methodology

The digestive system was analysed with reference to the systems criteria outlined in the last section. Questions framed on this basis were grouped into three open-ended tests, dealing with structure and function, the mechanistic or organismic nature of the system, central control, and self-regulation. (The tests, and the

Table 1. Sample sizes (number of students).

Standard (Age)	*Test 1*	*Test 2*	*Test 3*	*Diagrams*	*Interviews*
II (6+)	—	—	—	11	8
III (7+)	—	—	—	7	13
IV (8+)	30	—	—	—	10
V (9+)	44	49	40	27	10
VII (11+)	54	36	51	28	10
IX (13+)	57	47	60	25	9

categories used for coding the free responses of students, may be obtained from J. Ramadas.)

The written tests were administered to 9 to 13-year-old children. An open-ended drawing test, which was meant to probe ideas about the structure of the digestive system, was administered to all age groups. In the drawing test, an outline of the body was given, and students were asked to show the path of food. The coding criteria and response categories used for analysing the drawings are given in the Appendix.

Each of the tests (written and drawn) was followed by interviews with selected students. The interview format was structured but flexible, starting with a set of pre-planned questions, which were followed up as necessary. Younger children were asked about the nutritional aspects of food, growth (What parts of your body grow? Why?), the role of food, and the structure and function of the digestive system. Older children were asked these, and also further questions based on their test responses. Each interview lasted about 30 minutes. All the tests were administered and the interviews conducted by one of the authors.

The tests were administered in the Marathi language to students between six and fourteen years of age in five different schools, two rural, two semi-urban and one urban. The urban school belonged to the Bombay Municipal Corporation; the children were in lower socio-economic strata. Students in the other four schools were middle-class. Table 1 shows the numbers of students to whom the tests were administered.

Results are presented in the next section. Inferences about developmental trends are based on 95% confidence limits, derived from the appropriate binomial distributions.

Results

Structural aspects

Ideas about the structure of the digestive system were tested in three ways: through free-response drawings, through guided drawings (connecting up the given drawings of individual organs), and through written responses. The first two of

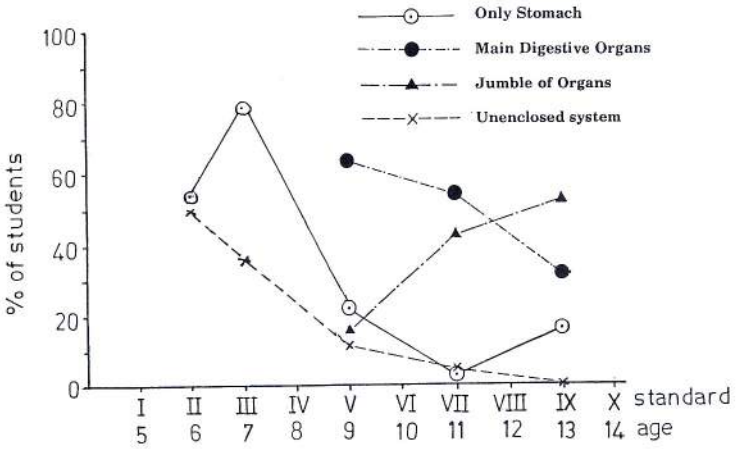

Figure 1. Characteristics of the digestive tract drawn by students.

these data sources gave clear and consistent differences between younger and older students; surprisingly they showed some reversals of developmental trends. Figure 1 summarizes the results for free-response drawings.

Figure 1 shows that the idea of the digestive system as an enclosed structure through which food passes, develops in the majority of students between the ages 6 to 9. Since many 6-year-olds think of food as directly going everywhere in the body, they do not imagine an enclosed structure, and often, do not even show a stomach. The 7-year-olds tended to show the stomach as a bowl or of some irregular shape, while older students represented the individual organs in their correct shapes. Although 13-year-old students showed an enclosed system, they were often inaccurate in details. At all ages, the students thought that the digestive organs were made of bones, skin and flesh (consistent with Nagy's (1953) results).

Most students thought of the digestive system as a continuous channel through which food passes. In 7-year-olds this model consisted of simply a mouth, gullet and stomach. Auxiliary organs (which link with function) were understood by only about 10% of the students (age 8 upwards). Most students, when asked to show auxiliary organs, drew them in the direct path of food.

The digestive system is introduced in the school curriculum in Standard 4 (age 8 years). At this point students were found to start differentiating the system into organs (figure 1). The apparent downhill trend after age 9 was not statistically significant. However, the increase with age of the tendency to draw a jumble of organs, and to include irrelevant organs like the lungs, was statistically significant. This despite the fact that the digestive system recurred in the curriculum for Standards 6 and 8, where the details of enzyme action, absorption into the body, and the idea of dynamic turnover were dealt with. Perhaps these complex ideas had been introduced without reinforcing the basic structural aspects of the system.

In general, results from the drawing tasks showed that the 8- and 9-year-olds had a better idea of structure than did the 13-year-olds. However, on written responses this difference disappeared, perhaps because the younger students were less able to express themselves in writing.

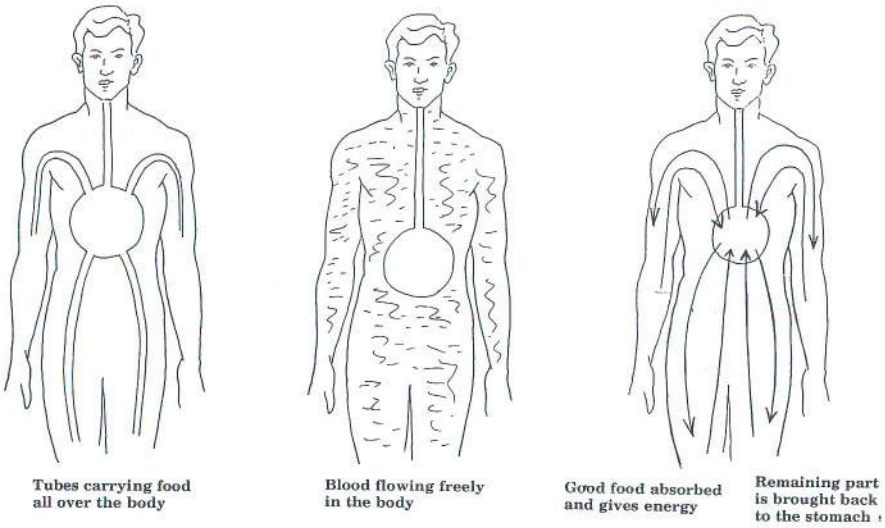

Figure 2. Ideas about distribution of food in the body (7 to 8-year-olds).

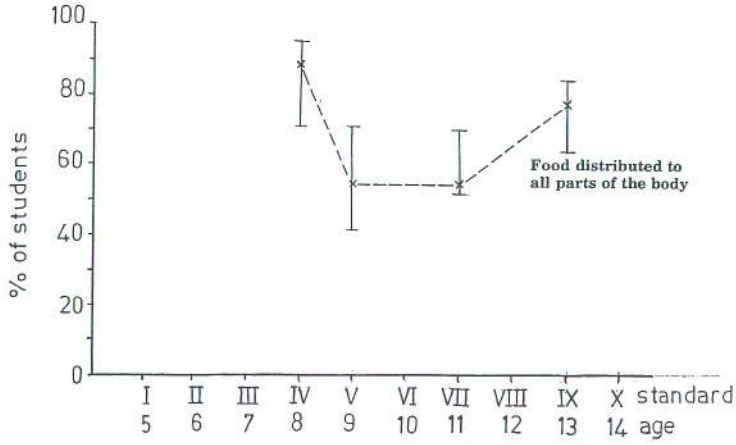

Figure 3. Is food distribution through the whole body? Developmental trend.

It is interesting that the youngest children (6 to 7 years), who imagined no definite structure, still had some idea of food being distributed to all parts of the body (figure 2). The drawings in this figure are the interviewer's depiction of some typical ideas expressed by 6 to 7-year-olds in response to the question, 'Where does the food go?'.

The idea of distribution of food showed another interesting U-shaped developmental trend (figure 3). Apparently, at ages 9 and 11, students did not think of food going everywhere in the body, perhaps because they tended to interpret the newly-learnt definite structure too rigidly. Again at age 11 they returned to the idea of distribution of food, going to the organs not directly, but via absorption into the bloodstream.

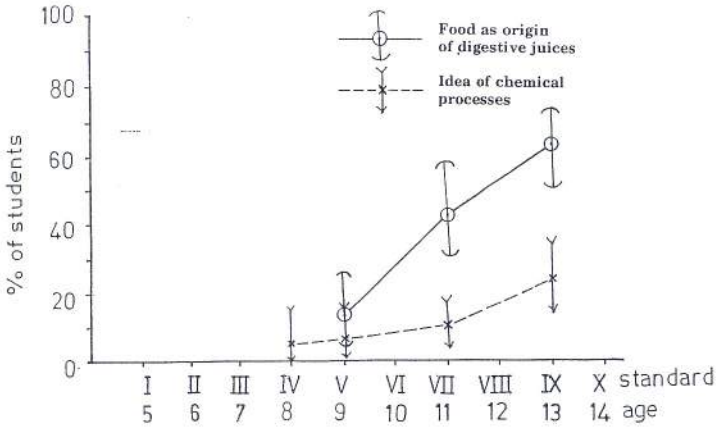

Figure 4. Percentage of students who have an idea of chemical processes and dynamic turnover.

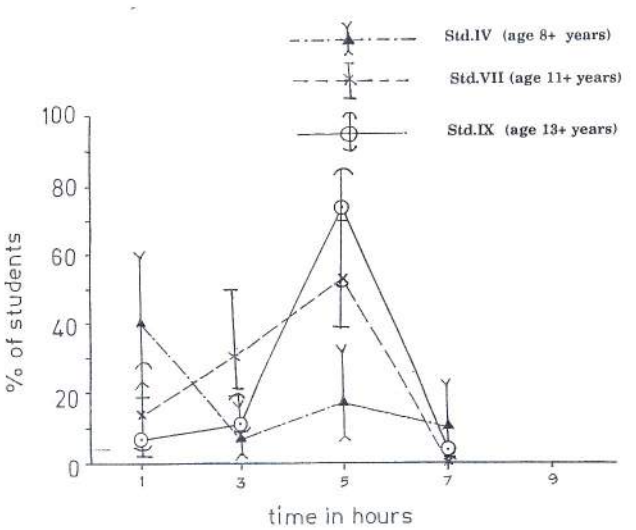

Figure 5. Students' estimates of time required for digestion.

Functional aspects

When explaining the functional aspects of the system, the majority of students across age groups referred to the mechanical break-up of the food, particularly as it occurred in chewing. About 40 to 50% of students above 8 years of age talked of food being converted to 'liquid food', or water, or blood. Although the idea of chemical transformation (via enzymes) was not known to the majority of students, many 13-year-olds seemed to have some conception of a dynamic turnover in the body (figure 4).

The relation between structure and function was probed through a series of questions about what would happen if digestive organs were of a different shape (if the gullet was coiled, stomach and intestines were straight tubes). Across ages,

students gave more correct responses for the stomach, fewer for the gullet and least for the intestine. Older students were better able than younger students to answer the question about shape of the intestines. What seemed to develop with age was not a general tendency to relate structure with function but specific knowledge about individual digestive organs.

Figure 5 shows that the students' estimates of the time required for digestion improves considerably with age, converging to the accepted value of 4 to 6 hours. These time estimates were all based on physiological effects, like intervals between feeling hungry, and frequency of evacuation.

Interestingly, when this question was posed to a college student, he asked, 'Do you want the time required from the stomach's point of view, or from your own?'. Perhaps older students might be more aware of an alternative level of explanation, in terms of what is happening inside, rather than simply what one physically senses.

Purposive nature

Students' views of the digestive system could be described as implicitly purposive. At all ages, they listed the favourable consequences of digestion: growth, energy, strength, health, and providing the body with essential substances. Very few statements were explicitly teleological, e.g. 'The body digests food so that we can grow'. Even the youngest students (6 to 7 years) had the idea that some types of food are better than others. For example, milk, pulses, vegetables, eggs, meat and fish were considered to be more nutritious than bread, rice, biscuits and fried food. The nutritious food was thought to lead to growth and strength, while other kinds of food led to laziness or ill-health.

There was a pathos to the conversations on nutritional values. While the children from the small-town school, who came from middle-class families, spontaneously expressed ideas about good and bad food, the urban children, who came from poor families, and could not afford milk, eggs and meat, were understandably unsure about their responses. Often they remarked that all food is good food. Still, they too gave many of the same responses as the children from middle-class families, showing that these ideas were well learnt is school even when they could not be practised.

There was a developmental trend in the types of consequences attributed to digestion. Older students (11 to 13 years) were more likely to respond to this question. They emphasized energy, while the younger students (9 to 11 years) restricted themselves to growth and provision of essential substances (figure 6). The youngest students (6 to 7 years) only mentioned growth. The mechanism of growth was not mentioned, but two of the six 13-year-olds talked of cell division.

The optimal nature of the functioning of the system was obvious to the older students, who stated invariably that excess food would not indefinitely give extra energy, but would lead to weight-gain, laziness, stomach-ache or indigestion. No mechanism was given by any of the students.

Purposiveness was not tested in relation to specific aspects of the functioning of the system, since these were clearly beyond the knowledge level of the students. One example used was that of the expulsion of harmful material (spoiled food) by the body. Although the students were unfamiliar with concepts like gastric motility, secretion and anti-peristalsis, about 60% of the students in all age groups did have an intuitive notion that the system would try to get rid of harmful substances through

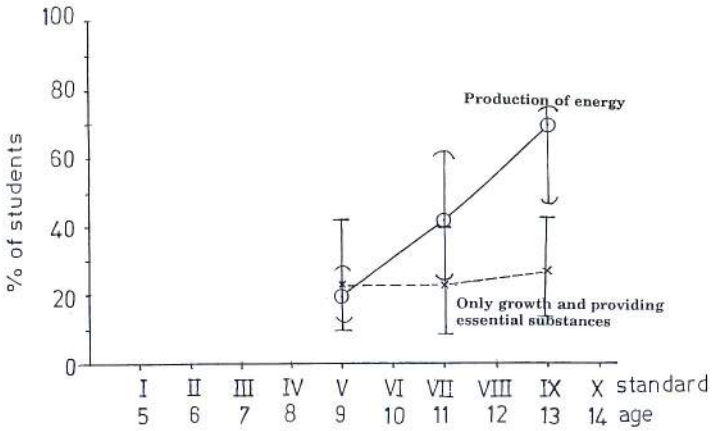

Figure 6. Consequences of digestion.

diarrhoea and throwing up ('Stale food might make us sick, so it has to be thrown out'). The other prevalent idea, held by 18% of the students, was that the system would simply stop working in order to avoid digestion of the harmful matter.

Mechanistic–organismic nature

Two questions were framed to probe the mechanistic–organismic idea in an indirect way: 'Could a robot be constructed that could digest food?', and, 'Is the digestive system like a food processor (grinding stone)?'. The responses were expected to reveal any vitalistic conceptions as opposed to mechanistic ones. Organismic conceptions might have led to responses in terms of complexity and interdependence in the body.

Students seemed to have some intuitive vitalistic notions: about 50% of the students at all ages said that a robot could not digest food, since it was non-living, and therefore intrinsically different from a human being. About 10% of the students at all ages said that digestion was possible in a robot, if digestive juices were supplied. There were no age differences in vitalistic notions.

It seemed as if the older students tended more towards a mechanistic view than the younger ones. When asked whether the digestive system was like a food-processor, 50% of the 11 to 13-year-olds agreed, while only 8% of the 9-year-olds did. The younger children also had a high no-response rate (51%) and most of them were not able to justify their positive or negative answers. The 11 to 13-year-olds, even when they said the digestive system was different from a food-processor, gave justifications involving differences in mechanism, such as presence of digestive juices and absorption into the bloodstream. Explicitly organismic responses were not obtained from any group.

An interview question on removal of the stomach was a more direct probe of mechanistic thinking. Here all of the six 9 to 11-year-olds said that we would simply die, indicating that they held a holistic conception of the body. All three of the 13-year-olds said that only specific functions involving the stomach would be affected, or that simply 'We would not be able to live properly'.

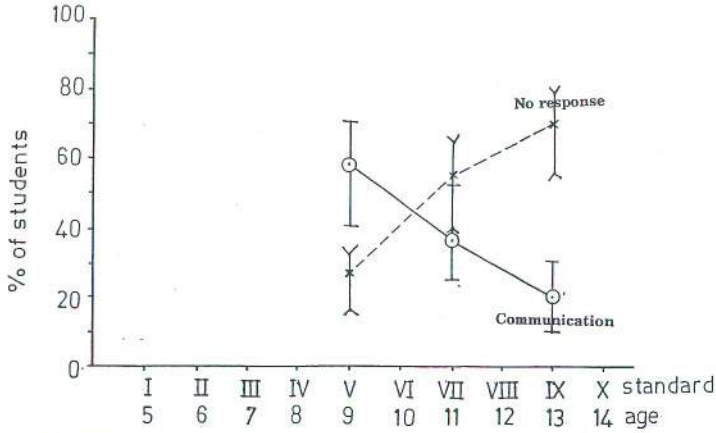

Figure 7. How does one bring about self-regulation in a robot?

Self-regulation

The idea of the nervous system as an agent of central control was absent at all ages. When students were given a choice of organs that would play a role in the feeling of hunger and in the secretion of digestive juices, or whose removal would affect the working of the system, they tended to select the digestive organs (44–68%), or irrelevant organs like the heart and the lungs (25–56%), but rarely identified the brain and nerves as important (8–20%).

Students were asked to speculate about how an empty stomach leads to feelings of hunger. Most students explained hunger by attributing some intentionality to the person ('Hard work makes us tired', 'We need food to live', 'Our cells need blood supply'), or specifically to the stomach ('The stomach needs to be satisfied'). They did not find the need to postulate any mediating mechanism.

When asked whether a robot could be made to feel hunger and to ask for food, a decreasing percentage with age (figure 7), thought that a speech mechanism would be sufficient. The need for a sensory mechanism was not realized. However, the higher non-response rate for the older students perhaps indicates that they were not happy with this simple answer.

The interviews confirmed the impression that students did not see a role for the brain/nervous system in the process of digestion. All twelve of the 9 to 11-year-olds, and four out of five of the 13-year-olds said that the food is pushed forward by the walls of the digestive system, and the process of digestion occurs on its own ('automatically'). The idea of a central control, when suggested by the interviewer, was vehemently denied. Similar to Johnson and Wellman's (1982) results, the brain was related only to thinking, learning and judging between right and wrong.

Conclusions

The use of general systems criteria enabled a new and useful characterization of students' understanding of the digestive system.

An idea of structure was found to develop by age 8, when students imagined a continuous channel, initially consisting of simply a mouth, gullet and stomach, while later the small and large intestines were added. The notion of unidirectional passage

of food was so strong that even auxiliary organs were made to fit into this scheme. Although the linear sequence of the digestive organs was understood early by primary school children, older students had many confusions, probably as a result of forgetting, compounded by the learning of many more systems. This shows that while the basic information could be handled at an early age, there was a lack of integration with other knowledge.

An interesting result was the initial rigid interpretation of the enclosedness of the digestive system, leading students to ignore the distribution of the products of digestion to all parts of the body (a simpler version of the latter idea was quite familiar to younger students). This was an example of a temporary regression in understanding which could be avoided by linking digestion to growth of the body. This aspect has been followed up in a subsequent study of students' ideas about growth.

A comparison between performance on the verbal and drawing tasks showed that the younger students had an advantage in the latter. This result corroborated earlier work on optics (Ramadas and Driver 1989) which showed that diagrams as opposed to verbal descriptions enabled students to work within an abstracted context consisting of light sources, rays and geometrical projections. Drawings thus appear to be a more appropriate mode for teaching as well as testing young children.

On function, it was evident that students had no idea of the chemical transformation of food. Most students imagined digestion to be just the physical passage of food, involving little more than mechanical crushing and mixing. Clearly, their ideas about digestion had not been integrated with related concepts of respiration, metabolism and growth. The similarities between digestion and other kinds of chemical breakdown could be dealt with in teaching, as could the role of the nervous system in regulating the digestive process.

At all ages, students had a spontaneous tendency to relate structure with function. Their actual success in doing so varied according to their knowledge level, showing that there was much potential is using structure-function relationships to make information about systems more intelligible to students.

The results on mechanistic thinking have considerable implications for further research. Modern biology is essentially the study of mechanisms (Guyton 1986). Research done so far in Western countries (Carey 1985) has implied that children develop some form of mechanistic thinking by age 10. This conclusion needs to be tested more stringently, and also cross-culturally. Traditional ways of thinking, particularly as reflected in alternative systems of medicine, imply a holistic view of the body. Thus, treating the body as a system of relatively isolable mechanisms, may not come naturally to children in all cultures.

There are other ways in which the present study needs to be extended. It would be interesting to see whether the concept of a 'system' can be used to study the understanding of other body systems, and specifically, to find a rationale for curricular decisions regarding how and when the systems can be taught. For example, the digestive system, where physical structure is prominent, is certainly easier to learn than the immune system, where function and mechanisms are prominent. If the system concept provides a useful organizational principle for knowledge, then a conscious application of it should lead to efficient storage and retrieval. If such metacognitive knowledge does lead to better learning, it would be a convincing demonstration of the validity of this research approach.

Appendix: Free response drawing test

Given below is an outline of the human body. Can you complete this diagram by tracing the path taken by food in the body?

Coding criterion	Categories derived from students' drawings
1. Enclosedness	A Bound by definite walls (enclosed system) B Not completely enclosed
2. Fate of food in the body	A Food is eventually egested B Food is localized in the abdominal region
3. Organs shown in the path of food	A All digestive organs (including accessory organs) in order B Only major organs (from mouth to large intestine) included C Mouth–gullet–stomach D Any other organ E No answer
4. Shape of the stomach	A Irregular B Round C Tube-like D J-shaped

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