What Do Cells Really Look Like? Children's Resistance to Accepting a 3-D Model

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In our explorations of children's concepts in science we have found that children of grades 6 and 7 visualize cells as 2-D objects. This aspect of children's understanding of the cell has not been reported before, to our knowledge. In this paper we describe our motivation for exploring this concept and report our discovery of children's resistance to accepting the idea of the cell as a 3-D object. We discuss the implications of our results for teaching this fundamental concept in biology. Further, we give recommendations of teaching strategies that we developed and found to be successful.

Introduction

The concept of the cell is a fundamental concept in biology. Yet little research appears to have been done on children's understanding of this basic concept (AAAS Project 2061 website; Driver et. al., 1994). While many curricula introduce them as the building blocks of all life, it has been reported that a common misconception children have is that of cells as being inside the body, but not as making up the body that the term 'building block' would imply (Dreyfus and Jungwirth, 1988). In our interactions with children of grades 6 and 7 we found, that they conceive of the cell as a 2-dimensional object. We suspect that this has a direct impact on their understanding (or lack thereof) of many cellular processes in later years. We give a brief account of the factors that led us to this study, describe the study, present the results, and finally discuss the implications for teaching.

Several lines of inquiry in different contexts led us to explore the difficulties children might have with the concept of the cell as a 3-dimensional building block of living organisms. In our earlier biology classes, we had found that students had no idea of respiration and energy production as cellular processes. The majority of a class (of about 35 students) thought that energy is produced by the digestive system and it is transported by blood to other parts of the body. They even wrongly attributed the source of digestive juices – saying it comes from the space between the cells in the stomach wall. It has also been reported that children often leave the lungs out in their drawings of the circulatory system, as though oxygen being carried to each cell has nothing to do with blood circulation (Arnaudin & Mintzes, 1985). It is in the context of these experiences that we investigated students' concept of the cell.

Methodology, Results

We regularly conduct classes with students to explore their ideas and test curricular material. In the summer of 2006 we conducted classes with two batches of about 25 students each. One batch had just passed grade 6 (average age 11.5 years), the other grade 7 (average age 12.5 years). The students came from an urban school system in a cosmopolitan city. The medium of instruction in their schools was English. The students, who came from a varied socio-economic background, were chosen randomly from among volunteer applicants with complete disregard to their scholastic performance. They had already been taught about cells, some cell structure, and tissues in their schools. Most of them, particularly students who had completed grade 7, had also seen cells (onion skin and cheek cells) under a microscope.

We wish to emphasize that this study was conducted as part of a larger program, whose ultimate aim is to develop curricular material, so our methodology is somewhat different from that of a typical study of children's concepts in science. For example, our interventions went hand in hand with diagnostics to elicit children's concepts. Our results are therefore being presented along with the interventions in the order in which they took place in the class, and not separately. Indeed, it was during classroom discussions that many of their ideas were identified or further clarified and during which some teaching took place, guided by their response. While there were follow up questions and discussions as teaching progressed, and written tasks and other activities, there were no formal interviews with individual students. We describe our studies with children of grade 6 and grade 7 separately.

Grade 6

We started with these questions in class: "What does a cell look like? What is its shape and size? Is it hard or soft? What is inside the cell?" We asked them to depict their ideas through drawings and descriptions. We found that the idea of a generalized cell was difficult for the students (many of them wanted to know which cell they had to write about, and could not start until one was specified); they were allowed to choose any particular type of cell. It has been reported that students think in terms of two kinds of cells – plant and animal (Berthelsen, 1998).

Written and Oral Responses: Some Salient Features

Cells visualized as 2-Dimensional objects: Children's descriptions of the shape of cells were indicative of their idea of cells as 2-D objects. Two of the students explicitly said this: "It is 2-D circle" [sic], "It (plant cell) is flat". Five of the students used adjectives like "rectangular", "circular" and "oval" while three students wrote that the cell is round. Later discussions in class revealed that these students meant circular and not spherical when they wrote 'round'. Only one student described the cell as 3-D: "It is tube like structure".

Incorrect prototypes of plant and animal cells: "Animal cells are somewhat circle [sic] in shape. Plant cells are rectangle in shape."

Students who wrote about the plant cell described it as "rectangular". During later discussions the entire class unanimously said that the shape of a plant cell is "rectangular". Also, students' idea of flat rectangular cells becomes all the more clear with this statement of a student: "Plant cell is bordered by a cell wall". On the other hand, their descriptions of the animal cell reveal that they think it has no proper shape: "Cell looks like an oval shaped object but with some curvy edges", "They (skin cells) are shapeless", "Cell…might be a circular wobbly".

During the discussion, we found that students hold a similar view of the nucleus; they think it is something like a jelly or "butter spread" which cannot retain its shape. Another noteworthy misconception that was verbalized by a student: "The cells contain most probably a jelly like liquid or blood". This point was discussed and clarified in class.

Cells as filling/ being contained in the body, not making up the body: Eight of the students reproduced the sentence from their textbook "Cells are structural and functional units of living organisms". However, we found during the ensuing discussion that no student understood the meaning of this sentence. On the contrary, some of their statements clearly portray a very different picture of the cell. One student wrote "The cells protect us from hurting the bones" while another drew an outline of a hand filled with cells. About "skin cells" one child wrote, "The cells under our skin are soft". These indicate that they think that cells fill up the body rather than make up the body, a misconception that has already been reported (Dreyfus & Jungwirth, 1988 and Missouri Department of Higher Education website)

Cell membrane - soft or hard? This is one aspect they got right; even in the case of plant cells they said "it won't be that hard". One student argued this very well "cells need food and all the nutrients. If the cell covering is hard it will be difficult for the cell to absorb the food." Intriguingly however, this student held a 2-D concept of the cell!

Classroom Discussion: More on the 2-D Aspect

When the worksheets were turned in, we held further discussions in class on the shape of a cell. We asked, "How would a cell look if magnified, i.e., made bigger from all sides?"

The students chose to speak about a plant cell first. All of them said that it was rectangular. We showed them an A4 sheet of paper and asked, "Is this how a cell would look then?" Most of the students agreed; a handful were not sure. We further clarified the analogy, "Suppose the length of a cell is this big (the length of an A4 sheet) and its breadth is as big as this (breadth of the A4 sheet) then what, do you think, will be the thickness of this cell? Will it be the same as this paper or more?" Most of the responses were "Yes". To the few who disagreed, we asked what they thought the thickness of the cell would be, "Would it be as much as this book (of around 100 pages)?" They responded with an emphatic "no" and said it won't be "that thick". Finally they settled for the thickness of 2-3 pages kept together!

When asked how they thought an animal cell would be, they said it will be round. However when probed further, whether it would be like a ball or flat like a *chapatti* (tortilla like bread), they were not sure. Then we gave then the option of a *paratha* (which is thicker, like a pancake) - most of them agreed.

Teaching that Cells are 3-D

We started with activities that would help children appreciate that the drawings they encountered in their textbooks were 2-D perspectives/ depictions of 3-D objects. We put a ball in a plastic bag and blew into it to puff it up. We then invited children to the blackboard to draw this bag with the ball in it. They were eager to have a go at it, and drew with inputs from other children in the class - the whole class participated in this exercise. They realized that most of the drawings they made did not reveal the 3-D nature of this object. We compared their diagrams with the diagrams of cells they had seen.

Then we drew an analogy between our bag with the ball and a biological cell and its nucleus. We emphasized that – most cells are not flat; that the nucleus too is not flat but is almost round like a ball; that the nucleus is not a semi-liquid "jelly" ''without firm shape''; that cells are of many different shapes - not every animal cell is round and not every plant cell is cuboidal. We specifically discussed the shape of an RBC which is difficult to visualize from a 2-D picture. We showed them a clay model of the RBC the next day.

We went on to discuss how rectangular 3-D objects are seen from different angles and related this to drawings of transverse and longitudinal sections of plant stems that are typically shown in textbooks. We compared these drawings with what they would be like if all the plant cells were really flat as the students had thought. We clarified that under the microscope too they would see just one face of the cells, as in diagrams and so they may appear to be 2-D. (The next day, we showed them onion cells and those of spirogyra under the microscope).

We assigned a homework task, asking them to make a model of a cell and bring it to class the next day. Right then, however, they had to write down what they intended to use to make the models lest the task get delegated to parents or someone else at home. We emphasized that it should not be a drawing but a model that should actually look as if a cell has been magnified.

Some children brought their model the very next day while others took time. Meanwhile we proceeded with teaching and this did influence the type of cell models that were made.

Models: After Some Teaching

Six models were submitted the next day: three flat plant cells, three 3-D animal cells. It is noteworthy that 2-D models were submitted in spite of the elaborate and detailed teaching on the first day, indicating how robust this 2-D mental model is.

Models of Plant Cells

Underestimated third dimension: Dimensions of the models: 8cm x 8cm x 1cm, 6cm x 10cm x 1.5cm and one model was a piece of cardboard covered with a sheet of plastic

Cell walls as borders on only four sides: Cell walls in plant cell models are shown on just four sides like a picture frame. Also two of the models show the organelles on only one side while one student has taken care to show the nucleus and other organelles on both sides of the 2-D model.

Flat organelles: Two of the models had flat things like coins and paper cut-outs as cell organelles. Interestingly, these were stuck outside only on the "front" surface. The other model was made with special effort - organelles of clay were carefully stuck on both sides of the 2-D model, as though they extended across the thickness of the flat cell.

Models of animal cells

All three animal cell models were 3-D. One animal cell was similar to what was done in the class - a ball and water in a plastic bag. The other two were collar cells found in sponges. These were inspired from our previous lesson on reproduction in sponges and were remarkably well made.

Further intervention involved focusing different layers of cells at different depths by changing the focus of the microscope; drawing of macroscopic objects from different perspectives, imagining their transverse and longitudinal sections (T.S. and L.S.); showing cells such as those of vascular bundles from different perspectives under the microscope, i.e. T.S. and L.S, and asking students to visualize their shape; analogy with soap bubbles made by blowing into a glass container of soap solution - they too look flat from above but a side view shows the depth; discussing what is inside the cell: it holds water, has different organelles which are not flat; presenting a dynamic picture of the transport of materials across the cell membrane; discussing substances (secretions like digestive juices) made inside the cell (and not between the cells as students had thought).

Models Submitted Later (As Teaching Progressed) – 18 Models

As teaching progressed, much to our satisfaction, the models that were submitted evolved and approached a 3-D structure.

3 models depicting cells as flat: one RBC model – completely flat (a kidney shaped cardboard cut-out), one animal cell – back surface circular and flat, front surface convex, one plant cell – made of dough spread on a cardboard sheet.

15 models were 3-D: using balls, matchboxes and cardboard blocks (with a sizable third dimension: for example, 4cm x 8cm x 5cm, 8cm x 11cm x 7cm, 11cm x 17cm x 14cm)

However, even some of the 3-D plant cell models had cell walls only on four sides like a frame. Also, 4 out of these 15 models had cell organelles stuck on the "front" side of the cell. A peculiar thing about these organelles was that they were 3-D but were compressed - paper balls or clay balls were flattened a bit to make the front and back flat. The rest of the models had small spheres like marbles as organelles inside the cell.

The flat models and those with flattened organelles were the ones submitted during the initial period of intervention.

Grade 7

The grade 7 students had learnt about cells as the smallest living unit in their regular classes in school, and had been taught about the processes of nutrition, respiration, excretion; they also had learned about the nervous system in some detail – an entire chapter had been devoted to it in their school text book.

Before any intervention from us, they were asked to write what they knew about a cell, and then make a model of it in class. They had to work with only the material we had provided from our 'treasury' of low cost equipment (small foam spheres, marbles, balls, metal washers, straws, cardboard boxes and sheets, bottles, tape, modelling clay, buttons, thread, etc.)

Written/ Oral Responses: Some Salient Features

Use of 2-D adjectives for cells: 13 children used words like "circle", "rectangle" and "oval" to describe the cell. Sample responses: "It can be a circle, rectangle or triangle." "It would be oval or rectangular."

Incorrect prototypes of animal and plant cells: 5 students have written about a plant cell and all of them say it is "of rectangle shape…" The picture of animal cell they have is that of a "shapeless" cell. Descriptions in 11 of the worksheets reveal that they think cells, especially animal cells, have no proper shape. It is noteworthy that this idea is more pronounced in grade 7 compared to grade 6. Sample responses: "Cells do not have proper shape" "It is shapeless" "Cell has shape like Amoeba". Thus, students have not got the connection between the structure and function of cells though they have been taught about different organ systems; only three students got it right, "Their shape is appropriate to their function." Amazingly, four students think, "Cells vary in shape and size according to the creature, for example the cells present in the human body are in circular shape."

Persistent misconception – cells fill the body: 12 students have reproduced this sentence from their science textbook: "A cell is a structural and functional unit of a living organism". As in grade 6, it was clear that they did not understand it despite having learnt more about tissues and systems in grade 7. At least 5 students had the misconception that the cells fill up the body. Some responses indicating this: "There are two types of cells in our body – RBC and WBC" "The plant cell is inside the stem."

Cells: hard or soft? 6 students have the idea that some cells are soft while some are hard depending upon their function or type, for example, "Cells of our cheek are soft whereas cells of our bones are hard". This is similar to another common misconception among students wherein they extend macroscopic properties of the element to the atom (Harrison and Treagust, 1996 and references therein).

Models: Out of 22 Models Only One was 3-D

Not a single child in grade 7 picked from among the boxes or balls for making the cell model. Clay was the most popular choice; interestingly, even students who used clay flattened and spread it out to make flat models!

7 models of neurons: All but one neuron models show cell body as flat (star-shaped card paper cut-outs) though straws and fine threads are used for axons and dendrites. For nucleus, the students have used a button or a metal ring. Interestingly, all of them have a strip of card paper stuck behind the axon as myelin sheath, instead of surrounding the axon (looking just as in the diagram of neurons – myelin sheath sandwiching the axon).

The single exception is a neuron model with a 3-D cell body; however the third dimension is *simply added on,* in essence making the picture 'thick'. The shape is therefore not quite correct - a star shaped block of clay instead of a flattened sphere with extensions; axon and its branches made of straw; dendrites made of thick thread. Myelin sheath made with strips of tape stuck around the "axon" (straw). But the nucleus is flat, shown using a button stuck on the surface.

3 other animal cells: A RBC model and an amoeba model were made of clay spread flat on a sheet of card paper as an irregular blot with more clay at the centre and on the boundary to represent the nucleus and the cell membrane respectively. A similar clay model of amoeba had a spherical nucleus shown with a marble protruding out of the flat cell.

4 models of arrays of onion cells: Students have tried to model what they have seen as onion cells under a microscope. They have stuck tiny foam balls or clay balls *which they flattened*, depicting the nuclei, in a row or many rows on a piece of card paper. Two of them have stuck tape on the surface as cell membrane. The interesting part in these models is that they have straws as cell walls which are just partitions between two rows of cells, the cell walls are absent even between two adjacent cells of the same row.

4 models of a single plant cell: These were hexagonal card paper cut-outs with straws on the border as cell walls and buttons or metal rings used as nucleus.

All the cell models in this grade represent only the front view of the cell; the organelles are stuck or drawn only on the front of the block or sheet used to depict the cell.

Students' analogies: We asked for concrete analogies for the shape of the nucleus to confirm that the use of 2-D adjectives is not merely a language problem. The responses - bangle, pupil of the eye, rubber band, planetary orbits (!), Saturn's ring, egg yolk, watch battery, top of a pencil battery, bottle cap, balloon, earth, full moon (!) and ball. Interestingly, some students used both 2-D as well as 3-D analogies; for e.g., both "sphere" and "ring" were given as analogies by the same student.

We clarified whether they really understood what a model means; We showed them a cut-out of a house (analogical to students' cell models) and asked if this is a correct miniature model of a house and all the students answered that it was not, it was just a picture.

Analysis and Discussion

It is clear from the results presented here that students' conception of the cell is quite different from what it would have to be if it were to be understood as a functional and structural unit of life – a fact that is 'taught' in their curricula but which is often reduced to unthinking repetition of the statement.

It is particularly instructive that in the initial stages of teaching children continued to make 2-D models, pointing to how strongly this idea is held. This is particularly interesting because children do have an innate feel for the 3-D nature of their world; indeed their sense of depth is clear from their attempts, even in the early stages of infancy (3 to 4 months), to reach for an object in front of them only if they judge that it is possibly within reach (Flavell, Miller and Miller, 2002).

It took several days for children of grade 6 to internalize the idea of the cell as a 3-D body. We believe many factors contribute to this resistance:

a) Textbooks rely on 2-D illustrations with neither explicit mention of their being a projection of 3-D objects nor is it supplemented by teaching.

b) The small dimensions of the cell - even when viewed through a microscope it is impossible to get a sense of the third dimension i.e. "the depth".

c) A curriculum that relies heavily on rote memorization, so much so that students have gotten into the habit of it. There is a clear disconnect or conflict between their mental images and the meaning of the statements; the students are not even aware of this conflict.

d) Perhaps part of the reason for above point is that English, the medium of instruction in their schools, is not the first language of a single child enrolled there. Unfamiliarity with language gives rise to difficulties in more ways than one: on one hand, simply not knowing what a word means (for example 'sheath' essentially means a covering but the students have not visualized the myelin sheath, as is evident from their models of neurons) and on the other hand, applying meaning from common usage in daily life to a word in a specialized context (for example, cell 'walls' are take as a frame similar to the walls of a room or a fence). Unfortunately such aspects of language are rarely, if at all, addressed explicitly in a science class.

e) Teaching structure of units such as cells, organs, etc. without connecting it to the function that the structure supports. Likewise, teaching functions of cells and tissues without connecting them to their structure.

f) Teaching processes of respiration, expiration, etc., without relating them to cells.

Most importantly, unless pedagogy explicitly addresses ways to help children *visualize* the cell these conceptual problems will continue to hinder a clear understanding of many concepts in biology. It is noteworthy that students in grade 7, despite having been 'taught' more material on tissues and systems of the human body, continued to have a 2-D mental model of the cell, despite the many opportunities they had to question their models. Only one student in class had made a 3-D model! The situation in grade 6 was quite different, where despite an initial strongly held 2-D model, children's ideas evolved as a consequence of the targeted efforts to get this point right.

Recommended Pedagogy

It is clear from our study how difficult and non-trivial it is for children to conceive of the cell as a 3-D body. Activities and questions need to specifically address this issue, helping children visualize the cell. We recommend the following strategies for teaching:

Making models: We strongly recommend that making physical models of cells be an essential part of the pedagogy on this topic. In general, the third dimension of biological entities needs to be explicitly brought out, as was recommended as long ago as 1938 (Payne, 1938). In the case of cells, this approach is all the more important because even seeing cells through a microscope fails to clearly bring out their 3-D nature. This works because it helps children *visualize* the cell as 3-Dimensional, and appreciate that the cellular processes they have been introduced to are consistent with the 3-D model, and, more importantly, *not* with their 2-D ones. We believe this might be more significant than mere physical manipulation of cell models leading to a change in their mental models.

Beyond just seeing – other ways to use a microscope: Children should be shown different layers of cells at different depths by changing the focus of the microscope. Structures such as vascular bundles should be shown from different perspectives under the microscope – T.S and L.S., followed by discussions, aided by gestures and by drawings of these perspectives. The macroscopic analogy of soap bubbles will help them understand these perspectives better.

Different perspectives of common 3-D objects: Looking at a common 3-D object from different angles, and drawing it as seen from these perspectives, helps students appreciate that textbook drawings do precisely that.

The inside of a cell: Teaching what is inside the cell helps to build the third dimension. The 3-D structure of organelles like the nucleus should be brought out. Pointing out that to contain cytoplasm, which is mostly water, a cell has to be 3-D is an essential step.

Dynamic picture: Another important approach is to convey the dynamic picture of the processes inside the cell and transport across the cell membrane.

Examples of cells: The notion of a typical or generalized cell cannot be presented to children at so young an age – they need to be introduced to many cells of different kinds which would allow them to build the idea of a typical cell in their minds. Clement (2005) discusses the origins and problems of introducing the cell concept through the two prototypes of plant and animal cells. An amusing anecdote from a recent interaction with children starting grade 9 serves to illustrate this point – when asked to list all different kinds of cells they could think of in the human body, a few wrote 'typical cell' as one type! Moreover, the text books used by the students not only depict 'typical' plant and animal cells, they convey an incorrect picture – showing the animal cell as irregular. In an attempt to make sense of what they encountered in their previous classes, children seemed to attribute the irregular shape of animal cells to the lack of a cell wall - which they understand gives shape and support to the plant cell.

References

AAAS Project 2061 website: Research on commonly held student ideas provided to analysts for the high school biology textbooks evaluation (n.d.). http://www.project2061.org/publications/textbook/hsbio/report/StudentIdeas.htm. Accessed 02 June 2008.

Arnaudin, M.W., & Mintzes, J.J. (1985). Students' alternative conceptions of the human circulatory system: A cross-age study. *Science Education*, 69, 721-733.

Berthelsen, B. (1999). Students' naïve conceptions in life science. *MSTA Journal*, 44(1), 13-19.

Clement, P. (2005). Introducing the cell concept by both animal and plant cells: A historical and didactic approach, presented at the 8th International History, Philosophy, Sociology and Science Teaching Conference; www.ihpst2005.leeds.ac.uk/papers/Clement.pdf. Accessed June 02, 2008.

Dreyfus, A., & Jungwirth, E. (1988). The cell concept of

10th graders: Curricular expectations and reality. *International Journal of Science Education*, 10, 221-229.

Driver, R., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994). *Making sense of secondary science: research into children's ideas*. London: Routlede Falmer.

Flavell, J. H., Miller, P. H., & Miller, S.A. (2002). *Cognitive Development* (pp. 43). New Jersey: Prentice Hall.

Harrison, A. G., & Treagust, D.F. (1996). Secondary students' mental models of atoms and molecules: Implications for teaching Chemistry. *Science Education*, 80(5), 509-534.

Missouri Department of Higher Education website: Alerts to student difficulties and misconceptions in science (n.d.). http://dese.mo.gov/divimprove/curriculum/science/SciMisconc11.05.pdf. Accessed June 02, 2008.

Payne, M. (1938). The third dimension in the teaching of Biology. *Transactions of the Kansas Academy of Science*, 41, 295-298.