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Representations as mediation between purposes as junior secondary science students learn about the human body

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ABSTRACT

The aim of this article is to investigate students' meaning-making processes of multiple representations during a teaching sequence about the human body in lower secondary school. Two main influences are brought together to accomplish the analysis: on the one hand, theories on signs and representations as scaffoldings for learning and, on the other hand, pragmatist theories on how continuity between the purposes of different inquiry activities can be sustained. Data consist of 10 videotaped and transcribed lessons with 14-year-old students ($N = 26$) in Sweden. The analysis focused instances where meaning of representations was negotiated. Findings indicate that continuity is established in multiple ways, for example, as the use of metaphors articulated as an interlanguage expression that enables the students (and the teacher) to maintain the conversation and explain pressing issues in ways that support of the end-in-view of the immediate action. Continuity is also established between every day and scientific registers and between organisation levels as well as between the smaller parts and the whole system.

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Introduction

In the recent *Handbook of Research in Science Education*, Treagust and Tsui (2014) concluded that research on representations in the past decades has been extensive, for example, about analogies, visualisations, models and multimodal representations. In particular, findings about MERs, multiple external representations (Ainsworth, 1999, 2008; Eilam & Gilbert, 2014), were found promising since the approach makes use of the benefits of coordinating various representations as scaffolding for students' learning. Treagust and Tsui (2014) recommended more research in this area, especially on developing theoretical models for analysing teaching. In line with this suggestion, the aim of this article is to investigate students' meaning-making processes fusing multiple representations during a teaching sequence about the human body in lower secondary school.

The analytical framework is theoretically underpinned by theories on how representations mediate action and pragmatist theories on how continuity is established in

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action over time where continuity refers to students' learning progressions towards more epistemic understandings. Numerous representations are used in producing new scientific knowledge. Graphs and mathematical models are widely applied and different technical innovations to produce images and maps, as for example, functional magnetic resonance imaging, electron microscopy or satellite imaging, are ubiquitous (e.g. Briggs, Canas, Shamma, Scargle, & Novak, 2004; Latour, 1986; Prain & Tytler, 2013). When science is communicated, for example, in pedagogical settings, additional representations may be introduced and valued partly for other reasons than in research settings (Hubber, Tytler, & Haslam, 2010; Kress & Van Leeuwen, 2001; Lemke, 1998). A representation in scientific research may be valued because it reliably makes salient certain features of the phenomena studied, its possibilities to make predictions and its communicative power. Representations and models in pedagogical settings may also be valued on merits such as affinity to students' experiences and everyday life (Gericke & Hagberg, 2010; Gilbert & Boulter, 2000; Talanquer, 2011).

The construction of representations and models in education may be understood as an inquiry process (Kress, Jewitt, Ogborn, & Tsatserelis, 2001; Lehrer & Schauble, 2012; Prain & Tytler, 2012) resembling that of science practices (Osborne, 2014). Detailed empirical studies of learning progressions indicate that representation construction has the potential to scaffold students' meaning-making (Lehrer & Schauble, 2012). Prain and Tytler (2012) adopted a theoretical framework which they called representation constructing affordances to demonstrate how semiotic (representations as signs), epistemic (scientists' validation and use of representations) and epistemological (what students are afforded to learn) dimensions are necessarily integrated in learning through constructing representations. The semiotic dimension focuses on cultural tools (Vygotsky, 1986) divided into material tools (artefacts and instruments) and symbolic tools (visual, linguistic, mathematical and gestural) which have the ability to constrain the learners' attention and direct their learning progression towards specific aspects. In the study of Prain and Tytler (2012), their framework was illustrated by data from a composite Grade 5/6 where students were making meaning of solid, liquid and gaseous states of water mediated by material tools like a set of beads and symbolic tools like a role play and visual diagrams of molecular motion. For example, in the role play, where each student represented a molecule, this specific form of representation placed constraints on molecular size, and directed students' attention to spacing and movement of molecules.

At the same time, as pointed out by Prain and Tytler (2012), the cultural tools do not alone determine the meaning that can be made of them (Wertsch, 1995). Although the tools afford certain meanings in the sense of Gibson (1979), these affordances of the tools function more like enablers and constraints for certain meanings to be noticed rather than others (Norman, 1999). Critical for the meanings made are also the students' prior experiences and the purposes given to the activity of which the tool is part. The meanings afforded by the tools of a role play of molecular motion, for example, are dependent on what the students already know about molecular motion and the purpose given which, in the specific case of Prain and Tytler (2012), was to design a molecular model of the process of evaporation. Likewise, Jakobson and Wickman (2015) showed how purposes and tools together mediated the noticing of different characteristics of leaves depending on whether elementary students were engaged in an art activity making pictures of them with crayons or in a science activity making observations with magnifiers.

In this way, developing representations with students is not a deterministic process, but a guided inquiry. To paraphrase the pragmatist Peirce (1878/1960, p. 104), the scientific meaning of the representations is not something students 'are immediately conscious of', but rather 'mediately conscious of'. Representations are tinkered with and assessed jointly by teachers and students semiotically in relation to their epistemological qualities in supporting students learning and transforming their purposeful participation in familiar activities into new, more scientific epistemic practices (Johansson & Wickman, 2011; Prain & Tytler, 2012).

Because of the epistemological significance of representations in school science, it is important to analyse the use of representations in classrooms and how these representations enable and constrain students' meaning-making of science. In line with the background given, two main influences are brought together to accomplish this analysis: on the one hand, theories on signs and representations as scaffoldings for learning (Ainsworth, 2008; Tytler, Prain, Hubber & Waldrip, 2013 ; Vygotsky, 1978) and, on the other hand, pragmatist theories on how continuity between the purposes of different inquiry activities can be sustained (Dewey, 1938/1997; Hamza, 2013; Johansson & Wickman, 2011; Wickman, 2014). In summary, we here merge these theoretical influences into an analytical framework that deals with students' meaning-making of representations and operationalise the framework in an analysis of teaching in secondary school and focus the analysis on how continuity emerges in student action over time.

Aim and research questions

The aim of this article is to investigate students' meaning-making processes fusing multiple representations during a teaching sequence about the human body in lower secondary school. Two main influences are brought together to accomplish the analysis: on the one hand, theories on signs and representations as scaffoldings for learning including the multi modal representational resources that direct, sharpen and expand students' understandings, and also the natural language resources through metaphor and analogy. On the other hand, pragmatist theories on how continuity between the purposes of different inquiry activities can be sustained. The analysis focuses on how continuity is established in action over time and the specific questions are:

(1) In what ways do representations afford the students' ways of making sense of the content?
(2) In what ways is continuity established between purposes?
(3) How does the refinement of representational systems relate to the establishment of continuity of purposes across the sequence?

Theoretical background

In order to make meaning of science in school, students are dependent on representations as mediating means. Hence, the point of departure in this article is ideas about mediated action in general (Vygotsky, 1978, 1986; Wertsch, 1995, 1998) and specifically in relation to representations and science teaching and learning (Kress et al., 2001; Lemke, 1998;

Tytler, Prain, Hubber, & Waldrip, 2013). In this section, we explicate how mediated action depends on the representations used and the purpose of the activity. We also highlight the particular role metaphors play as proxies in mediating action in new situations and for learning.

Vygotsky (1978) adopted the idea of mediation to explain how people make sense in a roundabout way or detour between stimuli and response (Figure 1(a)). He used this notion as part of his argumentation against the contemporary reflexologist/behaviourist views on a straightforward, simplistic and unreflected pathway (reflex arc) between stimulus and response. Vygotsky (1978) expanded the notion of mediation as an indirect complex activity involving not only signs but also tools (Figure 1(b)).

Vygotsky (1978) used *internalisation* in describing how signs and tools come to mediate action and particularly remembering. Wertsch (1998) in line with Rogoff (1995) argued that in contemporary language, the term *appropriation* as translated from Leontiev's work better describes the relation since it does not imply a division between internal and external activities and by that a dualistic view of mind and world. Wertsch's (1998) connotations of appropriation are more in line with Bakhtin's (1981) view that it is a process of taking over something from others: 'The word in language is half someone else's. It becomes "one's own" only when the speaker populates it with his own intentions … ' (p. 293).

Wertsch's (1995) reading of mediation is also more in accord with pragmatist ideas and with Dewey's (1896) critique of understanding human behaviour as a simple reflex arc from stimuli to response. There is not a direct link between the stimuli and action but the link is better described as 'the development (or as it seems convenient to term it) the mediation of an experience' (Dewey, 1896, p. 360). To Dewey, human behaviour is best approached as purposeful (intentional) and so as action. What might seem as the same stimuli or sign may mediate different meanings depending on the experience as a whole and its purposes. The sound of a gun in a bank office to most people would mean something radically different from the same sound on a shooting range. The response of a certain stimulus is thus not just the stimulus as such, but also its experienced consequences as part of purposeful action which may be escaping, in the first case, or nothing apart from putting on hearing protectors, in the second one. These meanings are, of course, influenced by your prior experiences of guns (a tool) and what they mean in various situations. Hence, the meanings of representations, as appropriated by a student, are not direct and not merely internal, but mediated as part of an activity and the consequences the student can see of the representations in relation to the purpose of the activity.

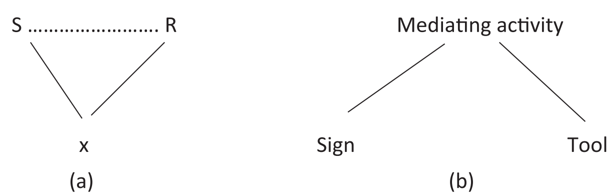

Figure 1. (a) The mediating process (Vygotsky, 1978, p. 40) as a detour via sign activity between stimuli and response. (b) Mediating activity as involving signs and tools (Vygotsky, 1978, p. 54).

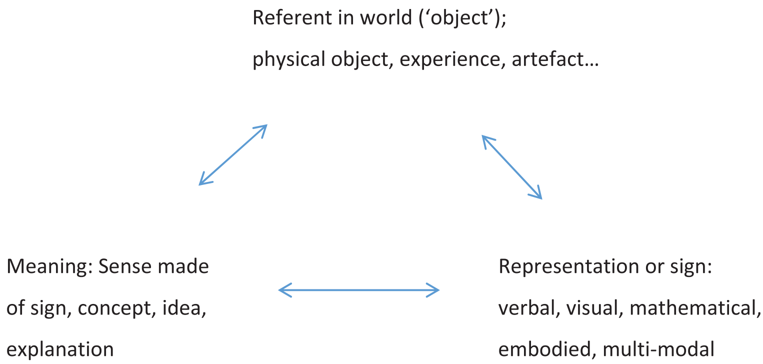

Figure 2. Peirce's triadic model of meaning-making of signs or representations according to Waldrip and Prain (2013, p. 17).

This idea of mediation through representations, foremost by language but also through other mediating artefacts like images, diagrams, formulas and graphs may also be formulated as the triad *signs*, *meaning* and *referents* of Peirce (Waldrip & Prain, 2013). Approached in this way, representations may be equated to Peirce's signs. Meaning accordingly is the sense that people, as for example students, make of the representations to deal with the referents in the world. Several researchers have represented this triadic relation, and Figure 2 is the way that Waldrip and Prain (2013) choose to do it. This relationship should not be understood as static. Rather, according to the pragmatic maxim of Peirce (1878/1960), the meaning of an idea or conception, and so of any sign, is to be found in their practical consequences through action (Peirce, 1878/1960). A sign and the meanings associated with it thus do not have a direct relationship to the referents in the world, but is mediated through activities and the actions (habits in Peirce's terminology) they become part of. Waldrip and Prain (2013) claim that '(L)learners are expected to recognize the differences between an idea, the different ways this idea can be represented, and the phenomena to which it refers' (p. 17) and by that, the unfolding of action during a teaching sequence is a candidate for analysis of meaning-making of representations.

Hence, to study the way students appropriate epistemic meanings of representations as a result of teaching and learning, we need to study how the representations as part of an activity with a certain purpose orient student action in certain directions through their consequences in action. As this transformation of the meaning of signs in an ideal classroom also entails the transformation of the activity from one that is already familiar to the students in terms of their prior experiences to one that is more epistemic, it also means a transformation of the purposes of the activities from familiar ones to more epistemic ones. This connection between representation and purpose necessitates also an explication of the role of purposes for learning.

When Dewey summarised his ideas on education in *Experience and Education* (1938/1997), he focused on 'The meaning of purpose' in chapter 6 and noted that '(A)a purpose is an end-in-view. That is, it involves foresight of the consequences which will result from action' (p. 67). Dewey further elaborated on the notion of 'end-in-view' in *Experience and Nature* (1929/1958):

> To a person building a house, the end-in-view is not just a remote and final goal to be hit upon after a sufficiently great number of coerced motions have been duly performed. The end-in-view is a plan which is *contemporaneously* operative in selecting and arranging materials. […] Literally, they *are* the end in its present stage of realization. The end-in-view is present at each stage of the process; it is present as the meaning of the materials used and acts done. (pp. 373–374)

Purposes, just like representations, have the important role of directing attention through the mediation process, influencing what students find relevant and not relevant to pay attention to. As noted by Dewey, as students press forward with an activity the purposes change, as it becomes clearer to students where they are heading. As a consequence, the 'meaning of the materials used and the acts done', including the meaning of representations used, is also changed. This transformation, or progression, can be described in terms of how activities with purposes more close to students' prior experiences could be made continuous with new more epistemic activities where representations come to be used for more scientific purposes.

This notion of learning was operationalised by Johansson and Wickman (2011) as the progression from proximate purposes (close to students' prior experiences) to ultimate purposes (new, more scientific ones) when analysing teaching about friction in a Swedish Grade 5 (12 years old) class. The unit of analysis was whole class teacher/student talk with the aim to investigate ways that continuity was established between proximate purposes (activities and talk around why we, for example, have tyres on our cars) and ultimate purposes (a scientific explanation of friction). Johansson and Wickman (2011) defined end-in-view as:

> Ends-in-view designates the purposes we use in the current moment to make choices even though the final end, in the future, may be different. A fruitful end-in-view helps students to make intelligent choices together with the teacher even if the students do not yet understand what the over-arching goal of the lesson is. (p. 47)

The concepts of proximate and ultimate purposes, jointly termed organising purposes, are here applied together with the theories on the mediation of action through signs. The subject content in science classroom is mediated through different semiotic resources or forms of communication. These semiotic resources could be seen as different modalities, they are multimodal (Kress et al., 2001; Kress & Van Leeuwen, 2001; Lemke, 1998). Science content has often multiple representations such as verbal, gestural, pictorial or mathematical (Lemke, 1998). Each modality makes use of different (material) resources or signs, for example, text including metaphors, analogies, video, drawings, pictures, physical models, mathematical models and gestures. Each modality and the way it is communicated in the classroom offer different constraints and possibilities for meaning-making (Kress et al., 2001) depending on the organising purposes given and how they together give students ends-in-view that allow them to reach more ultimate purposes (Johansson & Wickman, 2011).

Analogies and metaphors have long been recognised as important in science education, for example, Shulman (1986) argues that use of appropriate and powerful metaphors and analogies is an essential component in pedagogical content knowledge. In *Metaphors we live by,* Lakoff & Johnson (1980) made a strong case for the fundamental impact of metaphors: 'This book grew out of a concern, on both our parts with how people understand their language and experiences' (p. ix). These two concerns, with language and with experience, are in the centre of the present article. Later, Lakoff and Johnson state that metaphors pick 'out what is "important" in the experience. And by picking out what is important in the experience, we can categorize the experience, understand it, and remember it' (p. 83). This statement corresponds well with Dewey's (1896) point, described above, about 'mediation of experience' (p. 360).

Interest in metaphors has historically been rooted in linguistics (Aubusson, Harrison, & Ritchie, 2006) but with influence from, among others Gentner and Gentner (1982) and Lakoff and Johnson (1980), has become more articulated in terms of conceptual metaphors. Taking influences from sociocultural perspectives where learning science involves learning the language of science (Lemke, 1990, 1998), metaphors are not to be seen as either or, because ' … work on metaphor stresses that it works on two levels: conceptual and linguistic' (Cameron, 2002, p. 674).

The general idea underpinning the use of analogies and metaphors is 'understanding and experiencing one kind of thing in terms of another' (Lakoff & Johnson, 1980, p. 5), for example, to try to connect one 'target domain', which you are unfamiliar with, to a 'source domain', of which you have experience. Thus, metaphors and analogies may be a powerful vehicle to enhance students learning by connecting different domains, for example, everyday experiences and scientific accounts of the same phenomena (Aubusson et al., 2006; Pramling, 2009; Tobin, 2006).

Methodology

Data, sample and settings

Data were generated within a teaching sequence in school year 8 with 26 students (12 girls and 14 boys) approximately 14 years old. The teacher was formally qualified to teach biology, chemistry, mathematics and physics at this school level, and had approximately 35 years of teaching experience and was well acquainted with the actual school. The school was owned and run by the municipality and had approximately 400 students in grades 6–9 (for more information, see Olin & Ingerman, 2016).

The Swedish national syllabuses (LGR11) state that biology should help equip students with 'tools that influence their well-being' and exemplify this with areas to be taught including learning objectives relating to understanding the human body at this school level (grades 7–9). The objectives are 'The cells, organ systems and organs plus their function and integration'. Most of these are also objectives for the previous grades (4–6); however, cell biology is introduced as objective in grades 7–9. The teacher in the group we studied formulated the ultimate purpose of the teaching sequence as 'explain how substances that enter the body reach the cells'.

Different representations are in focus in this article and many of them are commonly used in Biology classrooms throughout the world, for example, physical models of torso, heart and skeleton. However, in the studied classroom, a specific representation known from children's books, *Barbapapa* (see Figure 6) was frequently used (http://www.barbapapa.com/the-barbapapa-family-video/). It was introduced by the teacher during the first lesson and then referred to throughout the sequence. The teacher's intention in selecting this type of representation was that Barbapapa, on the one hand, might be

Table 1. Lessons in the human body sequence (1, 3, 4 and 6 are whole-class and 2, 5 and 7 are half class lessons).

	Content (and key activity)	Representations and tools
1	Teacher led introduction: (what is known/not known). Activity: student work with 'Barbapapa' picture	Words and drawing on white board (WB); Student Barbapapa picture constructions; Analogy: fire wood/stove resembles nutrients/cell Analogy: substances 'jump'
2a/2b	Roundtable seminar: organs Activity: student work with 'Barbapapa' picture	Barbapapa picture: plasticine and drawing. Analogy: 'the power plant of the cell' (mitochondria) Analogy: substances are 'fetched/dropped off'
3	The cell. Activity: watching microscope slides (cells) and writing exercise (circulation)	Physical model: cell (Styrofoam) Display of Paramecium culture Analogy: cell respiration as reversed photosynthesises
4	Circulation of blood. Activity: video of circulation	Physical model: torso, heart and molecular model Key words (for production of text) Analogy: little wagons that loads/unloads Analogy: highway/allies resembles aorta/capillary
5a/5b	Roundtable seminar: heart Activity: measuring of blood pressure and pulse	Physical models: torso and heart Analogy: ice cone resembles heart (beat) Equipment: stethoscope, blood pressure cuff
6	Breathing Activity: writing exercise and graph interpretation	WB: Barbapapa (breathing organs) Physical models: torso, larynx and lung model Key words (for production of text) Graph (breath volume)
7a/7b	Roundtable seminar: muscles Activity: static/dynamic muscle work	Physical models: skeleton, torso and spine Gesture: hinges Visualisation: muscle work (antagonists) Analogy: fire wood/stove resembles nutrients/cell

known by the students and, on the other hand, resembles more or less an 'empty sac', which provides rich opportunities to work with organs and substances.

The 'human body' was the topic of the teaching sequence and all lessons were videotaped: four whole classes (50 min each) and three half classes (40 min each) which means that each student attended seven lessons (see Table 1).

The video camera focused on the teacher who was equipped with a wireless microphone. Two groups with three students each, chosen by the teacher for reasons of representativeness, were also audiotaped during two group discussions. The talk recorded by the teacher microphone was transcribed verbatim as well as the talk during the two group work sessions. Handouts and other teaching materials were collected and scanned.

Analytic procedure

The first step of the analysis was to watch all videos and focus on when and how representations where used. Representations are cultural tools and include material and symbolic tools that serve as resources in students meaning-making. For example, physical models, drawings, metaphors, analogies, formulas, words, speech and so on. (see Figure 2, below right). In our analysis, we focused on physical models, visual diagrams, formulas and pictorial language, particularly metaphors and analogies. This led us to a collection of instances where representations were negotiated and established as part of an agreed language. As an example, the metaphorical term 'jump' that was introduced into the discussion by students continued to be used, contrasted with the an analogy mentioned once by the teacher, between the mitochondria and a Christmas glass bulb, which met no further response and was not mentioned again.

Secondly, we applied the analytic framework that focuses on how representations mediate meaning as part of particular activities and the purposes given to these activities. We are especially interested in how the signs relate to specific referents in the world depending on the purposes in terms of the end-in-views of students and thus how the signs and their meanings change as the activity moves from a more proximate to a more ultimate one. The meaning of signs cannot reflect a well-defined epistemic meaning from the start, but to begin with must just be good enough to carry the specific proximate activity forward in a way that eventually affords the more epistemic understanding connected to ultimate purposes. This, as noted earlier, is an inquiry process depending on the ends-in-view enacted by the students. An end-in-view can be recognised through the aims the students are trying to actively accomplish as a result of the purposes given to them by the teacher.

The analytical framework focuses on the way meanings are expanded from informal and restricted perspectives on the phenomenon to more inclusive and scientific perspectives through the dual operation of the invention and refinement of representations including abstracted and metaphorical language, and cycles of activities through proximate and ultimate purposes. The analytical framework is supposed to discern moments where continuity is established, for example, continuity between purposes (Hamza, 2013), use of progression in use of language (Olander, 2010) or as end-in-view (Dewey, 1929/1958) which are communicative actions seen as negotiations of signs (Figures 3 and 4). In the next paragraph, a brief example of the analytical procedure is presented.

During lesson 2a/b, the students were to represent a phenomenon in the world, that is, they were given a proximate purpose. Their task was to represent a human organ system with plasticine together with another representational mode (e.g. talk, arrows, written words, etc.) to explain connections between a specific given organ system and other organ

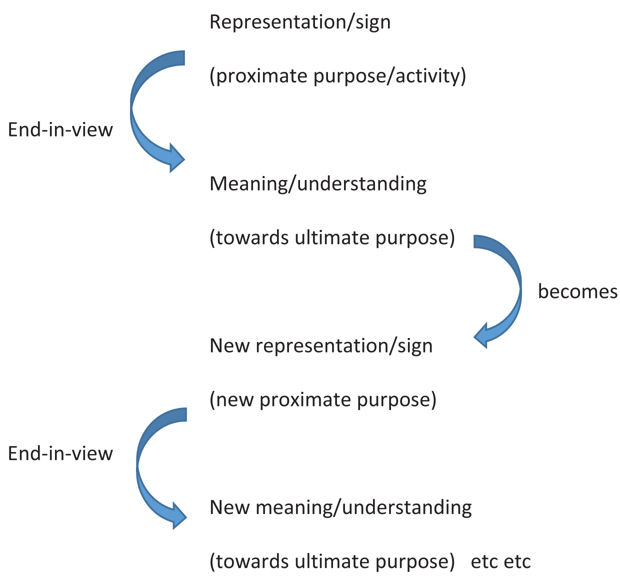

Figure 3. Analytic framework. Arrows show the continuity necessary to establish to render signs increasingly more epistemic meanings.

Rep/sign: "Barbapapa with organs"

Activity: represent the pathway of "food and oxygen"

End-in-view

"jump" (metaphor in L1)

becomes

jumps on/ jumps off;

End-in-view

fetch/drops of (metaphor in L2)

little wagons that loads/unloads (metaphor in L5)

Figure 4. Example of use of analytical framework (theme a).

systems. The analysis focuses on the three elements in the Peirce model (see Figure 2): one group was given 'blood circulation' (referent in the world) and represented it with red plasticine (representation) and explained connections (meaning-making) by drawing arrows between a blood vessel and a cell and labelling it with 'oxygen' and 'O_2' (see Figure 5). In their talk, students referred to the process where substances move between systems using the metaphor 'jump' (see more in theme a below). The proximate purpose functioned as an end-in-view, in that the students were able to accomplish this activity (proximate purpose) and they did so in the direction towards the ultimate purpose, 'substances that enter the body should reach the cells'. In this way, the metaphor 'jump' used for the proximate purpose afforded students to make it continuous with the more epistemic ultimate purpose.

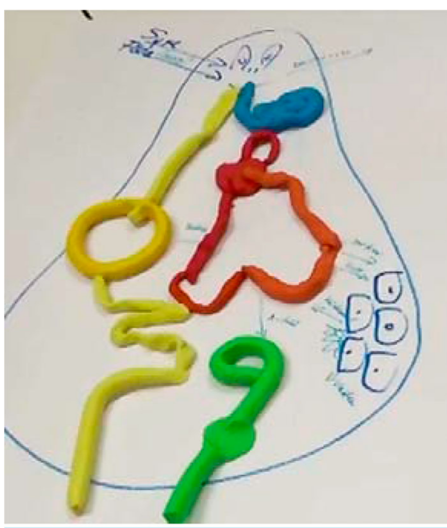

Figure 5. Student's representation of organ systems.

Results

The results section is structured around three themes (a–c), which were negotiated with reference to representations. The themes highlight and exemplify different ways of establishing continuity. The developments (trajectories) of these themes are exemplified within episodes chosen from the 7 (10) lessons. Themes that were negotiated were:

(a) transport and exchange of substances
(b) naming of substances
(c) description/function of organs and cellular respiration

Transport and exchange of substances (theme a)

During the first lesson, the second activity involves that the students, in groups of three/four, are given a paper copy of an empty Barbapapa, and with coloured pencils, they draw and connect the lung, heart, blood vessels, stomach, intestinal channel, kidney and cells. In excerpt 1, three students discuss how substances move from one organ to another, in this case, the intestinal channel and a blood vessel.

Excerpt 1 (from lesson 1)

100	Emma	shall I make a hole where it [*blood vessel*] comes in?
101	Kasper	no there is no need for holes … draw it beside instead because I don't think it goes into the intestines because then we would have blood in your intestines
102	Albert	then you would have
103	Kasper	and that would not be nice
104	Emma	why alongside … why … how does it get in
105	Kasper	it [*nutrition*] jumps over
106	Emma	where is it [*blood vessel*] going
107	Albert	it should get back to the heart
108	Kasper	you draw it back to the heart with carbon dioxide
109	Albert	and then it pumps
110	Emma	so it [*nutrition*] just like jumps in on its way
111	Albert	yes … nutrition jumps on
112	Kasper	draw an arrow and write nutrition

Connections between organs and mechanisms for exchange of substances between organs are not evident for the students. Emma who is drawing at the moment asks if the blood vessel should enter the intestinal channel through a hole. Kasper argues with reference to his own experience that it cannot be like that, otherwise 'we would have blood in our intestine'. Emma accepts this but wants to clarify 'why alongside … how does it [*nutrition*] get in' and also 'where is it [*nutrition*] going'. They agree on this representation (sign), but the *sense* and the temporary *meaning* they make are somewhat vague and communicated in everyday language. At this stage, the students do not have the discursive tools: either vocabulary, metaphor or visualisation to construct an explanatory account of the material exchanges. The descriptions generated are so vague that Emma is not convinced and asks in line 150 'so it just like jumps in on its way'. Here, the students agree on a representation involving an arrow with text as explanation … 'make an arrow and write nutrition' (line 112). A prior utterance by Emma in line 106 is a request that relates to continuity as Emma seems aware of an ultimate purpose concerning the passage of materials across organs in the system: 'where is it going?'. The activity has thus raised, through the specificity of demands of the drawing and positioning of organs in relation to each other, questions concerning the pathways of nutrition through or across organs in the body.

The next lesson, which is a half class (2a and 2b), is arranged like a round table seminar (see Figure 5) and first all students discuss how many organ systems we have; is it one, two, three or maybe four systems. The students agree on four systems, represented with four colours, and each system is given to a group of students with the assignment to represent their system with plasticine and display it on an empty Barbapapa. This activity functions as end-in-view, in that students were able to use their previous knowledge in order to place the systems on the model (see Figue 5) and thus articulate how the organs are arranged, and participate in productive discussions that distinguished between the different systems. There was, for instance, discussion about the duality of the blood circulatory system, and pulmonary and systemic circulation. In Swedish, the two loops in Figure 5 are labelled 'small blood system' and respectively 'large blood system'.

When all groups are gathered again, the systems are to be connected. The excerpt starts when the blood system is presented.

Excerpt 2 (from lesson 2a)

Janina then it goes down to the stomach and then to the intestines and then the blood catches the nutrition from the intestines and then it goes further and jumps off in the cells and then leaves … yes … oxygen comes from the lungs and it has jumped on and it jumps off in the cells.

Excerpt 3 (from lesson 2b)

Niklas so it has to go here first, and yes it must … it goes from the heart to the lungs to fetch oxygen and then it goes round there … no wait what am I doing ... it should go there and fetch it from the intestines where nutrition is and goes to the cells and then drops off the oxygen and nutrition and picks up carbon dioxide.

When, in lesson 1, labelling the process when substances cross barriers and enter new organs as *jump,* it was a temporary agreement, articulated with an interlanguage term in a mode continuum. Now, in lesson 2, the intermediate term jump seems established and is used again, however, with some extensions like *catches*, *fetch it*, *picks up* and *drops off*; but there is no intention to explain any mechanism for the jump-catch-fetch-pick-drop formulations.

The teacher accepts the language and uses the wording 'jump', for example, in lesson 5b when explaining the blood circulation using an analogy involving 'little wagons' and a physical model (a torso where the blood vessels are represented with blue and red colours).

Excerpt 4 (from lesson 5b)

Teacher It is like little wagons that either load oxygen or unloads carbon dioxide [*points towards the torso*] you can see where it is red and blue and it goes into the lungs and the oxygen can like jump into the blood and carbon dioxide can jump off there.

The word jump is also maintained during lesson 6 when the teacher explains breathing 'you have to look at the pictures … these alveoli are small … but it is here the important things happen and it is here that the gases jump to and through the blood'.

Naming of substances (theme b)

Representations served as a vehicle for naming substances within a mode continuum between an everyday register and a scientific register. At the beginning of the first lesson, substances that enter the body were first articulated by the students as 'food and air' and then specified to 'oxygen, food and water', names which were written on the white board (see Figure 6).

The purpose of the lesson was to introduce the topic by externalising students' current reasoning on the human body and to sketch the ultimate purpose of the whole sequence, thus establishing continuity in relation to the whole sequence.

The first activity was formulated as a question to the whole class: 'let us see what you know about the human body and what you don't know yet' and with the students' answers, the teacher constructed the whiteboard inscriptions shown in Figure 6, which has been recreated with English words replacing the original Swedish. On the board, we can see where the teacher has articulated what the students already know (above the blue line) and what the students do not yet know (below the blue line). This means that below the line are the ultimate purposes of the whole sequence, which relate to understanding the function of specific organs and how substances are transported and exchanged in the body which incorporates the cellular level. These purposes mirror the themes we identified through the analysis.

During lesson 2, the students are to represent organs and organ systems with plasticine and explain the circulatory system of the body. The activity seems to create a need for refining vocabulary and partly with the help of the teacher's re-voicing, the names of

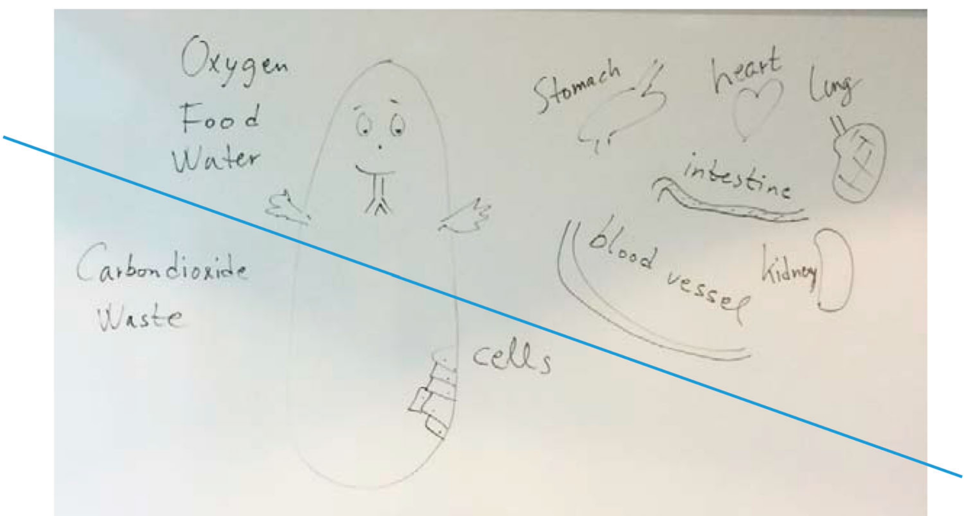

Figure 6. Whiteboard (recreated picture with translation from Swedish). (Note that the diagonal line is inserted by the authors.)

substances are changed. In excerpt 5, the students and the teacher are gathered around a table rephrasing and summarising earlier statements from students:

Excerpt 5 (lesson 2b)

501	Teacher	you have got this … did you understand what he said … what substances shall jump in
502	Stella	nutrients
503	Teacher	nutrients like …
504	Stella	fat, proteins and carbohydrates
505	Teacher	and the cells' favourite?
506	Stella	oxygen

Here is the label *food* reformulated as *nutrition* and then further to *nutrients* and lastly as the components *fat, protein and carbohydrates*. Using plasticine in the representation helped students to make sense of the arrangement of organs and reach the intended meaning that the body organs can be arranged sensibly into four systems. The plasticine as a spatially flexible representational tool also scaffolds students to label arrows indicating material exchange with names of substances (sugar and oxygen/carbon dioxide). Here, a clear progression is visible in the use of language to more precisely name substances. In lesson 1, there were mainly everyday labels on substances (such as 'food' and 'air/oxygen'), while here in lesson 2a/b, the teacher repeatedly scaffolded students in the group and whole-class discussion with feedback, often given in the form of re-voicing student utterances into more scientifically precise language.

In lesson 3, the cell is in focus and when discussing the process of cellular respiration, a need for labelling oxygen as oxygen molecule is established. Some students even use the formula as shortcut and talk about 'O two' and 'C O two' as well as using sugar and dextrose/glucose as labels. Thus, a shift in the naming of substances is discernible, which in short can be described as: food-nutrition-nutrients-fat, protein, carbohydrates-sugar-dextrose-glucose and air-oxygen-oxygen molecule-O two. This indicates a shift of register, and the consequences of the shift from an everyday register to a more scientific one will be discussed later.

Description/function of organs and cellular respiration (theme c)

One of the goals formulated in the syllabuses concerns 'organs plus their function and integration' and in order to describe and explain the organs in the classroom, they are frequently represented as material tools (physical models) or symbolic tools (analogies, metaphors and gestures). The physical models are, on the one hand, standard representations that most schools in Sweden are equipped with, for example, plastic torso, skeleton, larynx, heart and so on, but also 'homemade' models like a *breathing model* and a *cell* of styrofoam (see Figure 7). These models generally function as levers for students' meaning-making, for example, the model of the cell is used when summarising organelles like mitochondria and membrane (lesson 4).

The breathing model accompanied an explanation of shallow (diaphragm) breathing which is presented later in this section.

The symbolic tools are more linguistically driven and by that harder to explain since they often are embedded in the national language and translations to English may seem strange. However, metaphors and analogies are important learning strategies and

Figure 7. Breathing model (lesson 6) and a cell model of styrofoam (lessons 3 and 4).

frequently used in teaching as evidenced in the studied classroom. For example, is a heart-beat paralleled with the formulation 'when this muscle [*points at the lower part of a heart model*] contracts it is almost as an ice-cone … you compress like that [*clenching his fist*] and then it [*the blood*] runs off both to the lungs and to the aorta' (lesson 5a/b).

The teacher used an analogy at several times during the sequence (1, 2a/b, 3 and 7a/b). It is a story of how the teacher brings in firewood but does not put the firewood in the hall. Instead, the firewood is taken to the stove (wood burning stove) because it is there 'it is useful'. The analogy is supposed to exemplify that the food (sugar) which enters the body needs to be transported to the cells in order to react.

Excerpt 6 (lesson 1)

Teacher … if it [*the sugar*] stays in the stomach or the blood then I have not reached all the way … I have a wood burning stove at home and have to chop fire wood and if I prepare the fire wood and put it in the hall it would be of no use, it has to reach the wood burning stove (lesson 1, 03.40)

/ … /

Teacher … the cell – that is where it should be, that's where stuff happens, like I said I must carry the wood to my stove that's where it burns off (lesson 1, 06.18)

The second utterance above from the teacher also introduce a synonym to cell respiration when saying that it is there 'stuff' happens' and 'it is there it burns off … '. The analogy with the wood burning stove is also used in lesson 2 a/b where the cell respiration is reformulated as 'it is there the energy is released'. Which in lesson 3 is commented on when showing a physical representation of a cell ('homemade' from Styrofoam, Figure 7)., when a student introduce a metaphore for mitocondria, "the power plant of the cell". *Excerpt 7 (lesson 3)*

700 Teacher This is a mitochondria and it has a special task it is here it should happen, what does the book say?

701 Adam it works like the power plant of the cell

702 Teacher	yes, in my house I have a wood burning stove and I have to carry fire wood there, it is a kind of the burning stove of the cell … it is here the combustion is happening. Does anyone know how warm this combustion in the cell is?
703 Elma	100
704 Teacher	no it doesn't have to be 100
705 Elma	thirty-seven degrees
706 Teacher	yes, it is kind of unusual fire or there is no fire with a flame … this happens slowly and at 37 degrees

In excerpt 7, the analogy is extended to a place, the mitochondria and referred to as 'the power plant of the cell'. There is a pointer towards a delimitation of the analogy since the combustion temperature in the wood burning stove and the cell differs: 'yes, it is kind of unusual fire … this happens slowly and at 37 degrees'.

The analogy actually gets the final word in the sequence when the teacher in lesson 7b concludes the lesson about muscles with:

> … you do not get more muscle cells, but it is the cells that become bigger when you exercise. And more mitochondria which means more heating stoves. Then we used the time pretty well today, let us be content with that.

Gestures are more 'international' and by that easier to make sense of in different languages. In the studied classroom, gestures were used to represent, for example, joints between skeleton parts in the body (hinge, ball and saddle joints), for example, in lesson 7a/b where the elbow joint (hinge) was paralleled by opening a door. During lesson 4, the teacher got the whole class on its feet and with closed eyes performing and contrasting shallow (diaphragm) and deep (abdominal and ribcage) breathing (see also Figure 7). The difference between skeleton and cartilage was demonstrated during lesson 7a/b when all students were wiggling the top of their noses.

The idea that the cell is the goal of the circulation of substances is introduced in lesson 1, but it is the main topic in lesson 3 focusing more on scientific representations at the level of chemical interactions within cells, for example, analogies with reference to two previous activities, in grade 7, unicellular organisms and photosynthesis.

The teacher refers to previous teaching about cells. First, he shows a beaker with hay infusion and reminds the students of Paramecium which they studied the previous year. The idea is to make an analogy between a human cell and the unicellular organism Paramecium, for example, that both require the same substances in their metabolism. Then another link to the previous year is presented: an analogy to photosynthesis. The formula for photosynthesis (in words) is written on the whiteboard and the task of the students is to 'reverse' it and write a 'narrative/report' with the help of selected keywords (cellular respiration, cell membrane, mitochondria, oxygen, carbon dioxide, energy, glucose, water, waste and organs).

When summing up the lesson, the teacher asks for volunteers to read their narratives, which is exemplified in excerpt 8.

Excerpt 8 (lesson 3)

800 Teacher	Is there someone that has a good beginning of the narrative?
801 Anna	[*reads*] eh cell respiration is photosynthesis although backwards in that cells get sugar and oxygen which they then combust to energy and carbon dioxide
802 Teacher	That was a good way to describe … someone else?

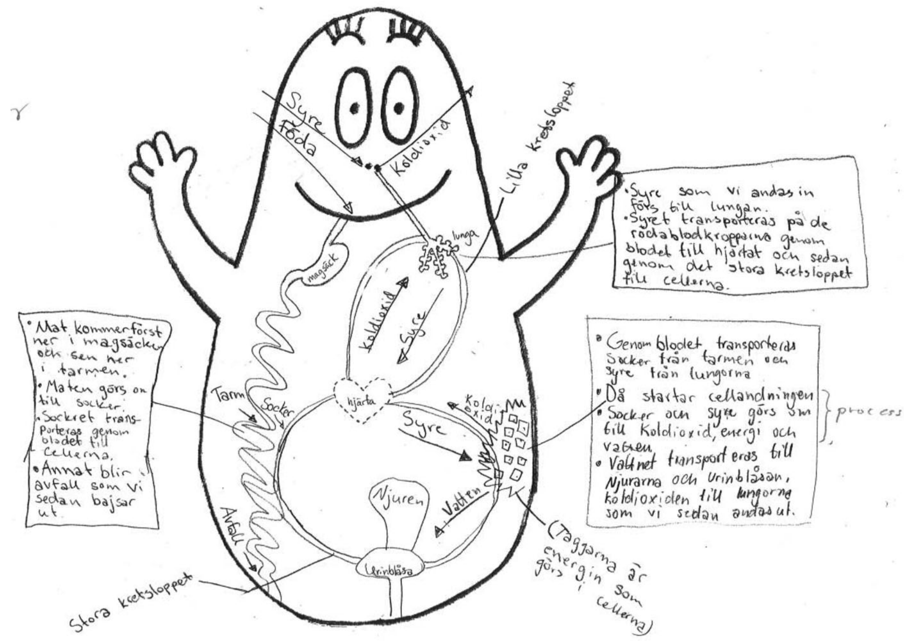

Figure 8. Example of a Barbapapa handed in as 'assessment' of the sequence (in Swedish).

803 Kasper — [*reads*] … in the cell there is also mitochondria and it is there the cell respiration takes place it is the nucleus power plant of the cell … because if there is to be any cell respiration the cells need to get glucose from the blood and when they have got both sugar and oxygen they can start the cellular respiration and create energy and then a gas is formed called carbon dioxide and it could be harmful

There is no indication in the data concerning students' talk and visual representations that they make any references to the Paramecium analogy; therefore, it seems that no ends-in-view are constructed from the activity. On the other hand, the analogy with photosynthesis seems to work as end-in-view, in that students are able to reformulate the formula when they discuss and write a 'narrative/report' (see excerpt 8). The development in representational tools is visible in the students' drawings of Barbapapa (see Figure 8 for a typical example); thus, the sense-making progresses into a scientific language that is more precise and applicable at the chemical exchange level and therefore consistent with the ultimate purposes of the sequence.

Concluding analysis

The aim of this article was to investigate students' meaning-making processes fusing multiple representations during a teaching sequence about the human body in lower secondary school. As guidance, the questions are repeated here: (1) in what ways do representations afford the students ways of making sense of the content? (2) In what ways is continuity established between purposes? (3) How does the refinement of representational systems relate to the establishment of continuity of purposes across the sequence? Both the aim and the questions are analysed within the three themes: (a) transport and exchange of substances, (b) naming of substances and (c) description/function of organs and cellular respiration.

The first theme, the transport and exchange of substances, is a theme that undergoes a progression over time in the use of metaphors, which gradually transforms from an everyday register through an interlanguage expression towards a more scientific register. This theme is an issue that is on the agenda throughout the sequence but a temporary agreement is expressed already in lesson 1 in a rather everyday manner, in response to a problem raised by the spatial model as to whether organs could be directly connected (they could not) and what the nature of material exchange was across the interface between systems of organs. The group decided that substances 'jump' between systems thus avoiding articulation of the specific mechanisms of material exchanges that the next school level eventually will establish. Nevertheless, through the representation construction activity, the question of material exchange has been raised. This sense-making metaphor is kept through the second and sixth lesson, although the words associated with the materials that 'jump' change, for example, 'oxygen is picked up' or 'unloads carbon dioxide'. Thus, the language becomes more refined and discriminating in terms of specifying particular chemicals that are exchanged, but no scientific mechanisms for the 'jumping' are mentioned. However, the metaphor 'jump' functions well in relation to the end-in-view; it keeps the conversation going as other more pressing issues are able to be solved. The meaning of a sign needs just to be good enough to fill its purpose in the activity in the sense that it mediates the transformation process from more everyday signs to more epistemic ones. In lesson 2a/b, the students represent the systems with plasticine and they put the systems close to each other to interact, and visualise 'jump' with arrows and labels of the 'jumping' substances. In the third theme (later), the students' discussion and reports do not focus on transportation of substances in and out of cells; the metaphor 'jump' is again a scaffold that allows the students to focus on the main issue of the lesson – material processes as part of cellular respiration. In this way, the metaphor 'jump' offers an agreed term that 'stands fast' (Wickman, 2014) and allows students to move forward even though the material processes associated with jumping are not clear. It acts as a place holder metaphor that sequentially becomes more articulated and refined as students' views of what is being exchanged, and where, are developed as part of the ultimate purposes of the sequence.

The second theme, naming of substances, is a theme that undergoes a progression over time in a mode continuum between every day and scientific registers (Gibbons, 2003). The sense and wording at the beginning of the first lesson are *food* and *air*, but during the lesson, food is replaced by *nutrition* and air by *oxygen*. Later, the teacher actively rewords/re-voices students' comments and the discourse changes to become more consistent with a scientific language; in short, the transformation of wording across the sequence is: food-nutrition-nutrients-sugar-glucose and air-oxygen-oxygen molecule. At the end of the sequence, the students use a school scientific language, for example, they talk about particles not substances and they refer to a chemical reaction in the cells. The progression and successive shift in language is affected by the teacher's verbal interventions but also due to the inquiry process when students work with the visual diagrams and what becomes necessary to handle in relation to the end-in-view enacted by the students. The affordance of the visual diagram lies in the way it productively constrains attention (Prain & Tytler, 2012) to the spatial elements of the material exchange in relation to the organs. There is only a limited space to draw in which creates a need (Wickman, 2014) in line with the end-in-view for inclusion of other semiotic resources like arrows and words. Since the organs in the representation (Barbapapa) are fixed and the students agree with the idea that substances (food and air) have to be transported another need is created (Wickman, 2014), a need to phrase the substances as particles (nutrients and oxygen). The multimodal character of the representation construction that the students are part of is essential because, according to Kress et al. (2001), it 'enables students to express ideas and make meanings which neither they nor the teacher could readily do in a different mode of communication or in one mode alone' (p. 127).

The third theme, descriptions/functions of organs and cellular respiration, is a theme that put extra pressure on establishing continuity between part/whole relations (Brigandt, 2013; Knippels, 2002). Explanations in science are performed on different organisational levels and this theme exemplifies the crucial importance of, on the one hand, examining each organ/organ system specifically and, on the other hand, connecting each system to the whole body. When establishing this continuity, we argue that the recurrent references to the Barbapapa representation were beneficial and the students did experience ends-in-view in this respect which was shown by repeated student questions about the next step and circularity.

This theme also contributes to answering research question two and three since it focuses on the progression of sense-making of the cell and specifically, cellular respiration. The scientific language progression towards more discriminating and technical terms, as described above, is one of the key factors that scaffold the progression. Another factor is that the ambition of establishing continuity between proximate and ultimate purposes (Johansson & Wickman, 2011) seems to work for these activities. The students often ask each other 'where does this substance go now?' or 'how does it reach the cell?'. During the first lessons, these questions referred to undifferentiated substances such as food and air, but during the sequence, the meaning of the 'substance' that was exchanged changes towards chemical substances involved in cellular respiration. The use of the analogy 'reversed photosynthesis' may also have contributed in establishing continuity in this process in establishing the chemical representations that constitute the discursive tools through which material transformation is understood.

Discussion

In summary, we have focused on establishment of continuity, exemplified in the first theme by the use of a metaphor (jump) articulated as an interlanguage expression that enables the students (and the teacher) to maintain the conversation and explain pressing issues in ways that support the end-in-view of the immediate action. Continuity between proximate and ultimate purposes is established. The second theme illustrates how continuity between registers or social languages (Bakhtin, 1981; Olander & Ingerman, 2011) is established, in this case, everyday and scientific languages, and even more than in theme one, a mode continuum between the endpoints is discernible. The third theme points towards establishing continuity between organisation levels as well as between the smaller parts and the whole system.

We have discussed the affordances of the representations in relation to productive constraints (Prain & Tytler, 2012) when modelling the visual diagram and the multimodal sense-making (Kress et al., 2001) that takes place during talking, drawing and annotating the visual diagram. Continuity between ultimate and proximate purposes is established by recurrent pointers from the teacher towards the ultimate purpose of the sequence, transportation and transformation of substances specifically in the cells. The students contribute to this process and by that we infer that they have the ultimate purpose in sight. The activities (proximate purposes) during lessons work, at least partly, as ends-in-view, which we infer on the basis that the students are able to act and discuss productively (Johansson & Wickman, 2011).

Looking across themes, there is another issue that we would like to comment on, an epistemological and/or an ontological one, which surfaces as shifts or changes in attention. 'What do we want to explain' or 'on what level do we want to explain' is an epistemological issue. In this sequence, the starting up questions relate to the whole body and necessary substances; however, soon, parts of the body and chemical compounds are focused on. These changes in attention to different organisation levels (BSCS, 1993; Schwendimann & Linn, 2015) are part of the semantic pattern (Lemke, 1990) that explanations in Biology make use of. It has been argued (Knippels, 2002; Olander, 2010) that the ability to explain at the relevant level is as important as using the relevant concepts. In this sequence, we see a shift from the level of organism (human) to organ systems (respiratory, circulatory, digestive and excretory), to organs (heart, lungs, blood vessels, etc.) to cells and cell organelles (mitochondria).

The epistemological issue leads to an ontological issue, 'what do we want to explain', in that there is a shift in how humans are perceived during the sequence. If the beginning focus is on humans' well-being or in the wording of the syllabuses, 'tools that influence their [the students] well-being', this soon turns to depicting humans more as containers for chemical reactions. Food is important, but aesthetic values (Wickman, 2006) like taste, appearance and aroma are not important in comparison to the chemical elements. This shift in focus is partly due to the syllabuses and introduced representations, which gradually deal more and more with parts like ingestion and respiration in terms of chemical compounds. This is, of course, a legitimate aim of schooling and scaffolding students' efforts to shift their use of language towards a more scientific register is fundamental to the development of scientific literacy. In our opinion, it is the code switching between colloquial and scientific registers that points towards quality in knowing.

We argue that the analytical framework has potential in describing students' meaning-making processes since the research questions are answered within the three themes. Some representations, for example, the Paramecium-analogy and the wood-fire-analogy, fail to create ends-in-view, while many other representations scaffold sense-making, and through negotiations, temporary but fruitful meanings are established. The scientific explanation has been 'talked into existence' (Ogborn, Kress, Martins, & McGillicuddy, 1996, p. 14) which is in essence what has happened during this sequence. The progressive way that the multiple representations are introduced allows the students to start their meaning-making processes with their own (everyday) expressions and step-by-step appropriate the scientific expressions. Meaning-making is context-dependent and relies on an ability to verbalise and communicate your own current understanding. We suggest that this verbalisation and communication have greater potential to scaffold students' in their progression towards scientific meaning-making if students' are encouraged to use their everyday language 'on the way'. In other words, students experience fruitful ends-in-view and can make intelligent choices towards continuity.

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References

Ainsworth, S. (1999). The functions of multiple representations. *Computers & Education*, *33*(2), 131–152.

Ainsworth, S. (2008). The educational value of multiple-representations when learning complex scientific concepts. In J. Gilbert, M. Reiner, & M. Nakhleh (Eds.), *Visualization: Theory and practice in science education* (pp. 191–208). Dordrecht: Springer.

Aubusson, P. J., Harrison, A. G., & Ritchie, S. M. (2006). *Metaphor and analogy in science education*. Dordrecht, The Netherlands: Springer Science & Business Media.

Bakhtin, M. M. (1981). Discourse in the novel. In M. Holquist (Ed.), *The dialogic imagination* (pp. 259–434). Austin: University of Texas Press.

Brigandt, I. (2013). Explanation in biology: Reduction, pluralism, and explanatory aims. *Science & Education*, *22*(1), 69–91.

Briggs, G., Canas, A., Shamma, D., Scargle, J., & Novak, J. (2004). *Concept maps applied to Mars exploration public outreach*. In A. J. Cañas, J. D. Novak, & F. M. González (Eds.), Proceedings of the first international conference on concept mapping. Pamplona, Spain.

BSCS. (1993). *Developing biological literacy*. Colorado Springs: Author.

Cameron, L. (2002). Metaphors in the learning of science: A discourse focus. *British Educational Research Journal*, *28*(5), 673–688.

Dewey, J. (1896). The reflex arc concept in psychology. *The Psychological Review*, *3*(4), 357–370.

Dewey, J. (1929/1958). *Experience and nature*. New York, NY: Dover.

Dewey, J. (1938/1997). *Experience and education*. New York, NY: Touchstone.

Eilam, B., & Gilbert, J. K. (2014). The significance of visual representations in the teaching of science. In B. Eilam & J. Gilbert (Eds.), *Science teachers' use of visual representations* (pp. 3–28). Heidelberg New York Dordrecht London: Springer International.

Gentner, D., & Gentner, D. R. (1982). *Flowing waters or teeming crowds: Mental models of electricity* (No. BBN-4981). Cambridge, MA: Bolt Beranek and Newman.

Gericke, N., & Hagberg, M. (2010). Conceptual incoherence as a result of the use of multiple historical models in school textbooks. *Research in Science Education*, *40*(4), 605–623.

Gibbons, P. (2003). Mediating language learning: Teacher interactions with ESL students in a content-based classroom. *Tesol Quarterly*, *37*(2), 247–273.

Gibson, J. (1979). *The ecological approach to visual perception*. Boston, MA: Houghton Mifflin.

Gilbert, J. K., & Boulter, C. (Eds.). (2000). *Developing models in science education*. Dordrecht: Springer Science & Business Media.

Hamza, K. M. (2013). Distractions in the school science laboratory. *Research in Science Education*, *43*(4), 1477–1499.

Hubber, P., Tytler, R., & Haslam, F. (2010). Teaching and learning about force with a representational focus: Pedagogy and teacher change. *Research in Science Education*, *40*(1), 5–28.

Jakobson, B., & Wickman, P.-O. (2015). What difference does art make in science? A comparative study of meaning-making at elementary school. *Interchange*, *46*(4), 323–343.

Johansson, A.-M. & Wickman, P.-O. (2011). A pragmatist approach to learning progressions. In B. Hudson & M. A. Meyer (Eds.) *Beyond fragmentation: Didactics, learning, and teaching* (pp. 47–59). Leverkusen: Barbara Budrich.

Knippels, M. (2002). *Coping with the abstract and complex nature of genetics in biology education: The yo-yo learning and teaching strategy*. Utrecht: CD-B Press, University of Utrecht.

Kress, G., Jewitt, C., Ogborn, J., & Tsatserelis, C. (2001). *Multimodal teaching and learning: The rhetorics of the science classroom*. London: Continuum.

Kress, G., & Van Leeuwen, T. (2001). *Multimodal discourse. The modes and media of contemporary communication*. London: Arnold.

Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago: University of Chicago Press.

Latour, B. (1986). Visualization and cognition: Drawing things together. *Knowledge and Society*, *6*, 1–40.

Lehrer, R., & Schauble, L. (2012). Seeding evolutionary thinking by engaging children in modeling its foundations. *Science Education*, *96*(4), 701–724.

Lemke, J. (1990). *Talking science: Language, learning and values*. Norwood, NJ: Alex Publishing Corporation.

Lemke, J. (1998). Multiplying meaning. Visual and verbal semiotics in scientific contexts. In J. R. Martin & R. Veel (Eds.), *Reading science, critical and functional perspectives on discourses of science* (pp. 87–113). London: Routledge.

Norman, D. (1999). Affordances, conventions and design. *Interactions*, *6*(3), 38–43.

Ogborn, J., Kress, G., Martins, I., & McGillicuddy, K. (1996). *Explaining science in the classroom*. Buckingham: Open University Press.

Olander, C. (2010). *Towards an inter-language of biological evolution: Exploring students' talk and writings as an arena for sense-making*. Gothenburg: Acta Universitatis Gothoburgensis.

Olander, C., & Ingerman, Å. (2011). Towards an inter-language of talking science: Exploring students' argumentation in relation to authentic language. *Journal of Biological Education*, *45*(3), 158–164.

Olin, A., & Ingerman, Å. (2016). Features of an emerging practice and professional development in a science teacher team collaboration with a researcher team. *Journal of Science Teacher Education*, *27*(6), 607–624.

Osborne, J. (2014). Teaching scientific practices: Meeting the challenge of change. *Journal of Science Teacher Education*, *25*(2), 177–196.

Peirce, G. S. (1878/1960). How to make our ideas clear. In M. R. Konvitz & G. Kennedy (Eds.), *The American pragmatists* (pp. 99–118). Chicago, IL: Meridian Books.

Prain, W., & Tytler, R. (2012). Learning through constructing representations in science: A framework of representational construction affordances. *International Journal of Science Education*, *34* (17), 2751–2773.

Prain, W., & Tytler, R. (2013). Representing and learning in science. In R. Tytler, P. Hubber, & B. Waldrip (Eds.), *Constructing representations to learn science* (pp. 1–14). Rotterdam/Boston/Taipei: Sense.

Pramling, N. (2009). The role of metaphor in Darwin and the implications for teaching evolution. *Science Education*, *93*(3), 535–547.

Rogoff, B. (1995). Observing sociocultrual activity on three planes: Participatory appropriation, guided participation, and apprenticeship. In J. V. Wertsch & A. Alvarez (Eds.), *Sociocultural studies of mind* (pp. 139–164). Cambridge: Cambridge University Press.

Schwendimann, B. A., & Linn, M. C. (2015). Comparing two forms of concept map critique activities to facilitate knowledge integration processes in evolution education. *Journal of Research in Science Teaching*. doi:10.1002/tea.21244

Shulman, L. S. (1986). Those who understand: Knowledge growth in teaching. *Educational researcher*, *15*(2), 4–14.

Talanquer, V. (2011). Macro, submicro, and symbolic: The many faces of the chemistry 'triplet'. *International Journal of Science Education*, *33*(2), 179–195.

Tobin, K. (2006). Why do science teachers teach the way they do and how can they improve practice? In P.J. Aubusson, A.G: Harrison, & S.M. Ritchie (Eds.), *Metaphor and analogy in science education* (pp. 155–164). Dordrecht: Springer Netherlands.

Treagust, D., & Tsui, C. (2014). General instructional methods and strategies. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research in science education* (pp. 303–320). New York: Routledge.

Tytler, R., Prain, V., Hubber, P., & Waldrip, B. (2013). *Constructing representations to learn in science*. Rotterdam/Boston/Taipei : Springer Science & Business Media.

Vygotsky, L. (1978). *Mind in society*. Cambridge, MA: Harvard University Press.

Vygotsky, L. (1986). *Thought and language*. Cambridge: MIT Press.

Waldrip, B., & Prain, V. (2013). Teachers' initial response to a representational focus. In R. Tytler, P. Hubber, & B. Waldrip (Eds.), *Constructing representations to learn science* (pp. 15–30). Rotterdam/Boston/Taipei : Sense.

Wertsch, J. (1998). *Mind as action*. Oxford: Oxford University Press.

Wertsch, J. V. (1995). Sociocultural research in the copyright age. *Culture & Psychology*, *1*(1), 81–102.

Wickman, P.-O. (2006). *Aesthetic experience in science education: Learning and meaning-making as situated talk and action*. Mahwah, New Jersey: Lawrence Erlbaum Associates.

Wickman, P.-O. (2014). Teaching learning progressions: An international perspective. In N. G. Lederman & S. K. Abell (Eds.), *Handbook of research in science education* (pp. 145–163). New York: Routledge.