Representing Change Using Concept Maps

Meena Kharatmal* & Nagarjuna G.**
Homi Bhabha Centre for Science Education, TIFR, Mumbai, India
*meena@hbcse.tifr.res.in,**nagarjuna@hbcse.tifr.res.in

While concept maps have been quite extensively used to represent static descriptions, it has not been used for its full potential for representing changes or processes. We propose a template and a limited set of linking phrases for representing change, with partial amendments in the concept mapping technique and the CmapTools. Usually, a process is represented in a object-centric manner specifying the object's role in it. In this proposal, we suggest a process-centric strategy with certain heuristics for representing processes. Considering the view that a process is a name to a change of state of an object involving time, sequence, causes, we make necessary proposals to the vocabulary and the form of representing a process. We end with a discussion on implications of this proposal to science education and concept mapping in general.

Rationale

It may not be a hyperbole to say that most important breakthroughs happened in the history of science when scientists found a way of representing the changes or cracking the mechanisms of how things change. The study of *motion, chemical change, circulation, evolution, plate-tectonics* are a few examples of phenomena that have led to breakthroughs in science. Rom Harré (1970) emphasizes this point and said that we do not seek explanations unless there is a change – "*we are not required to explain the fact that something remains the same; only if there is a change is an explanation called for*" (p. 248). Change is therefore an important subject of study in science and in philosophy.

Change in science is studied in terms of change in the state of an object. In chemistry, a chemical equation represents reactants as the prior-state on the left hand side and products as the post-state on the right hand side of an equation. Similar method is introduced by Feynman to represent state transitions in quantum electrodynamics (QED). From the above instances, it is indicative that processes are depicted as state-change model of representation. In biological systems, processes get richer with respect to time, sequence, concurrence, cyclicicity or reversibility. Describing processes in the linear form of text is usually supplemented by diagrams. However, even diagrams also miss out the dynamic aspect of processes. A more prevalent form of graphic representation, such as concept maps packaged with comprehensive, consistent conventions can be effective in representing processes. The objective of this communication is to propose a method for representing change using concept maps by bringing in the existing wisdom.

Our research is informed by the tradition of representing processes in knowledge representation (Dori, 2002, Sowa, 2003) and philosophy (Davidson, 1980, von Wright, 1963). von Wright (1963) proposed a schematic representation of sentences that describe events as – *pTq*, where *p* is initial state of affairs, *q* is end state of affairs, and *T* is the transformation. The states of affairs were considered to be *'features'* of the worlds. The features in von Wright's model is similar to attributes in the knowledge representation model. In Sowa's model of process representation (2003), processes are described as *"evolving sequence of states and events"* occurring in time and are classified into discrete and continuous. According to Sowa, events as opposed to processes, are those changes that occur in discrete steps interspersed with inactive states. He draws a conceptual graph (CG) of the example *'Brutus stabbed Ceasar'* (p. 208) by making the properties of the object more explicit during the process of *stabbing.* Using the CG the process is depicted as *'Brutus stabbed Caesar violently with a shiny knife'* where the '*agent', 'instrument', 'manner', 'attribute', 'time'* etc. are all marked explicitly in the map. Such graphs were used in biology for eliciting students' knowledge structure (Gordon, 1996). In the study, the CG depicts nodes in the form of *concept name, state, event, style, goal, action,* with relations as *'is-a', 'implies', 'property',* and *'consequence'.*

In another proposal for representing processes, Dori (2002) proposes the *Object Process Methodology* (OPM) wherein the process is depicted as change in the state of an object. The three entities in OPM – *objects, processes, states* are building blocks, wherein objects exist, process transforms objects, and states are used to describe the objects. Following the OPM, the process of *melting* is depicted as change in the state of water from ice to liquid whereas in the process of *freezing* the change is depicted as change in the state of water from liquid to ice. In science education, some researchers consider static relations as describing, defining, and organizing knowledge, whereas dynamic relations as those that *"establish implication, functional interdependence and covariation among concepts"* (Derbentseva, Safayeni & Canas, 2006). While Miller and Canas (2008), consider propositions involving physical movement, action, change of state, causal relationship to be of dynamic form.

Concept mapping methodology has been a most influential and widely used tool to represent knowledge that depicts knowledge using concepts and linking words (Novak & Gowin, 1984). It is widely used in research for eliciting, depicting knowledge structure, as a diagnostic tool for students' understanding, misconceptions, in tracing conceptual change, being considered to be facilitating in meaningful learning (Mintzes, Wandersee & Novak, 1997, 1998). However, it has been explicated by Canas and Novak (2006), that although concept mapping tool is used almost worldwide, it is not being used up to its full potential. It has been mostly used for depicting descriptions and so far has not been used in probing for explanation based conceptions, depicting change or thinking about dynamic systems in which objects change over time (Canas & Novak, 2006). One of the reasons being projected was that the focus questions are more description based rather than explanation based. It is also reported that the concept maps have a strong advantage of representing static relations between concepts, but the methodology lacks the potential for representing change or dynamic relations (Derbentseva, Safayeni and Canas, 2004). This certainly calls for re-thinking about the method in order to utilize the concept mapping methodology to its full potential.

As far as the the structure of concept maps is concerned, it has been argued that the structure itself could be one of the reasons that the maps depict more of fact based knowledge rather than explanation based knowledge. It was suggested that concept maps with cyclic structure, which allows concepts to be linked in loops with one input and one output, would be more suited to construct explanatory maps and lead to thinking about dynamic systems, whereas concept maps with hierarchical structure would be creating more of fact based knowledge (Derbentseva, Safayeni and Canas, 2004). One of the hypotheses is that if the concept term is expressed with an attribution such as "number of cars", "color of cars" instead of just "cars" then it can as well lead to increase in thinking about propositions that express dynamic structure (Derbentseva, Safayeni & Canas, 2006). Further, they reported about two strategies wherein they encouraged learners to construct dynamic relations by changing the way a focus question is put forth, as in *"number of cars" instead of "cars"; "how do plants grow?"* instead of *"what are plants"*. These researchers suggested that this strategy triggered learners to think dynamically and construct maps with more quantifiers like quality, quantity, (Derbentseva, Safayeni & Canas, 2006) as in "*quality of soil", "quantity of soil"* instead of just *"soil"*. Later it was substantiated by findings from a study conducted by Miller and Canas (2008), suggesting that posing dynamic focus questions leads to depicting dynamic propositions. The open dynamic focus questions were of kind *"why do birds migrate?", "how do airplanes fly?"* i.e. posing more of *how* questions than *what* questions.

In our review of instances where concept mapping is used in science education, we find that both fact based (static) or inquiry based (causes, change, process, dynamic) expressions are depicted more like a description. In a sentence representing a fact, the proposition expresses a state of affairs for e.g. "*a bottle is on the table"*; "*cell consists of mitochondria"*. Whereas in sentences representing dynamic systems, the propositions expresses a process or set of events, or sequence that involves *change* over time e.g. "*chromatin undergoes condensation"*. The proposition, *"chromatin undergoes condensation"* is object-centric since *'condensation'* is not the focus of attention. However, how this change actually happens to chromatin: what is the prior-state and the post-state of chromatin is also amenable for concept mapping. Even in currently growing field of Biomedical Ontology some authors continue to use object-centric Aristotelian property names such as function, disposition, role, tendency etc. (Arp & Smith, 2008). Considering these known issues, we propose a framework for mapping changes holding to a process-centric view.

Concept maps for Mapping *Change*

Learning from the existing experience of representing processes, influenced from the representation of events, processes, states discussed in science, philosophy and knowledge representation, we propose the following vocabulary and the method for process representation using concept maps. We discuss the method with illustrating examples of mitotic cell division (prophase stage) and few other life processes.

- ***Structure term:*** An object or a system that is undergoing change, for example, *chromatin, cell,* etc.
- ***Process term:*** A term that depicts any change of an object, for example, *boiling, fragmentation, condensation, raining, respiration, pumping of blood, assimilation, growth*, etc.
- ***State of an object:*** We consider the state of an object as the properties of an object at a given time. The properties include the *attributes* and the *relations* of the given object. For instance, during prophase stage of mitosis, the process of *chromatin condensation* can be shown as change in attributes of the object in this case, chromatin. The state of chromatin changes from *long, thin* and it becomes *short,*

dense. A state of an object can also be depicted as relations at a given time, such as *'has location', 'covered by', 'attached to'*, etc. During metaphase stage, the alignment of chromosome is merely a change in the location and is depicted as '*chromosome has location towards the pole of the cell*' and towards the end of the metaphase state, the '*chromosome has location towards the center of the cell*'.

- ***Prior-state and post-state:*** As the term depicts, prior-state is the description of the object before undergoing a process, and post-state is the description of the object after undergoing a process. As stated in the above example, the prior-state of chromatin is that it is *long, thin* and the post-state of chromatin is that it is *dense, short.* Similarly the prior-state of location of chromosome is *towards pole* and in post-state it is at the *center of the cell.*
- ***Linking phrases for linking states and process*****:** The recommended linking phrases to link two states can be – *becomes, changes to (transforms into, converts into), moves to,* whereas the linking phrases suggested for linking two or more processes can be – *has sub-process, occurs simultaneously, followed by, causes/results in, etc.*

A process term is linked with either a structure term or a process term. If a structure term is linked to a process term, we use the linking phrase – *has role in.* If a process term is linked to a process term we use an appropriate linking phrase e.g. – *has sub-process.* If several processes occurs at the same time then we could use – *occurs simultaneously.* When the sequential or cyclical processes are involved, then we use --- *followed by*. Another prominent form of linking phrase – *causes (has effect/results in)* is used to connect the causal relations in the process. As in most of the processes the change that occurs in the form of state-transformations or state-changes, we depict these with the linking phrase – *becomes*, and wherever applicable if the process undergoes a change in location of the object, it is depicted with the linking phrase – *changes to.*

Given this enriched vocabulary of linking phrases, we can represent the dynamic relations i.e. processes depicting – *sequence, movement, transformation, cause-effect,* etc. Figure 1 shows a process-centric framework for mapping processes applying certain heuristics. In the next section, the proposed framework is illustrated with examples of processes from biology.

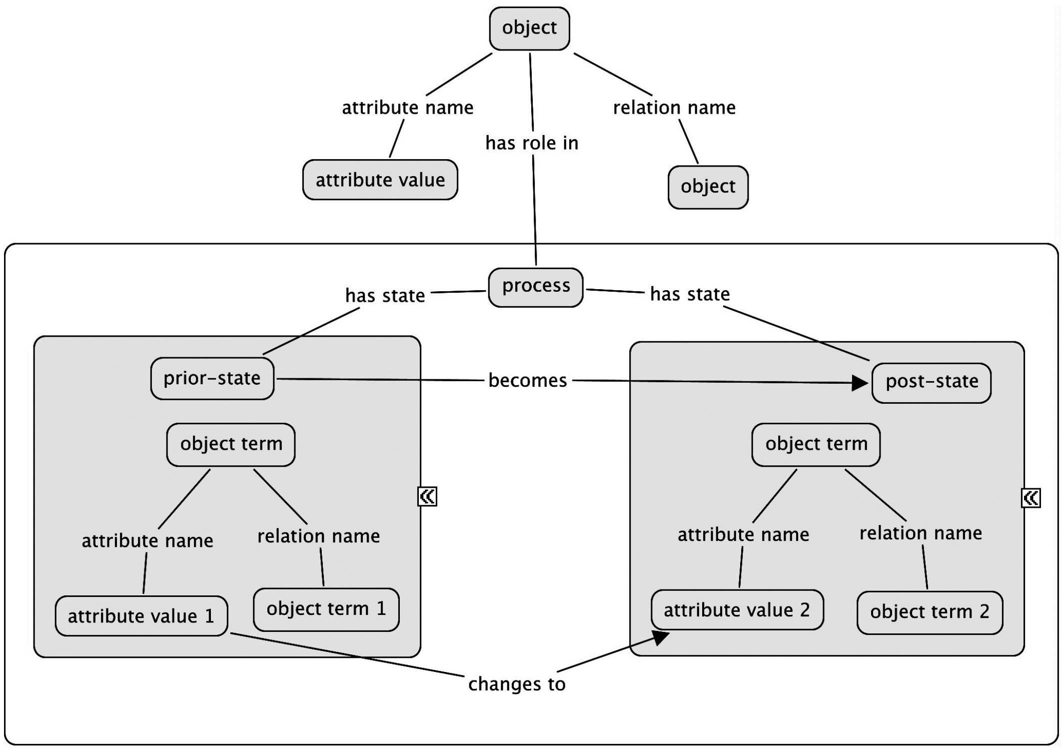

Figure 1. A template for process representation.

Illustrations

We illustrate the suggested mapping of processes taking examples from biology. We take a passage explaining the prophase stage from DeRobertis & DeRobertis (1987, p. 420). We present a regular concept map of this passage and then map the same passage using the proposed process representation framework to make the proposal explicit.

The beginning of prophase is indicated by the appearance of the chromosomes as thin threads insi*de the nucleus. In fact, the word "mitosis" (Gr., mitos, t*hread) is an expression of this phenomenon, which becomes more evident as the chromosomes start to condense. The condensation occurs by a process of folding of the chromatin fibers. At the same time, the cell becomes spheroid, more refractile, and viscous.

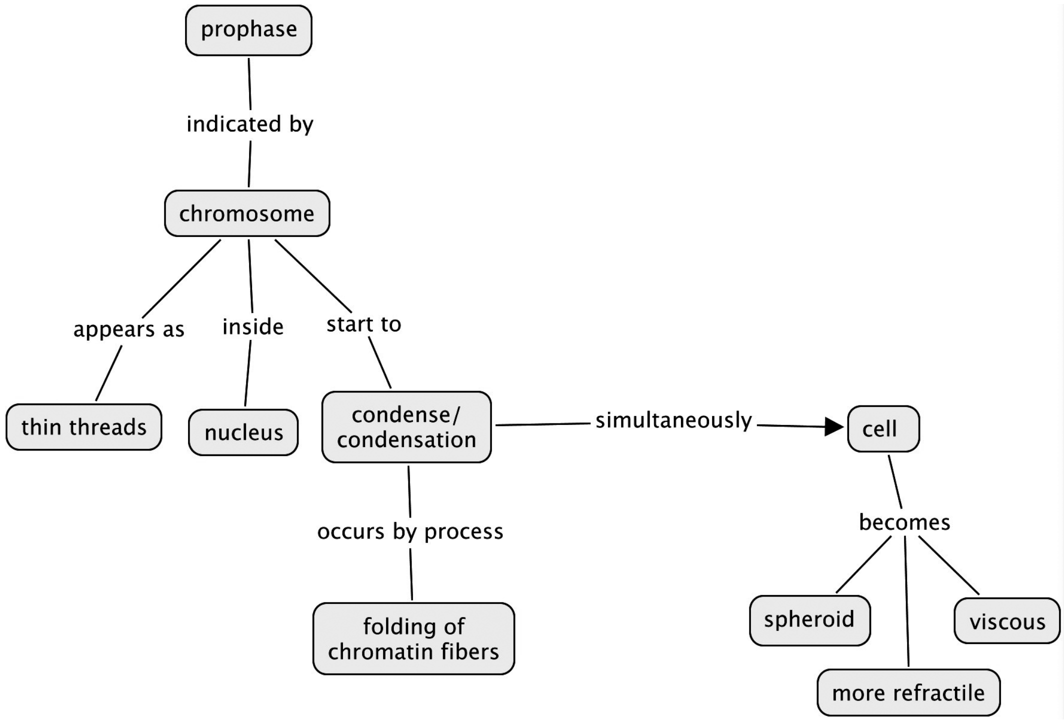

Figure 2. A process depicted using regular concept mapping method.

In the map shown in figure 2, the processes mentioned are *condensation, folding of chromatin fibers, changes in cell*. As we can see that these processes are just mentioned as process terms, and there is no explanation about what actually happens to chromatin during *chromatin condensation, folding of chromatin fibers*. Similarly, if there are certain changes in the cell, then one cannot know what was the earlier state of the cell. If a process alters an object, then it certainly requires that the change needs to be represented.

Our proposed framework suggests using the potential of *"nested nodes"* feature of the *CmapTools* (http://cmap.ihmc.us). Figure 3 shows the same passage depicted using the state change approach. The explanation of processes --- *chromosome condensation* (including *chromatin folding, shortening of chromatid*), *changes in cell* are shown. The process *chromatin condensation* has two sub-processes, one is *chromatin folding* and the other is *shortening of chromatid.* These two sub-processes provides explanation that the prior state of chromatin is that it is *less folded* and *longer in length* and it becomes *more folded* and *shorter*. When these change in state occurs in the chromatin only then we can say that *chromatin condensation* has occurred. Simultaneously with this process, the cell also undergoes changes in terms of becoming *spheroid, more refractile, more viscous*. When we compare both figures 2 and 3, we can see that the later adds more details in terms of providing explanations of "*how changes occurs*", and depicts the process in terms of change in the state of object. Moreover, while mapping the process using the process-centric framework, the implicit knowledge becomes more explicit, thereby bringing in more clarity.

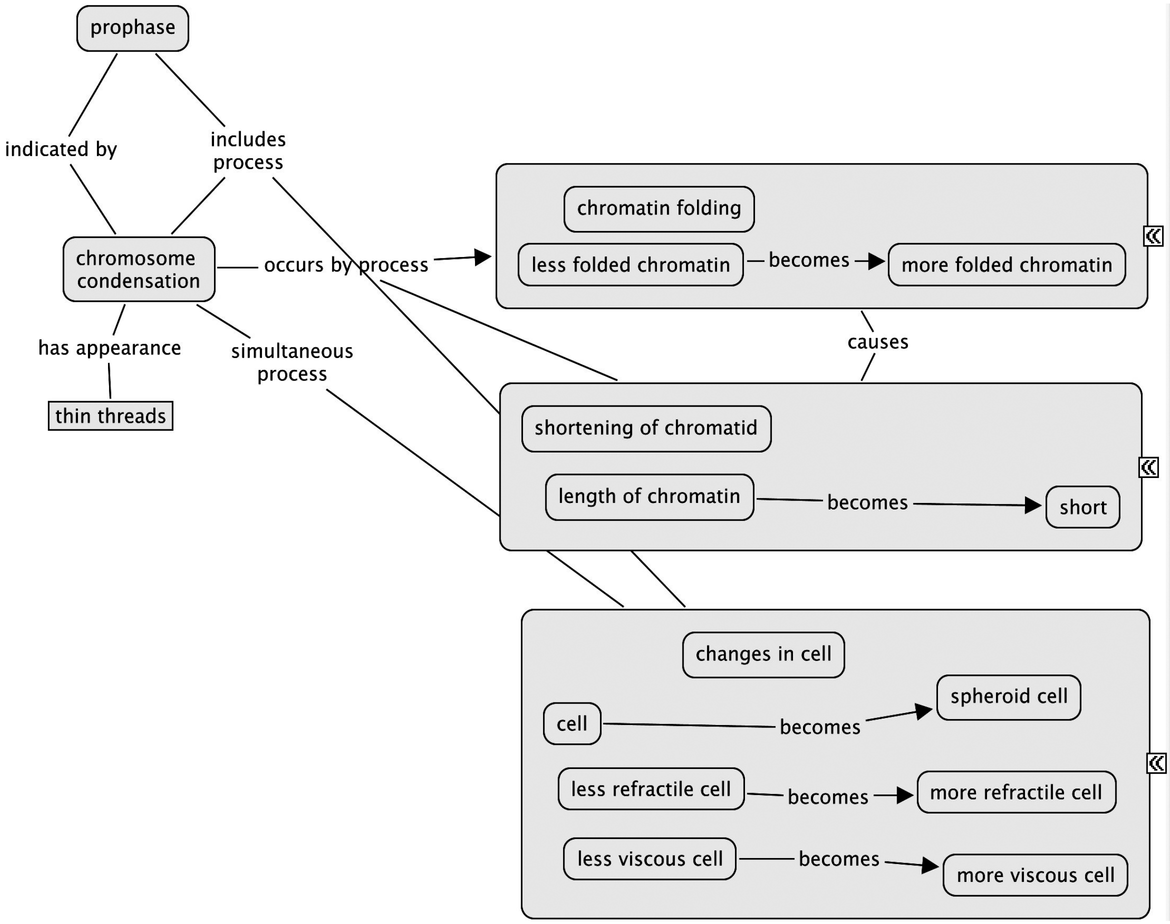

Figure 3. Process representation from an excerpt of the text on prophase. The rectangles holding submap are created using *"nested nodes"* feature of *CmapTools*.

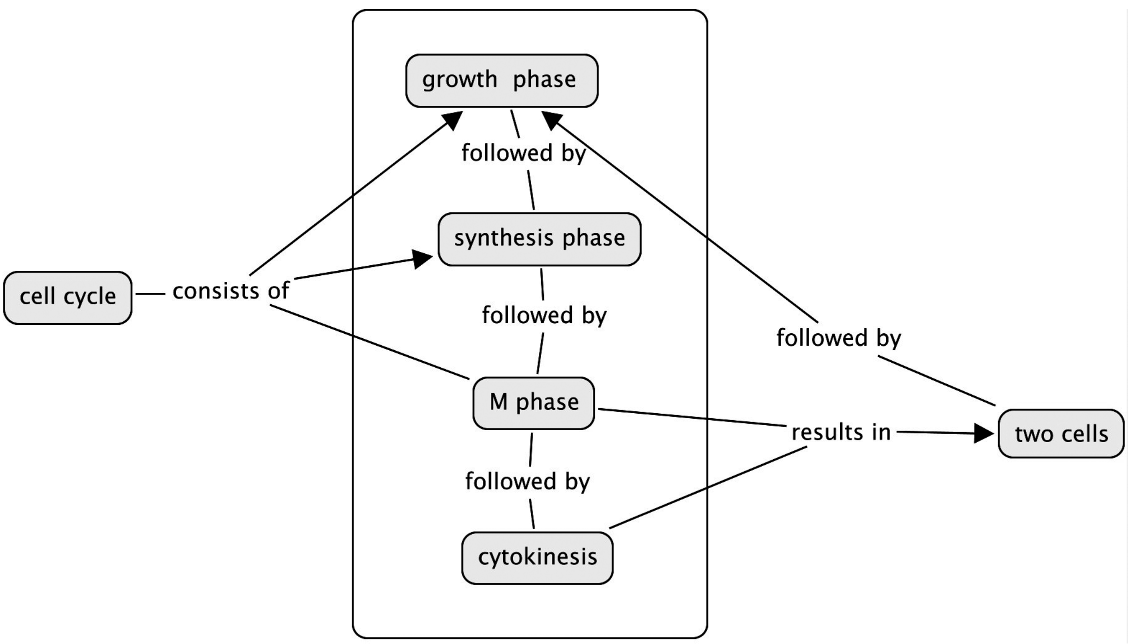

Figure 4. Map depicting sequence and cyclic process.

Applying the above illustrated method, we can now represent various other forms of processes --- *process-subprocess, transformation, sequence, cause-effect* and provide with some examples of life processes.

Sequence

Often we need to represent a sequence of events for depicting cycles, etc. We propose the use of linking phrase -- *followed by* – to depict processes involving sequences as shown in figure 4. In this examples, the various phases of *cell cycle* are depicted.

Cause-effect

As is well known causation has been one of the central idea in science. For processes related to cause and effect, we propose the linking phrase – *cause of / results in.* Another example from basic physiology book from a school is represented using the proposed framework in figure 5.

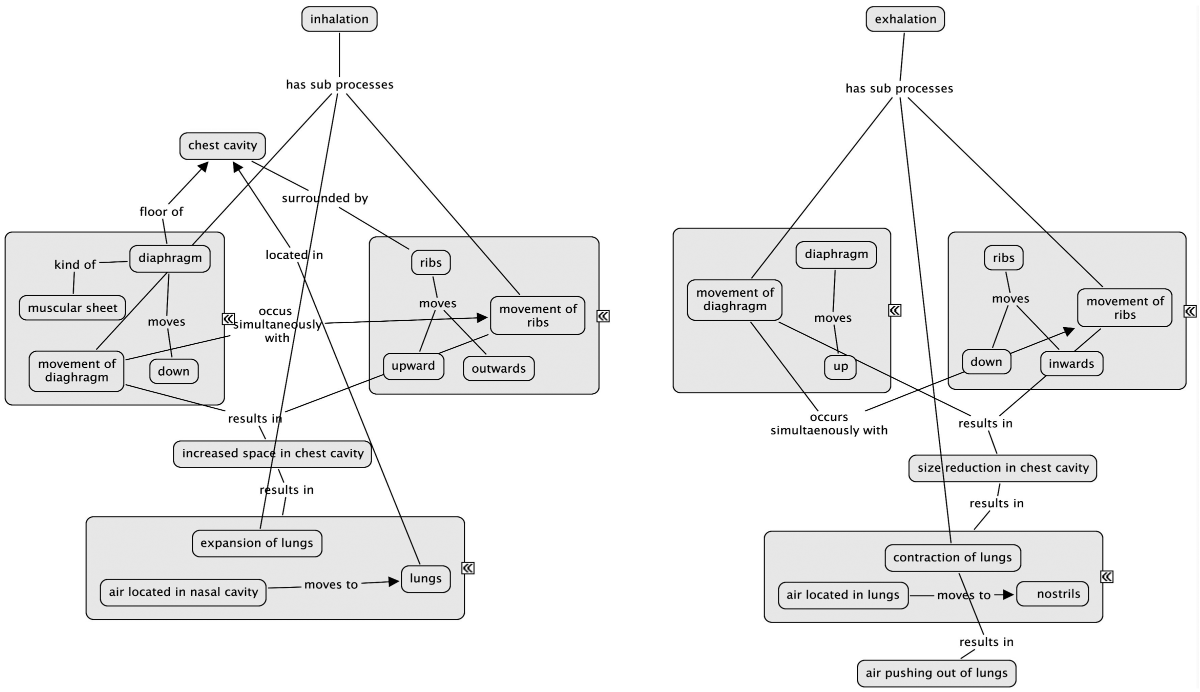

Figure 5. Process depicting cause-effect in inhalation and exhalation.

Discussion and Implications

Though the representation principles used are not novel, the steps suggested are important in the context of science education. As mentioned in the introduction, the science students are required to appreciate the detailed studies of changes. If the representation methods used explicitly seeks their attention to the properties that change over time, it leads to an enculturation of scientific style of thinking. Although, representing of states, processes and events occurring in time is considered to be important strand in knowledge representation (KR), more specifically in philosophy and linguistics (Galton, 2009), this is not explicitly addressed in science education. Within the concept mapping literature, e.g., Kharatmal and Nagarjuna (2011) have provided a list of linking phrases that can be used to represent cell biology domain. However, those linking phrases are mostly used for representing object-centric descriptions. We envision that with the suggested additional linking phrases for process mapping, concept mapping can become a richer tool for science education to bring in clarity and rigor as suggested by Kharatmal & Nagarjuna (2006, 2008). Though we have illustrated the proposal by taking examples from biological phenomenon, other processes like chemical change, ecological change, biochemical pathways, can also be represented. The assumption that concept mapping helps in making meaning explicit is well known (Mintzes, Wandersee and Novak, 1997). Re-representing text in the form of concept maps is an efficient method of making implicit knowledge more explicit. This approach to education is in line with the *Representational Redescription* theory of learning proposed by Karmiloff-Smith (1995).

Another strong point of the suggested approach to process representation is to prepare learners towards quantitative thinking. Since changes often involve a change in measurable dimensions, such as change in *number, position, dimensions, density, temperature, volume* etc., the process nominalization required for quantitative reasoning becomes apparent in this re-representation (Halliday, 2006). Halliday (2006) describes that the hallmark of scientific language is to nominalize processes so as to make them the focus of study. Therefore, we think this style of concept mapping for mapping processes can be encouraged in science education at secondary, undergraduate level. The change in knowledge that occurs while learning (ontogeny) and the conceptual changes (Thagard, 1992) in the evolution of scientific ideas (phylogeny) can also be represented using the same method.

It is to be noted that the process-centric framework applies certain heuristics. The process-centric strategy is just a thought regulating strategy representing process or change. It offers a way of having a check-list and serves as a template (non-exhaustive) when modulating thinking about processes. As the process-centric strategy is build over the prevailing concept mapping method, we think that learners would easily be able to understand the strategy and build their representation on the existing method. It is required that empirical studies should be conducted to study the efficacy and validity of the proposal. Of course the method as such can be done with paper and pencil as well. Considering that the CmapTools already has the support for nesting submaps, the proposal can be tried out in different contexts where processes are the focus of study.

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