Tracing knowledge re-organization - a fine grain analytical framework for looking at students' developing explanations

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Abstract: This paper presents an analytical framework for tracing knowledge re-organization through self-generating explanations and representations. The analytical framework, inspired by the knowledge in pieces perspective (diSessa, 1993), is applied on one case study, to illustrate the type of insight the framework could provide. The scientific domain explained by the students in the case study is the phases of the moon. Pairs of students (5th grade/11 year old) met for an hour and a half to generate and elaborate paper and pencil representations in order to explain and develop their understanding of the cause for the phases of the moon. The analysis traces the development of their explanations as an indication of their developing understanding, by tracing the re-organization of knowledge pieces throughout the process.

Theoretical and methodological approach

This paper presents an analytical framework for tracing knowledge re-organization through the process of self-generating explanations and representations. The analytical framework is based on the knowledge in pieces perspective (diSessa, 1993). The analytical framework is presented using a case study in which two students develop their explanations and representations regarding the phases of the moon. The focus on one motivating case study is used as an opportunity to look into some contentious issues of conceptual change.

Conceptual change is an established research field in which numerous theories exist (e.g., Carey, 1999; Nersessian, 1989; Strike & Posner, 1990; Vosniadou & Brewer, 1992; Wiser, 1988; diSessa, 1993), concerning what students know (specifically about "deep and difficult" topics), how that changes over time, and how to mediate that change. Within the field, there are critical disagreements (diSessa, 2006). One of the critical centers of dispute is the question of the fundamental attributes of the nature of students' intuitive knowledge and how it changes and develops into scientific knowledge.

Some researchers (e.g., Strike & Posner, 1990; Nersessian, 1989; Wiser, 1988) draw parallels between individual's conceptual change and scientific revolutions (Kuhn, 1962). For example, Strike & Posner (1990) argue that students' concepts change from one set of concepts to another, incompatible with the first. Similar to scientific revolutions, what needs to be changed during the process of conceptual change, are some central commitments. Vosniadou & Brewer (1992) maintain that students' knowledge is organized in the form of coherent models and that conceptual change involves a shift from one model to another due to the reinterpretations of the presuppositions that gave rise to the initial models. A considerable part of science and mathematics education research refers to student knowledge in terms of "conceptions" (e.g., misconceptions, preconceptions, or alternative conceptions) that students have about particular concepts. Preconceptions are known to be robust, intact elements of cognitive structure, and demonstrate resistance to instruction. The misconception movement pays little attention to students' productive ideas and the continuities between what students already know and what they need to understand.

The "knowledge in Pieces" theory (diSessa, 1993) suggests a somewhat distinct view on intuitive knowledge and conceptual change. The name "knowledge in pieces" (KiP) suggests an underlying epistemological commitment that knowledge is constituted by a multiplicity of diverse pieces, rather than being a coherent system (e.g., theory-like). Smith, diSessa & Roschelle (1993) provide a constructivist view of learning in which students' ideas play productive rather than destructive roles in the acquisition of expertise, and that the process of conceptual change is a process of reorganization (rather than replacement) in which existing pieces of knowledge are modified in terms of the contexts in which they are activated and used.

The analytical framework presented in this paper, espousing the KiP perspective, provides means for tracing the reorganization of intuitive knowledge elements using a moment-by-moment approach, and demonstrates their productiveness in a more advanced state of understanding. A sample analysis of parts of the case study is presented in order to provide the gist of the way the framework is applied. A detailed analysis is presented in Parnafes (in review).

The scientific domain – the phases of the moon

Research on students' understanding of the phases of the moon agree that students have difficulties understanding the cause of this phenomenon, and that they usually give a range of alternative explanations (e.g., Sadler, 1987; Baxter, 1989; Barnett & Morran, 2002; Hansen & Barnett, 2004; Kavanagh, Agan & Sneider, 2005; Trundle, Atwood & Christopher, 2007). The literature documents a range of students' alternative conceptions that include the following: The phases of the moon occur due to clouds covering parts of the moon; due to a shadow cast on the moon by the earth; due to a shadow cast on the moon by other planets (Baxter, 1989); or due to a viewer's geographic position on earth, and the supposition that people in different geographic locations see different moon phases (Schoon, 1992; Trundle, Atwood & Christopher, 2007). These alternative conceptions are considered to be fairly robust, hard to change by instruction, and persistent, many times until adulthood (Barnett & Morran, 2002; Baxter, 1989; Trundle, Atwood & Christopher, 2007).

The scientific explanation for the phases of the moon is that half of the moon is illuminated by the sun, and the portion of the illuminated half seen from earth varies as the moon revolves around the earth (Figure 1).

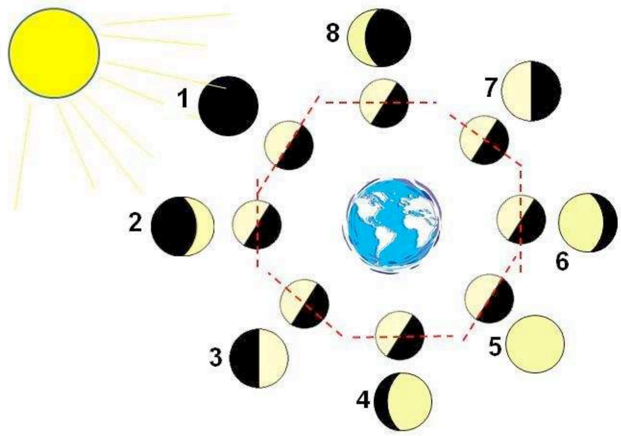


Figure 1 - The phases of the moon (The internal circle of moons represents the different locations of the moon, illuminated by the sun in the same way throughout the month. The dashed lines show which part of the moon is seen from earth at each location. The external circle of moons represents the way in which the moon is seen from earth in different locations)

A fair amount of the existing research concerns the classification of students' conceptions about the phases of the moon, and looks at trends of development following specific kinds of instructional interventions, or examines differences among different age groups. A common practice for studying trends of development is developing codes for students' conceptual understanding, and then classifying students' responses based on the type of understanding the codes collectively reflected (e.g., Callison & Wright, 1993; Barnett & Morran, 2002; Trundle, Atwood & Christopher 2007). This paper suggests going beyond this grain level and describing the structure of knowledge and the way it changes in a finer grain level. Taking a finer grain approach means keeping track of more diverse and low level elements rather than a rough unit such as a misconception, and examining how they change on small time-scales. At the fine grain size the "transformation" of a misconception into a scientific conception can be modeled and traced in detail, and in that provide useful instructional implications.

Methods

Data Collection

The study presented in this paper is based on observations of pairs of 11 year old (5th grade) students, as they generate representations and explanations and elaborate them while trying to understand the cause for the phases of the moon. During the session, the researcher's role was mostly that of a participatory observer. In principle, interventions were kept to a minimum, and if made, they were made for the purpose of clarifying meanings, or asking challenging questions when the students seemed to be satisfied with their state of explanation. The session was videotaped and then digitized for further analysis, and students' representations were collected and scanned. The sessions lasted an hour and a half and included the following four parts:

1. *An introductory activity:* a brief conversation about what the phases of the moon are, and the model of rotations and revolutions of the earth, moon and sun.
2. *Personal representations:* the students are asked to draw some representations (diagrams or sketches) to explain the cause of the phases of the moon.
3. *Collaborative representations:* the students are asked to share their representations and to explain the cause of the phases of the moon to one another. Then, they co-construct a shared representation.
4. *Presentable representations:* the students are asked to produce a diagram that explains the cause for the phases of the moon to people that are not present in the activity. At this point, the students design a PowerPoint presentation.

Data analysis and analytical framework

The analytical framework relates students' explanations to their conceptual understanding by considering their explanations as the external performance made on the basis of their conceptual understanding. Their conceptual structure is therefore inferred from the examination of their explanations. The analytical framework describes students' conceptual structure, in the context of developing explanations, as containing (see Figure 2):

1. *An explanatory frame*: a hierarchical structure that provides the rationale for the explanations, consisting of finer grained knowledge pieces such as general schemes and models;
2. *Attended information:* pieces of information that students attend to when attempting to construct explanations. These pieces of information could have a high epistemological status. For example, students rarely argue with direct observations ("I saw the moon several times during the day, so I know it can be seen in daylight",) personal experience ("I know it is night in the US when it is day here, because we make phone calls to my uncle in NY"), an authoritative piece of evidence (facts! "I read it in a science book" or "the teacher told us that…"). Because these pieces of information frequently have a high epistemological status, they support the explanation and contribute to its persistence.

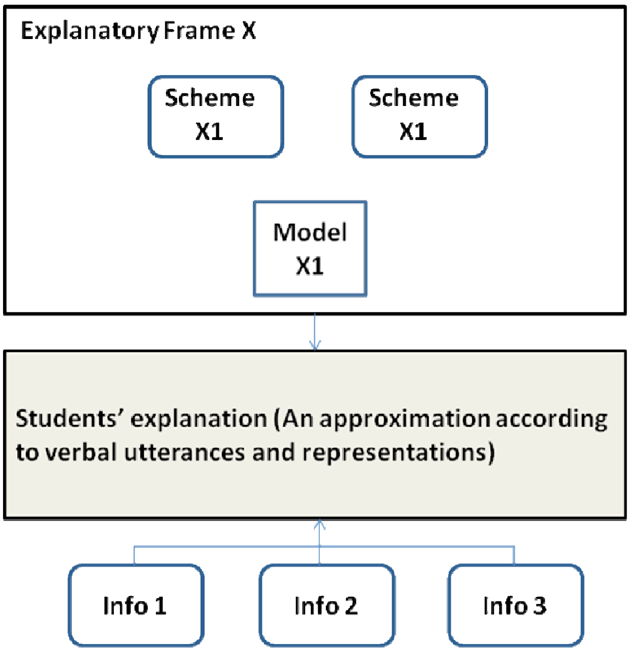


Figure 2 - A schematic diagram of knowledge pieces used in an explanation

An explanation is "satisfactory" when the explanatory frame, providing the rationale for the explanation, fits the attended information, or in other words, if these two components feel coherent (Thagard, 1997, Hammer, 2000) for the students at the moment.

A key element in the analysis is the movement from a "satisfactory" explanation to a "better" explanation. A "better" explanation is determined by the quality of coherence, which is characterized by its *resolution* and by its *range* (diSessa, personal communication). Resolution means the amount of available detail used in an explanation. Range means the part of the phenomenology covered by the explanation. In a sense, resolution provides the depth of the explanation and the range provides the breadth. The use of the framework in one case study is demonstrated in the following analysis.

Analysis and findings

Rose and Natalie explain the phases of the moon

The students in this study began the session having two different explanatory frames, which they tried to integrate with no success. When the researcher asked a specific question, she apparently provoked a higher resolution, which later on led to a co-construction of a new explanatory frame. A further elaboration of this frame led to a sophisticated explanation that is in line with the normative explanation.

Two different explanations for the phases of the moon

At the beginning of the session, after an introductory conversation, each student drew a representation in order to try and personally understand the cause for the phases of the moon (see Figure 3, Figure 4).

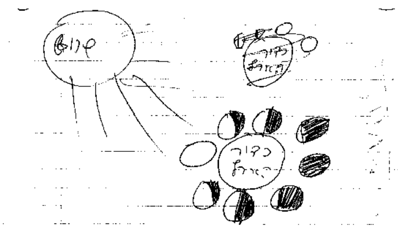


Figure 3 - Rose's representation

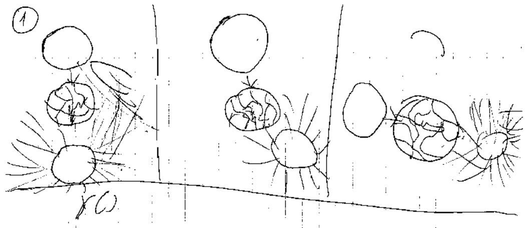
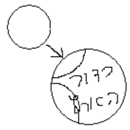


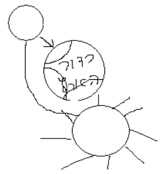
Figure 4 - Natalie's representation

When the students were asked to communicate their representations, Natalie focused on an observer's view who sees different parts of the moon when standing in different places on earth:

> …and in the first time, say, the moon is here *(Natalie draws the moon in front of the earth)*, and **only this part of the earth sees the moon** *(Natalie draws an arrow, and an arc on the earth, facing the moon)*, and **this part sees less** *(draws an arc on the side of the earth)*



> This part *(draws another arc on the other side of the earth)*, **this part doesn't see it at all, so in this part it's like there is day** *(Natalie draws the sun)*, **there s sun,**



Natalie explained that in different positions on earth, different parts of the moon can be seen, and integrated into this explanation, the consideration of day and night as experienced on earth.

Rose began generating her representation again, laying out her own explanation as she drew: in the dark phase, the earth blocks the sun rays, hence the moon does not get any light and it is dark:

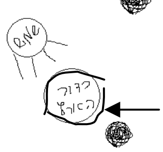
> *(Rose draws the sun and the earth) When the moon is here (draws one moon on the other sid the earth)*, **The earth entirely blocks the sun** *(darkens the moon)*, **and then the moon, like, doesn t get any light**

Rose's original representation looks quite like any standard textbook illustration of the phases of the moon: a sun shining on the moon and earth, with multiple moons drawn around the earth. It is likely that Rose was using a convention she'd seen before in a textbook. However, unlike in the textbook illustration, Rose drew the moon closest to the sun (location 1) as a full moon, and the one farthest from the sun (location 5) as a dark moon.

Rose was going to draw other moons around the earth to explain other phases, when Natalie stopped her, saying that Rose's drawing and explanation (so far) were exactly in the same as her explanation. Natalie indicated that, as in her explanation, the moon that Rose had just drawn is the "dark phase." However, while Rose referred to the dark phase as the occasion in which the earth casts a shadow on the moon, Natalie referred to this phase as the occasion in which the moon is not within the observer's field of view.

Natalie: So this is like…This is what I said, it's like the day, **we have sun on the entire earth almost,** *(illustrates with her pen the half circle of the earth facing the sun)*, almost, **and the moon, you can't see the moon**

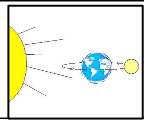
Except for this part *(illustrates the half circle facing the moon)*, and there…



Rose: No, it's like, **you cannot see the moon at all, it's dark** *(swiping her hand from the sun to the moon, showing that the earth blocks the sun light)*

Interpretation:
The last exchange marks a breakdown in the students' communication based on their two different explanatory frames. The discussion went on for a while, but they each remained within their framework. The following is an analysis of the organization of knowledge pieces that played out in each explanation.

Rose explains the phases within the "casting shadow" explanatory frame that provides the rationale for the explanation. A few schemes are included in this explanatory frame along with a model they operate with:

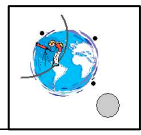
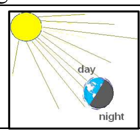
Explanatory Frame A	**"casting shadow"**
Scheme A1	Objects cast shadows in their shape on other objects
Scheme A2	The shadow cast on the obscure object is determined by the alignment of the source of light, the obscure object and the blocking object
Model A1	A moon revolving around the earth, illuminated by the sun 

The explanatory frame fits with two pieces of attended information, forming a "satisfactory" explanation:

Info 1	The moon looks different every day, varying gradually from an empty to a full moon
Info 2	A textbook illustration (similar to Figure 1)

The explanation is satisfactory in the sense that it forms low resolution coherence. The explanatory frame fits, to some extent, with the two pieces of information: the earth casts shadow on the moon differently when the moon is in different locations. Yet, Rose does not look at details such as the proportions of phases mapped to percent of shadowing. If she looked into the details of her explanation she would notice that the shadow which is presumably cast on the moon does not correspond to the phases she had drawn, to name one example.

Natalie bases her explanation on two explanatory frames. The first explanatory frame is the "occultation" frame, and the second is the "illumination" frame. A few general schemes construct each explanatory frame along with a model they operate with:

Explanatory Frame B	**"occultation"**
Scheme B1	Partial views of an object are occluded from the observer by obstructing objects.
Scheme B2	What is seen from a particular position is what is within the field of view
Scheme B3	Change in position entails change in the field of view
Model B1	The visibility of the moon from different locations on the earth 
Explanatory Frame C	**"illumination"**
Scheme C1	A source of light illuminates the part of an object facing it
Model C1	The sun as a source of light illuminating the earth 

The explanatory frame fits with four attended pieces of information:

Info 1	The moon looks different every day, varying gradually from an empty to a full moon
Info 3	Every day, is constructed of day time and night time
Info 4	When it is day time here, it is night time in countries on the other side of the earth
Info 5	The moon is usually seen at night

The two explanatory frames fit, to some extent, with the four pieces of information, and in that sense the explanation is satisfactory: different placement positions provide different occultation, and in Natalie's drawing, the moon is apparently seen at night and is obscured during the day. This shows low resolution coherence because Natalie attended to a very general aspect of the phenomenon and tried to account for it, but without getting down to the fine details of the phenomenon. For example, the occultation frame cannot account for the precise shapes of the moon seen throughout the month. In addition, it also shows narrow range coherence - the only one location selected for drawing the moon (location 5) happens to be the location where the moon is seen at night, which fits the pieces of information labeled no. 4 and no. 5. Other locations may challenge the coherence.

At this stage, neither of the students challenged their explanation by getting to a higher level of resolution or extending the range. Each student, presumably, judged her explanation as "satisfactory" in general. When interacting, each student reasoned about her peer's ideas using her own frame.

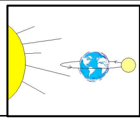
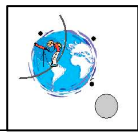
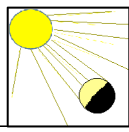
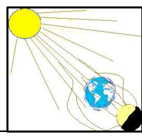
What happens when the moon is between the sun and the earth?

After a relatively long discussion in which each student explained her representation, the students were asked to produce a shared representation and collaboratively explain the phases of the moon. They made an honest attempt to integrate their explanations; however, they each still reasoned within their explanatory frame and the changes in their explanations were minor. The following instructional move set the stage to a major reorganization. The researcher added another moon to their drawing, between the sun and the earth (location 1), and asked them what is seen at this phase. This particular question was intended to promote further thought that may result in increasing the resolution of their explanations.

OP: **What is seen here?**

Rose immediately said: "When the moon is there, so, like, we see all of it. Right? Because the sun lights it." Her idea that a source of light could actually illuminate an object all around led to a deeper examination of how objects are illuminated exactly, and in particular, how the moon is illuminated in location 1. This discussion resulted in a reorganization of their explanatory frames. The students gradually developed the "combined illumination with point of view" frame, as they discussed the particular details of a specific location of the moon (increasing resolution) and later reasoned about various locations of the moon (increasing range). They kept refining the explanation to the point where a high resolution and a wide range of coherence were achieved, in which point their explanation resembled the scientific explanation. For a detailed analysis see Parnafes (in review).

Rose and Natalie ended the session with an approximately normative explanation of the phases of the moon, saying that half the moon is illuminated by the sun, and the portion of the illuminated half seen from earth varies as the moon revolves around the earth. Although there were still particular ideas that each of them emphasized, they shared this collaborative explanation for the most part. The "combined illumination with point of view" frame is constructed of a few general schemes along with a few models they operate with:

Explanatory Frame E	**"combined illumination with point of view"**
Scheme B2	What is seen from a particular position is what is within the field of view
Scheme B3	Change in position entails change in the field of view
Scheme C1	A source of light illuminates the part of an object facing it
Scheme E1	If the source of light is very big, relatively smaller objects will not cast shadows on other objects
Model A1	A moon revolving around the earth, illuminated by the sun 
Model B1	The visibility of the moon from different locations on the earth. 
Model E1	The sun as a source of light illuminating the moon 
Model E2	A big sun illuminates the earth and the moon 

Schemes B2, B3 and C1 were used in previous explanations, sometimes in different contexts, with different models. Scheme E1 is used to explain why there is no shadow on the moon in location 5.

The pieces of information attended by both Rose and Natalie, play an important role in the explanation, and they fit with the explanatory frame for the most part. Only one of these pieces of information begins to lose its status. The piece of information labeled no. 5, specifying that the moon is experienced only at night, is acknowledged as inaccurate and as presenting partial information. Natalie emphasized this when she reasoned about the moon in location 5. But as she moved on to think about other locations, she began to comment that the moon is sometimes seen also during the day.

Discussion

The analysis above was meant to demonstrate the kind of insight the presented analytical framework could bring to issues of conceptual change, and to potential instructional implications. Let us look at some of the issues.

It is still common within the science education community to believe that students' understanding involves alternative conceptions that are robust and are an obstacle for learning the scientific model. The two students in this study might be said to have "misconceptions." In fact, their initial explanations are documented in the literature as common misconceptions: 1. "the phases of the moon occur due to the shadow cast on the moon by the Earth" (e.g., Baxter, 1989); 2. "The different phases of the moon are seen from different parts of the Earth" (e.g., Schoon, 1992).

The above analysis demonstrates a more complicated model of students' understanding, built from finer-grained pieces of knowledge, whereas a configuration of these might appear, roughly, as a misconception. Breaking "misconceptions" into smaller elements, the way that is done in this analysis, suggests productive paths of development.

An important element of the analysis is tracing the knowledge pieces that play out in the explanation. What happens to them when the explanation develops? Are they being transformed? Eliminated? Replaced? It is striking that throughout the session there were not many new schemes used. Most of the schemes in the new explanatory frame E, have already been used in previous explanatory frames B, C and D, and are now re-used in new contexts and with new models. For example, the scheme of illumination (scheme C1), applied previously only on the sun-earth model to reason about the day and night, is now applied on the moon-earth model as well to infer how the moon is illuminated.

The significance of this observation lies in supporting the view that student's intuitive knowledge has continuity and productiveness through the process of conceptual change. It demonstrates that students' explanations are compiled from conceptual resources that are neither right nor wrong, although they may be applied appropriately, inappropriately, in composition with other such schemes or in isolation. The same schemes used in one explanatory frame can be re-configured to form a more adequate explanatory frame. In this sense, knowledge is reorganized (rather than replaced) in such a way that existing pieces are modified in terms of the contexts in which they are activated and used. This also means that students' intuitive pieces are also productive in some contexts and should serve as a basis for constructing scientific knowledge (Smith, diSessa & Roschelle, 1993). In addition to the productiveness of previously used schemes and models, previous explanatory frames may also be productive and useful for explaining other contexts. For example, the casting-shadow frame that is not useful for explaining the phases of the moon, can still be productive for explaining other contexts, e.g., eclipse phenomena. This is a process of shifting contexts, rather than knowledge replacement.

The analysis suggests some instructional implications. If students construct understandings that are composed of a cluster of schemes and models to form an explanatory frame that fits with other elements in their knowledge, they are most likely to respond to a provided "right explanation" by developing two explanations: "an explanation that makes sense" (may look like a "misconception") and "a school explanation" (written in exams with no understanding). The KiP approach suggests students' intuitive ideas should be engaged in order to facilitate continuity of understanding. Increasing resolution and increasing range is one example of a way to support this continuity. Such an approach engages both students' previously constructed knowledge structure, and their intuitive knowledge pieces.

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References

Barnett, M., & Morran, J. (2002). Addressing Children's Alternative Frameworks of the Moon's Phases and Eclipses, *International Journal of Science Education,* 24, 859.

Baxter, J. (1989). Children's understanding of familiar astronomical events, *International Journal of Science Education, 11*, 502.

Callison, P, L. & Wright, E, L. (1993) *The effect of teaching strategies models on Preservice elementary teachers' conceptions about Earth-Sun-Moon Relations.* Paper presented at the Annual meeting of the National Association for Research in Science Teaching, Atlanta.

Carey, S. (1999). Sources of conceptual change. In E. K. Scholnick, K. Nelson, S. A. Gelman & P. Miller (Eds.), *Conceptual development: Piaget's legacy* (pp. 293–326). Mahweh, NJ:

diSessa, A. A. (1993). Toward an epistemology of physics. *Cognition and Instruction, 10* (2–3), 105–225; responses to commentary, 261–280.

diSessa, A. A. (2006). A history of conceptual change research: Threads and fault lines. In K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 265-281). Cambridge, UK: Cambridge University Press.

Hammer, D. (2000). Student resources for learning introductory physics. *American Journal of Physics, Physics Education Research Supplement, 68* (S1), S52-S59

Kavanagh, C., Agan, L., and Sneider, C., 2005, Learning about Phases of the Moon and Eclipses: A Guide for Teachers and Curriculum Developers: *The Astronomy Education Review*, Volume 4, p. 19–52.

Kuhn, T. S. (1962/1996). *The Structure of Scientific Revolutions.* Third Edition. The University of Chicago Press, Chicago.

Parnafes, (in review). Developing understanding as reorganization of knowledge pieces – a case of students explaining the moon phases

Nersessian, N. J. (1989). Conceptual change in science and in science education. *Synthese 80*(1), 163–183.

Sadler, P. M. (1987). Misconceptions in astronomy. In *Proceedings of the Second International Seminar on Misconceptions and Educational Strategies in Science and Mathematics* (pp. 422–425). Ithaca, NY: Cornell University

Smith, J. P., diSessa, A. A., & Roschelle, J. (1993). Misconceptions reconceived: A constructivist analysis of knowledge in transition. *Journal of the Learning Sciences, 3*(2).

Strike, K. A. & Posner, G. J. (1990). A revisionist theory of conceptual change. In R. Duschl & R. Hamilton (Eds.), *Philosophy of science, cognitive science, and educational theory and practice*. Albany, NY: SUNY Press.

Thagard, P. (1997) Coherent and creative conceptual combinations. In T.B. Ward, S.M. Smith, & J. Viad (Eds.), *Creative thought: An investigation of conceptual structures and processes*. (pp. 129-141). Washington, D.C.: American Psychological Association. HTML

Trundle, K. C., Atwood, R. K & ,.Christopher, J. E. (2007). Fourth-grade elementary students' conceptions of standards-based lunar concepts. *International Journal of Science Education, 29*(5), 595-616.

Vosniadou, S. & Brewer, W.F. (1994). Mental models of the day/night cycle. *Cognitive Science, 18,* 123-184.

Wiser, M. (1988). The differentiation of heat and temperature: History of science and novice-expert shift. In S. Strauss, (Ed.), *Ontogeny, phylogeny, and historical development* (pp. 28–48). Norwood, NJ: Ablex,