Eurasia Journal of Mathematics, Science & Technology Education, 2015, **11**(6), 1621-1632

Contextualizing Action for the Abstraction of Scientific Knowledge

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•*Received 26 December 2014*•*Revised 13 January 2015* •*Accepted 25 January 2015*

In this paper, abstraction is associated with an activity in the sense of activity theory by Vygotsky. To him, participation in social activities is a fundamental act for the child in order to achieve higher mental functions. The present paper aimed to experimentally investigate the abstraction process and illustrate how meaning emerges on social plane from the perspective of theory of abstraction. The analysis is from a science classroom activity. The activity was videotaped, transcribed, and later translated into English. The results indicated that in a contextualizing action five central elements (Scene, Agent, Purpose, Act and Agency) played important role.

Keywords: abstraction, contextualizing action, social plane, and emergence of meaning

INTRODUCTION

The term 'abstraction' had been and is still being the focus of concern for many scientists and philosophers. The account of abstraction initially originated from the ideas of Aristotle and John Locke. Abstraction is viewed as a course of action in which one observes a set of instances, recognizes their general qualities, and unites them into one idea. One does this by leaving out unrelated qualities and retaining only relevant ones (Locke, 1690, pp 333-334).

Lately, a comparable account was reflected in the words of Jean Piaget (1970, 2001). He portrayed mainly three kinds of abstraction, which are empirical, pseudo-empirical and reflective abstraction. To him, empirical abstraction is acquired through sensory motor experiences and refers to observable characteristics of objects (i.e. color, shape, and toughness). The pseudo- empirical abstraction refers to actions on objects (i.e. counting, throwing, pushing, touching, and rubbing). The reflective abstraction, which is the focus of the present paper, refers to one's mental operations acted upon those actions (i. e. discovering commutativity by counting pebbles in various ways). According to this classical view, in the course of abstraction, one initially searches for a certain invariant or pattern in a set of objects or actions and then locates the common or general quality of them. This is a linear process of ascending from concrete to abstract and the product of this process, which is an abstract, represents higher order knowledge. Discovering, for instance, commutativity by counting pebbles in various ways is ascension from concrete to

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doi: 10.12973/eurasia.2015.1426a

ISSN: 1305-8223

abstract.

However, no scientific theory can be deduced from observations (Popper, 2004, p. 53). Theoretical ideas could not be discovered by exclusively reflecting upon concrete. In order for an observer to formulate an observation statement, the observer must already be in the possession of the appropriate conceptual framework (Chalmers, 1999, p. 11). That is, rather than extracting a common meaning from a set of instances, the observer tries to apply his/her previous conceptions to the new experience in order to provide a meaningful account for it (Dewey, 1991, p. 128). In accordance with Ohlsson and Lehtinen (1997):

> In order to recognize an object as an instance of an abstraction, the knower must already possess that abstraction. People experience particulars as similar precisely to the extent that, and because, those particulars are recognized as instances of the same abstraction. (p. 41)

Theoretical ideas in science such as gravity, gene, atom, molecules, electrons, and natural selection were not, as a historical fact, created by an inductive process of extracting commonalities from a pattern of related actions. Rather, the formulation of the idea always preceded its applications to specific instances (Ohlsson and Lehtinen, 1997, p. 40). For instance, during his voyage to HMS Beagle in 1831 (Lawson, 1995, pp 14-16), Charles Darwin realized that the organic life was perfectly adapted to the physical world and he thought if the physical world changes, then the organic world must also change. Through collecting and carefully observing plant and animal species, he was amazed by their remarkable numbers and variety. Hereafter, he changed his belief from a creationist view to that of an evolutionist and came to believe that organisms evolve. This was the most important theory in biology and developed in an inductive process; data collection–analysis–theory (Lee, 2000, p. 15). However, this was not what had really happened. Long before this voyage, Darwin was well aware of the evolutionary ideas. In fact, Darwin's own grandfather had published an article titled Zoonomia: or the Laws of Organic Life that included ideas about evolution and its possible mechanism. Therefore, Darwin did not indeed discovered this notion through deliberate observations of the species; rather, he considered primarily the idea of evolution to explain his observations, which is called abduction (Lawson, 1995, p. 93). Therefore, in order for one to discover an unobservable linkage amongst objects, which is *the concept of evolution* in this case, one must in the first place be familiar with this conception.

Still another instance (Wickman & Östman, 2002), in a biology laboratory, five groups of university students were asked to make morphological observations and study such insects as two different species of beetles, a stinkbug, butterfly, and bumblebee. In the lab, the students examined antennae, wings, mouthparts, compound eyes, ocelli, and hair cover of the insects. They were basically to find out which orders the insects belonged to and if there was anything special about the different parts. The students' audio records indicated that rather than formulating

State of the literature

- In the literature, abstraction is viewed as a course of action where one observes a set of instances, recognizes their general quality, and unites them into one idea. From this view, scientific ideas are always derived from concrete situations.
- On the other hand, to others, in the development of theoretical ideas abstract and concrete are internally linked and dialectically act together. That is, scientific ideas could not be derived solely from concrete situations.
- Although the latter view on the abstraction process have been argued in detail in the past and current literature, its meaning seemed to have remained unclear and accordingly not adequately understood. The empirical studies illustrating this process are therefore required.

Contribution of this paper to the literature

- The paper will provide info about abstraction process and contextualizing action.
- Understanding abstraction process will potentially contribute to the researchers' understanding of how meaning emerges on social plane.
- Understanding learning process will allow educators to create novel teaching models.

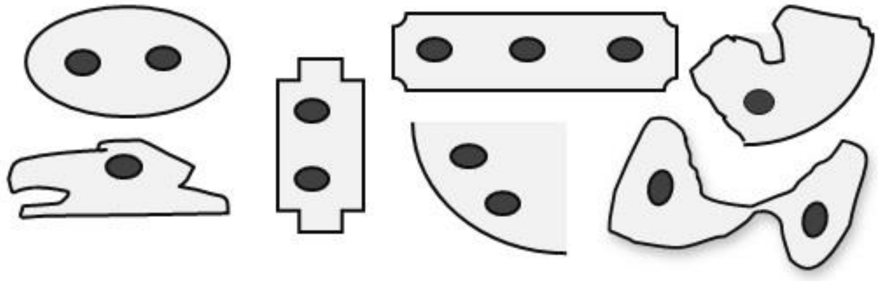

Figure 1. Microscopic organisms

or deducing inventive generalizations from their observations, the students applied their prior conceptions to this new situation. At first glance, this notion could sound bizarre, but it is rather realistic. To illustrate, what organisms depicted in Figure 1 are *livingex*, which is a species of microscopic organism.

In return for this question, one would most likely ask, 'what is livingex?' And 'what features does it have?' One queries because in order to figure out which of them are livingex, one needs to know what unique properties it holds. Without this knowledge, even if observing these creatures for many years, one will never discover and be able to distinguish them from others. Therefore, if observing is an insufficient action in the development of theoretical ideas, then how does one construct those ideas? In fact, in the development of theoretical ideas abstract and concrete are internally linked and dialectically act together (Davydov, 1990, pp 245-272; see also Hershkowitz, Schwarz, and Dreyfus, 2001; Monaghan & Ozmantar, 2006; Ozmantar & Monaghan, 2007a, 2007b; Tsamir & Dreyfus, 2002; White & Mitchelmore, 2010). To van Oers (2001):

> The split between the concrete and the abstract actually creates a misleading divorce between the perceptual-material and the mental-conceptual world. Abstraction can never produce meaningful insights unless there is some inner relationship between the concrete and the abstract. (p. 287)

According to him, the construction of theoretical ideas is the result of taking a point of view and focusing on particular elements of the activity setting, contextualizing action, which ultimately leads to one's seeing various elements of the setting as meaningfully interrelated. This paper therefore aims to analyze a classroom science activity, Footprint Puzzle Activity, from this dialectic perspective.

THEORETICAL FRAMEWORK: THEORY OF ABSTRACTION

In this paper, *abstraction* refers to an activity in the sense of activity theory by Vygotsky. To him (1981, p. 163; 1978, pp 56-7), participation in social activities is a fundamental act for the child in order to achieve higher mental functions. In other words, higher mental functions emerge when the child participate in an external social activity. He believed that any function in the child's cultural development appears on two planes: interpsychological or social plane (between people) and intrapsychological plane (inside the child). On social plane, according to Burke, five central elements interact: *Act, Scene, Agent, Agency*, and *Purpose* (see Wertsch, 1998, p. 13). That is, in order to understand human action, what was done *(Act),* when or where the act took place *(Scene),* who did it *(Agent),* what instruments were utilized *(Agency),* and why it is done *(Purpose)* must be studied all together.

In 2001, van Oers (pp 279-305), enthused by the works of several philosophers (Billig, 1991; Cassirer, 1957, 1923; Davydov, 1990; and Vygotsky, 1983, 1993), viewed abstraction as a discursive process of taking a point of view and progressively focusing on particular aspects of an activity setting, which is called contextualizing action. In this process, the learner focuses on particular and increasingly isolated elements of the setting, ultimately realizes how those elements, previously perceived as unconnected, are indeed meaningfully interlinked. Also, abstraction not once ends. It continues with a constant re-contextualizing action in which novel contexts emerge and every emergent context was followed by an action of adding a new meaning to it. So in abstraction, there is no a process of generalization, but there is a process of enrichment. Every emergent context is enriched by adding a new meaning to it. To van Oers, the situation in which one acts (the activity setting) is concrete. It represents the unity of diverse phenomena and functions as a context to which human action is internally related. The abstract, on the other hand, is not yet developed conception. It is through abstraction that one ascertains the meanings by establishing interconnections amongst the different elements of the setting.

The significance of the study

Investigating how meaning emerge on social plane is highly complex and multidimensional (Wertsch, 1998, pp 3-7). Expectedly, there are a variety of sociocultural frames that view meaning as emerging from social context. To illustrate, Bakhtin (1981) views social plane as a place in which voices come into contact. Rogoff (1990) sees it as a guided participation in joint problem solving activities. Blumer (1969, p. 4) sees it as a symbolic interaction between people and others see social plane as a negotiation of meaning within a particular community (Cobb, Yackel & Wood, 1989, 1993; Voigt, 1992; 1995, pp 163-201; Yackel, 2004; Yackel & Rasmussen, 2002) (see also Kennedy, 2009 for a detailed review of these and other perspectives). In this particular paper, it is aimed to reveal how meaning emerge from a specific social context. The frame offered by van Oers (2001) will contribute to our understanding and be a novel lens through which we will hopefully be able to see how meaning emerges through contextualization action.

The purpose of the study

In this paper, it is aimed to examine an external social activity, Footprint Puzzle Activity, from the perspective of theory of abstraction and the external activity is seen as the central unit of analysis, a core concept, for understanding the development of meaning. Specifically, the following question has become the focus of concern.

From the perspective of activity theory, how does meaning emerge through contextualization action?

THE ACTIVITY CONTEXT: THE FOOTPRINT PUZZLE

The Footprint Puzzle (National Academy of Sciences, 1998, p. 89) is a science activity and intended for making students appreciate the nature of science. In the activity, students are to observe and interpret fossil footprints depicted in Figure 2. The figure involves three positions and each one indicates new evidence. From the evidence, the students are to propose a defensible explanation for the events taking place in the geological past. The activity is designed for grades 5 to 8. In the course of the activity, Position 1 is initially projected. Afterward, the students are informed that in the picture are fossil footprints belonging to pre-historic animals and then asked to identify the species to which the fossils belong and predict what they could be doing at that time period. Later, position 2 and 3 are subsequently projected and the same questions are addressed. In this paper, the activity is used with the aim of enabling students to appreciate that (1) observations are affected by scientists' background knowledge and past experiences and (2) scientific explanations are subject to change as new evidence becomes available.

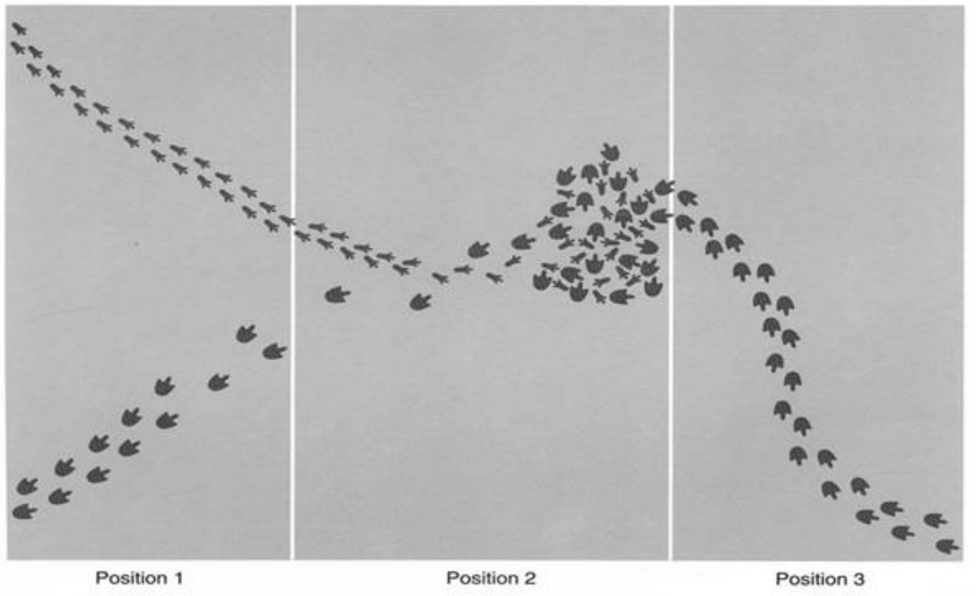

Figure 2. Footprint Puzzle (National Academy of Sciences, 1998, p. 89)

DESIGN AND PROCEDURES

A science teacher and a group of seventh graders participated in the study. The instructor initially acquired training about the activity. In particular, he was informed about the purpose and how to implement the activity. Furthermore, the students had not received any information about this subject matter before. In the activity, the teacher aimed to have the students gain an understanding of the nature of science. In particular, the aim was to have the students appreciate that (1) observations are affected by a scientist's background knowledge and past experiences, and (2) scientific knowledge is subject to change as new evidence becomes available. In the course of the activity, the teacher consecutively showed the position 1, 2 and 3 depicted in Figure 2, and initiated a discussion on the species of animals and what they do in each position. The students were to interpret the footprints, make inferences, and provide defensible accounts for the prints. The activity lasted approximately 33 minutes. As a data analysis method, a deductive approach (Patton, 2001, pp. 453-455) is adopted and the data was analyzed according to the concepts designated within the framework of theory of abstraction. In this approach, rather than discovering patterns, themes, and categories, the data was analyzed according to the existing concepts specified within the framework. Furthermore, in the present paper, intercoder reliability check for codes was not necessary (Patton, 2001, pp. 456-457) because the actual data, on which the analysis is based, was explicitly presented in the section of data analysis and results.

DATA ANALYSIS AND RESULTS

In this paper, Footprint Puzzle Activity is viewed as a social activity to be understood. In this activity, the interaction amongst the teacher, students and puzzle will be the central unit of our analysis. The activity is analyzed from the perspective of theory of abstraction. The activity was videotaped, transcribed, and later translated. The activity started with the depiction of Position 1. The teacher projected it onto a screen and stated that these prints belonged to prehistoric animals. Then, he initiated a discussion on the species of animals and asked the students to predict what the animals could be doing. Then, the dialogue continued as follows. In the dialogues, the letter T stands for the teacher.

Suna: They could be reptiles.
T: (Restating the student's answer and writing it down on the board) Do you know what they are doing here?
Suna: They are herd and going somewhere.
T: They are crawling and going somewhere (repeating the student's answer).
Suna: No! No! It is not crawling. They are herd and going somewhere.
T: (Restating the student's answer and writing it down on the board). Okay, good, any different idea? I would like to get your ideas?
Davut: They could be dragon, dragon.
T: (Restating the student's answer and writing it down on the board). Do you know what they are doing here?
Davut: They are informing us about the past.
T: Okay, they are informing us about the past. However, what are they doing now? Let us assume you are a scientist, a paleontologist. You inspected these prints and do you know what they are doing here?
Davut: They could do migration.
T: They migrate (Writing it down on the board).
Yigit: Teacher!
T: Yes, Yigit.
Yigit: I think they could be dinosaur prints.
T: Hold on one second (Writing the student's response down on the board).
Yigit: Uhmm. They are going somewhere and leaving their footprints behind because they do not want to get lost. They are leaving their footprints behind in order to be able to return to where they are coming from.
T: (Writing it down on the board). Okay, any different idea?
Koray: They could be camels.
T: (Writing it down on the board). Do you know what these camels are doing here?
Koray: (…)Laughing! They could be carrying loads and going to somewhere.

The dialogue continued and the students invoked, 'they could be dinosaurs and hunting', 'they could be ostriches and moving and migrating or just walking around', 'they are unobservable creators', 'they could be duck footprints and they are migrating to somewhere', and 'Red ones are chicken footprints, I do not know the others. They are going somewhere as a group'. In the meantime, the teacher wrote the students' responses down on the board.

In this first part of the activity, the teacher and students had dissimilar purposes. (1) The teacher's aim was hidden and it was to have the students appreciate that observation statement is depended on the observer's background knowledge and past experiences and whereas (2) the students' aim was visible and it was to predict the species of the creatures and what they were doing at that time period. In the course of the activity, the students invoked a variety of explanations and the teacher wrote them down on the board. This was a novel context created through the interaction amongst the teacher, puzzle and the students. That is, the new context was a result of the interaction between the agents (the teacher and the students) and the meditational tools (speech genres and the puzzle). Thereafter, the teacher asked, 'Even though you observed the same fossil footprints, do you know why you have provided different explanations?' Here, the students were asked to focus on particular aspects of the setting. That is, the teacher called the students' attention towards their varying responses written on the board and asked the students to ascribe a meaning to this variation. This activity of creating a meaningful context and having the students focus on particular elements of it is called contextualizing action (van Oers, 2001, pp 279-305). Hereafter, the dialogue continued as follows:

> Akif: Everyone is free to articulate their own thoughts.
>
> T: I am asking why your thoughts are different. Why are your thoughts different?
>
> Suna: Everyone has a different imaginative power.
>
> T: (Restating the student's answer) any different idea?
>
> Fatma: Yes, everyone has a different imaginative power. Everyone with differing potential thinks differently. Mine is different from others. Because of this, everyone has a different opinion.
>
> T: (Restating the student's answer) any different idea?
>
> Davut: Because everyone has a different idea, everyone stated a different thought. This different (…)
>
> T: I am asking why your explanations, opinions are different.
>
> Davut: Because everyone has a different idea.
>
> T: Why are they different?
>
> Yigit: Human is able to think. Human has a more thinking capacity than animals. Because of this, by improving their imaginative power, they could provide different opinions. (…)

In the remaining part of the dialogue, the students invoked comparable ideas. In particular, they thought different ideas resulted from the variation in their thinking capacity, intellect, or brainpower. In this part of the activity, even though trying to attribute a meaning to the concrete situation, the students failed to recognize that the variation occurs because of the differences in their background knowledge or past experiences. This was because in order for one to recognize an object as an instance of an abstraction, one must already possess that abstraction (Ohlsson and Lehtinen, 1997, p. 41). That is, in order for the students to recognize that the variation is the result of their different background knowledge or past experiences, the students must already have been familiar with this idea. The theoretical idea that different responses are the result of different background knowledge or past experiences is not an observable quality of the context and hence could not be derived from the observations of the objects themselves. Hereafter, the teacher interfered into the dialogue and stated:

> T: You had diverse ideas because of the variation in your past experiences, the books you had read and the movies you had watched.

The students were therefore provided with a novel perspective from which the elements of activity setting could be seen as meaningfully interrelated. The students were focused on the meaningful linkage between the variation in their responses specified on the board and their background knowledge or past experiences. This was an action of adding a novel meaning to the context (van Oers, 2001, pp 279-305). In this way, a new meaning is attributed to the newly created setting. Hereafter, the teacher stated:

> T: In a similar way, even observing the same object, scientists could provide different explanations because their past experiences and the books they had read are different. Like you, when they also examine the same object, the scientist could put forward different opinions.

Here, the students were now asked to focus on particular aspects of the former context. That is, the teacher this time called the students' attention towards how their background knowledge and past experiences led to the variation in their responses. The former context hence became the elements of the new setting. Namely, it developed into a new context. This was a *re-contextualizing action* (van

Oers, 1998, 138-39) created through the contextualizing of the former context. Then, the teacher again called students' attention towards the meaningful connection between *scientific observations and scientists' background knowledge and past experiences*. In this way, a new meaning is attributed to the setting. Hereafter, the teacher added Position 2 onto the screen and asked, 'what do you think now?' Then, the dialogue continued as follows:

> Fatma: I think, they are fighting (laughing).
> T: (Restating the student's answer and writing it down on the board).
> Davut: Two different kinds of animals are combining.
> T: Do you mean they are mating? (Writing it down on the board).(class laughing)
> Davut: Yes. Kind of.
> T: Do you still think that they are migrating?
> Davut: No.
> T: Yes, Yigit.
> Yigit: I think, they are coming together to communicate.
> T: Do you still think that they leave their footprints behind?
> Yigit: Yes, I still think that. I also think that they came together to communicate.
> T: Hold on one second (Writing it down on the board) (students are speaking aloud)
> Any different idea?
> Suna: They are two different kinds of animals and they are going to fight.
> T: Then, you do not believe that these are reptiles.
> Suna: I still believe that idea.
> T: Do you mean these are reptiles?
> Suna: No. I do not think.
> T: Do you think they are herd and going somewhere?
> Suna: They are going somewhere as a herd and they are fighting.
> T: (Restating the student's answer and writing it down on the board).
> Yes, Gonca. You formerly stated that they were ducks. Do you still hold on to your idea?
> Gonca: These are different groups of animals and going somewhere. They would like to cross over to the other side. One group wants to cross. The other also wants to cross. There is a competition between them so they fight in order to first cross.
> T: (Restating the student's answer and writing it down on the board).
> Hakan, do you still hold on to your idea?
> Hakan: No. I do not. I think these are the same kinds of animals. One is male and the other is female and they are mating.
> T: (Restating the student's answer and writing it down on the board).
> What else? Jale!
> Jale: These animals are coming together and becoming friends.
> T: You formerly thought that they were walking around. Do you still hold on to your idea?
> Jale: Yes. I still think they are walking around and I also think they are becoming friends.
> T: (Restating the student's answer and writing it down on the board).
> Yes, Koray! Do you still think that they are camels and carrying loads?
> Koray: No, I think they are coming together in order to solve their challenge.

The dialogue continued with the depiction of the Position 3. After projecting it on to the screen, the students continued to provide new ideas or made changes in their former ideas. In this part of the activity, the teacher and students had once more dissimilar purposes: (1) The teacher's aim was hidden and it was to have the students appreciate that scientific knowledge is a human inference and subject to change as new evidence becomes available and whereas (2) the students' aim was visible and it was to predict the species of the creatures and what they were doing. In the course of the activity, as the students changed their ideas, the teacher made changes on the board. In particular, when necessary, he erased former ideas and wrote down the new ones or made changes in the former ideas. This action was a new context created through the interaction amongst the teacher, puzzle and the students. Hereafter, the dialogue continued and the teacher asked, 'So far, some of you have changed your ideas. Why do you think you have changed your ideas?' Here, the students were asked to focus on particular aspects of the setting. That is, the teacher called the students' attention towards their shifting ideas and asked the students to ascribe a meaning to this shift. This activity of creating a meaningful context and having the students focus on particular elements of the setting is a new contextualizing action. In the remaining part of the dialogue, the students thought that displaying a new picture led them to change their ideas.

> T: So far, some of you have changed your ideas.
> Class: Yes, there was a change.
> T: Why do you think you have changed your ideas? Now (…). Why your explanations have been changed?
> Hakan: Because these two pictures are different, everyone has changed his/her idea and put forward a new idea.
> Jale: Because these are different images, we had different thoughts.
> Koray: You showed a different picture to us. At the beginning, there was a different picture.
> T: That is why you have changed your idea. What else? Yes, Davut!
> Davut: Because in the first picture, we have seen only one portion of the scene, but in the second one, we have seen the other part. This caused our ideas to change.
> Hereafter, the teacher interfered into the dialogue and stated that:
> T: Scientists, like you, when they get new evidences, data, pictures, or fossils, they change their ideas, opinions. If their former ideas are not valid today, they put forward new ideas, new theories. Sometimes, they make revisions in their former ideas. Scientists therefore act like what you did.

In this part of the dialogue, the teacher once more focused the students on the important linkage between new evidence and alteration of scientific knowledge. In this way, *a new meaning is added to the context*. The students, who are able to see the setting from this novel perspective, would gain a new understanding. For instance, at the end of the activity, after the teacher asked the students why they think they did this activity and why he repeatedly provided examples from scientists, Yigit stated:

> Like what we did, the scientists, when they get new evidence, when they get something visual, they change their former ideas. Their position is not stable, they change their ideas.

Yigit's statement provides evidence that he seems to grasp this important relationship. However, this single evidence could not be sufficient in order to say that the activity resulted in a success for all students and, in fact, this is not the aim of the present paper.

CONCLUSION AND DISCUSSION

The results indicated that theoretical ideas could not be explored through observation. As seen in the Footprint Puzzle Activity, the students were not able to discover the linkages between scientific observation and scientist's background knowledge and experiences and that between scientific evidence and alteration of scientific evidence. The results further indicated that in the course of the activity, four nested contexts emerged. The contexts were created through the interaction amongst the teacher, students and the cultural tools. To illustrate, the initial context where the students observed some footprints and discussed the likely species of the creatures involved the classroom, teacher, students, purpose, action, and such cultural tools as puzzle, language, board, pen, and scripts or handwritings. Therefore, five central elements (Scene, Agent, Purpose, Act and Agency) played important role in the creation of those contexts.

For instance, the Footprint Puzzle Activity involved a number of purposes and the teacher's and the students' aims were different. The teacher's aims were to have the students appreciate that (1) observations are affected by a scientist's background knowledge and past experiences, and (2) scientific knowledge is subject to change as new evidence becomes available. These aims were hidden. In other words, the teacher, at the beginning, did not notify the students about them. However, the teacher at the very beginning declared the students' aims and they were to predict or find out (1) the species of the creatures, (2) what they were doing at that time period, (3) why their ideas vary and (4) why they change their initial ideas. Further, in the activity a number of contexts emerged and every developing context was embedded in the previous one. The first context was the variation in students' responses and it gained the meaning that the variation comes from the differences in students' background knowledge and past experiences. The second context was the variation came from the differences in students' background knowledge and past experiences and it gained the meaning that scientific observations are affected by scientists' background knowledge and past experiences. The third one was the changes in students' responses and it gained the meaning that the changes resulted from the addition of the new pictures. The last context was the changes resulted from the addition of the new pictures and it gained the meaning that scientific knowledge is subject to change as new evidence becomes available.

Moreover, in the activity, four contextualizing actions occurred and every contextualizing action is followed by adding a meaning or perspective to it. In this action, the teacher progressively provided three important perspectives. This was an action of adding a meaning to the context. In this course, the emergent contexts were enriched by the addition of novel meanings to them. So, abstraction is not a generalization process; rather, it is enrichment one. For instance, in the first activity, the teacher created a context in which the students' ideas varied. Then, the teacher asked the likely reason(s) of this variation. The students initially thought that the variation in their ideas resulted from the differences in their thinking capacity, intellect, or brainpower. Hereafter, a new meaning is attributed to the context that the variation comes from the differences in the students' past experiences and background knowledge, which is provided by a more knowledgeable one, the teacher. Therefore, the context was enriched by the addition of this new meaning to it.

To sum up, the abstraction process exemplified in this activity had a number of phases. First of all, it started with different purposes. The teacher's and the students' aims differed. Second, the interaction amongst the teacher, students and the tool resulted in the emergence of several embedded contexts and the teacher had the students focus on the important elements of them. This activity of creating meaningful contexts and having students focus on the elements of them is called contextualizing action. This was a preliminary stage of the abstraction process. Third, in the course of abstraction the teacher also provided novel perspectives from which the students could see the different aspects of the contexts as meaningfully interrelated. These novel perspectives added new meanings to the contexts. Finally, abstraction involved nested contexts. That is, in the course of abstraction, new settings emerged and every emergent setting became the context of the succeeding one. These actions were recontextualizing actions created through the contextualizing of the former contexts.

Furthermore, the impact of abstraction on students' learning, whether it is applicable to all subject matters related to science education, and how dialogic and authoritative discourses mediated abstraction are all warrant further research and will be the focus of future projects.

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