Eurasia Journal of Mathematics, Science & Technology Education, 2010, **6**(2), 139-147

Is Conceptual Growth an Evolutionary Development of a Prime Structure? A dialectic Davydovian Approach

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Received 27 April 2009; accepted 25 January 2010

The aim of this study was to empirically examine the learning process from dialectic Davydovian perspective and ascertain in what way the students' conception grows in this process. Two students' dialogues became the focus of concern. The students at the start received a diagnostic test. The aim of the test was to ensure whether the students possessed the required knowledge necessary to fulfill the tasks in the protocol, and whether the intended structure was novel to them. The students then participated in a teaching interview. The results indicated that conceptual growth happened in an evolutionary way. That is, in the course of learning, the student's prior conception altered evolutionary from one form to another, but retaining everything positive.

Keywords: Abstraction, Conceptual Development, Conceptual Change

INTRODUCTION

Research on learning process in science education has been mostly affected by the ideas of Jean Piaget (1975). He viewed learning as conceptual change and, to him, the change occurs when one interacts with one's surrounding through two unchanging processes: assimilation and accommodation. These are called by him self-regulatory actions. To Piaget, one's self-regulatory actions lead to construction and reconstruction of more detailed and strengthened mental structures. To him, one cannot perceive a thing until his/her mind has constructed a knowledge structure that enables its perception. Enthused by this Piagetian approach, In 1982 Posner, Strike, Hewson, and Gertzog offered a conceptual change model (CCM).

According to this model, one's dissatisfaction with the existing mental structure initiates a revolutionary conceptual change process. When one gets dissatisfied with the present structure and finds the to-be-constructed structure (rival or competing structure) more intelligible, plausible and/or fruitful, the accommodation of the new structure may take place. This model was found effective in teaching scientific concepts (Baser, 2006). For instance, one might believe that acids are dangerous. The instructor shows that lemon juice is also acidic, but it is safe to drink (one getting dissatisfied with one's own knowledge) and informs that some sorts of acids could be dangerous, but some could be truly safe (one finding to-be-constructed structure more intelligible, plausible and/or fruitful). Since 1982, this approach has become the leading framework (Vosniadou & Ioannides, 1998) that guided research on conceptual change process of scientific knowledge.

This Piagetian approach to the growth of scientific knowledge through accommodation further assumes that within the conceptual change process, two different conceptions compete in terms of their intelligibility, plausibility, and/or fruitfulness and, consequently, one of them may become the winner of the competition. In this course, one's existing conceptual structure is fundamentally reorganized in order to allow understanding of the intended knowledge structure

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ISSN: 1305-8223

State of the literature

- Piaget viewed learning as conceptual change and, to him, the change occurs when one interacts with one's surrounding through two processes: assimilation and accommodation.
- The accommodation process is seen as resembling the revolutionary development of scientific theories in the history of science.
- Davydov views learning as an evolutionary development of a prime structure.
- According to Hershkowitz, Schwarz, and Dreyfus, in the course of learning one passes through three epistemic actions: recognizing, building-with, and constructing.

Contribution of this paper to the literature

- The paper offers new insights into the nature of students' conceptual growth.
- It provides a novel perspective (RBC model) for the construction of scientific knowledge.
- It further emphasizes the importance of recognizing the elements of the activity setting and contemplating the elements from the point of view provided in the construction of scientific knowledge.

(Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001; Stafylidou & Vosniadou, 2004). Accordingly, the change process is viewed as radical or revolutionary. Various comparable names have been attributed to this process. Amongst them are Revolutionary Science (Kuhn, 1996), Hard Core Changes (Lakatos, 1970), Strong Restructuring (Carey, 1985) and Radical Restructuring (Vosniadou, 1994) (see Harrison & Treagust, 2001 for a review of them). These approaches viewed the accommodation process as resembling the revolutionary development of scientific theories in the history of science. To them, how theories were revised or altered in the past seemed to be quite similar to what happens in one's own mental knowledge structure. For instance, the shift from the initial notion that the earth is a flat object with no motion to the idea that the earth is a sphere object rotating around its axis (Vosniadou & Brewer, 1992), and the shift from the conception of natural numbers to that of the fractions (Stafylidou & Vosniadou, 2004) are seen as radical conceptual changes.

Unlike Piaget, according to Hershkowitz, Schwarz, and Dreyfus (2001), in the course of learning one passes through three epistemic actions: recognizing, building-with, and constructing, abbreviated as RBC model. To this model, in the constructing action, the learner first recognizes the elements of the activity setting, contemplates the elements from the point of view provided and ultimately cognizes (come to understand) how those elements are meaningfully interrelated. This approach further alleges that conceptual growth is a not a radical reorganization of central conceptions. Rather, it is an evolutionary development of an existing structure constantly altering from one form to another (Davydov, 1990, pp 253-258), but retaining substantial elements of the former structure (Nussbaum, 1989). This view is elaborated in the following section and used as a theoretical framework for the present paper.

THEORETİCAL FRAMEWORK

Davydov referred to the learning process or scientific knowledge construction as 'abstraction'. To him, abstraction process starts from an initial unrefined first form and ends up with a developed more complex one. To Hershkowitz et al. (2001), this process occurs via three observable epistemic actions: recognizing, building-with, and constructing. *Recognizing* is referred to be identifying a formerly constructed knowledge structure within a particular problem setting. *Building-with* is associated with an action in which one recognizes an existing knowledge structure within the new problem setting and builds with it to a solution. This mental action could be observed when one solves a problem without getting assisted. Finally, *constructing* is viewed as an action in which one recognizes the elements of a problem setting, contemplates the elements from the point of view provided by a mediator, and finally cognize (come to understand) how these elements that once seemed to be unrelated are indeed meaningfully interlinked. And ultimately builds with this linkage to a solution. The constructing action hence leads to a creation of cognition, a novel mental structure. This novel structure could be a new method, strategy or conception. By making use of this new structure, one solves a problem or justifies a solution (see Hershkowitz et al., 2001; Ozmantar, 2005 for a detailed review of abstraction process).

However, the construction of this novel structure is indeed not an emergence of a completely novel idea (not a revolution or radical rearrangement of former conceptions); rather, it is a development of an existing idea (an evolution or constant progression of an earlier conception). According to, for instance, Davydov (1990):

> *"Within the evolving natural whole, all things are constantly changing, passing into other things, vanishing. But each thing, according to dialectics, does not merely change or disappear- it passes into its own other, which, within some broader interaction of things, proceeds as a necessary consequence of the being of the thing that has vanished, retaining everything positive from it (within the limits of all nature this is also a universal connection)"* (p. 253).

To Davydov (1990), the constructing action begins with the recognition of the elements of the activity setting, which involves both idealized objects of sensory observations (pp 246-247) and a prime conception (p. 255). Then, it continues with the alteration of the prime conception to a different more complex one. In this course of change, the prime conception constantly develops from one form to another, but retaining substantial elements of it. The aim of this paper is therefore to examine the learning process from a dialectic Davydovian perspective and to ascertain in what way the students' conceptions grow in this process.

THE RESEARCH QUESTION

The following research question became the focus of concern:

1. Is conceptual growth a constant development of a prime conception to a more complex one or a radical rearrangement of former conceptions?

DESIGN AND PROCEDURES

Task Design and Piloting

This study is part of an ongoing project on the abstraction process of scientific knowledge. In a former study by Saglam (manuscript submitted for publication), the learning process is examined within the RBC model (Hershkowitz et al., 2001). Accordingly, a teaching interview protocol (see Appendix A) was designed. The protocol is specifically designed so as to have the students discover that the formation rate of a compound depends on its coefficient in a balanced equation. The results of the former study indicated that in the abstraction of rate concept, one passed through three epistemic actions: recognizing, building-with, and constructing (RBC). In the present paper, however, the learner's conceptual growth will be focus of concern.

The protocol consisted of five questions and the questions asked the students to compute the speed of a racehorse, melting rate of an ice cube, rate of a reaction that involves a reactant and product, and rate of a reaction that consists of multiple reactants and products (Silberberg, 2003, pp 667-671). The questions aimed to have students be able to compute the consumption rate of melting ice and the formation rate of water, and also recognize that melting rate of ice is equal to formation rate of water, the consumption rate of reactants is equal to the formation rate of products, rate has a negative value for the reactants and a positive one for the products, and finally the consumption or formation rate of a compound depends on its coefficient in a balanced equation.

The protocol was piloted three times. This piloting enabled the researcher to formulate certain revisions in wording, order and difficulty of the questions. Furthermore, in the interviews he was principally to probe students' ideas, provide them with adequate response time, and ask to clarify and elaborate on their solutions. However, when the students get stuck, come up with inaccurate solutions or could not come to an agreement with their partner, the mediator then intervened the dialogue by directing and providing foci, rephrasing students' utterances, making comments on their solutions, and, when necessary, providing with detailed explanations for an appropriate solution.

Sample Description

For the present study, the students were selected purposefully (Patton, 2002, pp 45-46) on the basis of two criteria: (1) whether the students possess prerequisite knowledge necessary for the implementation of all the questions in the protocol, and (2) whether the target structure is novel to them. In the selection of the students, a diagnostic test was administered. The test aimed to identify the students who had prerequisite knowledge necessary to execute all the questions in the protocol. The test consisted also of five questions. The questions asked the students to compute the speed of a racehorse, identify the components of a chemical formula, balance a chemical reaction, figure out the concentration of a substance in a chemical reaction, and compute the rate of a reaction between hydrogen and oxygen gas. The students that became successful on the first four questions and failed on the fifth one were selected for an interview.

The data were collected from a total of six students, of whom four students were female and two were male. The students' ages ranged from 16 to 18 years old. In order to monitor students' learning progress over an extended time period, the students and the researcher met at the school four times within a two week period and each meeting lasted approximately 30-50 minutes. The data collection therefore lasted around 640 minutes. All interviews were videotaped, and later transcribed and translated from Turkish into English. In translating, special attention was paid to precision of the meaning.

The Method

In the present paper, a case study approach was utilized (Patton, 2002, pp. 447-457) and the case being studied is the abstraction process of rate concept. It is specifically aimed to gain deep understanding of the nature of conceptual growth in this course. Accordingly, in-depth interviews were conducted with students and the data was analyzed according to the RBC model. The model served as a framework and became reference in the course of analysis.

At the start of the interviews, the students were trained to think aloud (Ericsson & Simon, 1980; Patton, 2002, p. 385). For this purpose, the students were given a simple task (i.e. computing one of the internal angles of a triangle) and asked to utter vocally their thoughts while reflecting upon the task. The students were also told that whatever they think was important for us and no thought could be ridicules, meaningless or silly. In this way, it is aimed to encourage them to verbalize their emerging thoughts without restraining.

All the interviews were videotaped. During the interviews, the students were provided with some lab equipments such as a balance, ice cubes, and plastic containers. In order to see learning process within a group-interactive context, four students were paired. Each pair was trained to attain a number of skills. These include being able to work on the problem cooperatively, provide and explain a solution, argue and generate comments on the solution, try to persuade their partner, and come to an agreement if possible. Then, the students (two pairs and two individuals) were asked to go through the questions from the beginning and provide a solution. Having provided an acceptable solution for a problem, the students were then allowed to proceed to the next one. Nevertheless, when the students got stuck, came up with inappropriate solutions, or could not come to an agreement with their partner, the mediator interfered in the discussion by directing and providing foci, rephrasing students' utterances, making comments on their solutions, and sometimes providing complete and detailed explanations.

RESULTS

In the analysis, the students' video records and their written works were first transcribed and then translated into English. In the transcriptions, the names used are pseudonyms. The students' utterances were numbered and three dots were used to point at either the student paused or spoke inaudibly. The students' expressions were next analyzed based on the operational definitions shown in Table 1. Furthermore, two additional colleagues were also asked to code the data independently and discrepancies were resolved by discussion. Accordingly, the emergent codes were agreed on by everyone, indicating strong inter-coder reliability (Miles & Huberman, 1994).

Hershkowitz et al. (2001) refers to *abstraction* as theoretical conception in the sense of Davydov. They also refer to it as an activity in the sense of activity theory, in which a series of epistemic actions (recognizing, building-with, and constructing) are undertaken by an individual or group of people. *Context* (though possessing no one clear-cut definition in the science literature) is referred to the factors that framed the structure and meaning of human action. It involved one's conceptions and experiences, socio-cultural tools or instruments at one's disposal including both physical and symbolic means, procedures and social interactions. According to Davydov (1990), abstraction starts out from an initial entity and ultimately develops into a more complex structure through a dialectical activity. The *initial entity* referred to one's existing knowledge structure. In the course of abstraction, this structure developed into a more complex one.

One pair of the students' dialogue was selected for analysis. This particular pair uttered their ideas in detail. This is opportunely allowed the researcher to trace the flow of their ideas. In other dialogues, the students were not adequately able to elaborate on their ideas and this yet restricted to monitor them as they work on the problems. Accordingly, they were excluded from the analysis. The pair selected worked on the tasks for approximately 160 minutes, which were spread over a two week period. The interview was transcribed and later translated into English. In the subsequent dialogues, the letters F and A stand for the students and

Table 1. Operational definitions for epistemic actions and terms adapted from Hershkowitz et al. (2001)

1. Recognizing action	It refers to an action in which one identifies a formerly constructed knowledge structure within a particular problem setting. One recognizes, for instance, Newton's law of motion in a particular problem.
2. Building-with action	It refers to an action in which one recognizes a formerly constructed knowledge within a new problem setting and makes use of it in order to solve it. For instance, one recognizes Newton's law of motion in a particular problem setting and handles the problem using this notion (a=f/m).
3. Constructing action	It refers to an action in which one recognizes the elements of the activity setting, contemplates the elements from the point of view provided by the mediator, and ultimately cognize (come to understand) how those elements are meaningfully interrelated. To illustrate, in a problem setting let presume one is focusing on mass, force and acceleration, thinking over these elements from the perspective of Newton's law of motion, and cognizing the important linkage amongst them, (a=f/m).

the letter R stands for the mediator. The students' utterances are numbered to ease the analysis process. Note that the following data and its analysis were also utilized in the former study (Saglam, manuscript submitted for publication). In the previous study, this analysis signified the dialectic nature of abstraction process. In this paper, however, the nature of conceptual growth will be the focus of concern.

In Phase I, the students computed the speed of a racing horse, designed an experiment in order to find melting rate of an ice cube, computed the melting rate of ice and formation rate of water. They further found out that the melting and formation rates possess opposing signs. Then, the students computed the rate of an A→ B type reaction. They figured that the consumption rate of A is equal to the formation rate of B, but they had opposing signs. Thereafter, the students were asked to compute the rate of a reaction between ethylene and ozone gas. The dialogue then continued as follows:

Passage I. The students could not recognize to-be-constructed structure.

F345: Reaction rate.
A346: (Reading the question) Express the rate of reaction in terms of the change in concentration of each of the reactants and products.
A347: (Thinking on the problem)
F348: How can it be solved? (laughing)
A349: It is a little bit complicated. What is the question about?
F350: How can we find them separately?
A351: (Reading the question) Express the rate of reaction in terms of the change in concentration of each of the reactants and products.
F352: Shall we write the concentration of ozone underneath it (O_3)?
A353: How?
F354: The concentration of ozone gas.
A355: Okay, let's put it. This is ozone concentration. These are reactants and these are products.
F356: Uhu.
A357: (Reading the question) Express the rate of reaction in terms of the change in concentration of each of the reactants and products. The problem is asking to calculate these (C_2H_4O and O_2). I think we could not solve this problem. How can we find the rate of this (C_2H_4)?
F358: I do not know this one (C_2H_4).
A359: Shall we put 10 seconds here, I wonder.
F360: One oxygen moved from this side to another side. I wonder, If oxygen is formed, this belongs to this, does not it?
A361: I do not know. This is a very hard question.

In this passage, the students were asked to determine the rate of a reaction between ozone and ethylene gas. However, the students found the problem somewhat complicated (F348, A349, F350). The students were not able to recognize to-be-constructed structure within this novel problem setting. They could not recognize the internal connection between relative quantity of molecules and their coefficients in a balanced equation. Then, the dialogue continued as follows:

Passage II. The student F built with an improper knowledge structure.

F362: (Reading the question) Express the rate of reaction in terms of the change in concentration of each of the reactants and products.
A363: I wonder whether we could do it in the way as you said.
F364: Because this is ozone gas.
A365: Then, one O, one O (oxygen) is 2.1 times 10^{-5} molar, is not it?
F366: It is likely, but not exactly, not exactly.
A367: Then.
F368: Because this decreases, one oxygen, one element, is detached from ozone. Is this possible you think?
A369: Uhmm It is possible. Then, if this O (referring to C_2H_4O) is 2.1 times 10^{-5}, then this O (referring to O_2), I wonder, is 1.10 times 10^{-5} molar.
F370: Since uhmm, this decreases.
A371: How much of it decreased? 2.1. Then, out of 3,2, 2,1 decreased, did not it?
F372: Since this (referring to O_3) decreases, since this (referring to O_2) is detached. It (O_2) becomes 2.1 times 10^{-5} molar. I think something like this.
A373: Is this ozone.
F374: This one.
A375: is it O_3?
F376: Uhu.
A377: The concentration of ozone, then, if it is 3.2, if it decreases to 1.10.
F378: It happens this way, I think it should be like that. This (referring to C_2H_4O) becomes 1.1 does not it? Because this one (referring to O_3) is decreasing and that (referring to O_2) is detached.

In this passage, the student F recognized and built with an inappropriate knowledge structure and hence brought a mistaken solution for the problem. She incorrectly thought that there is a connection between subscript of an entity and its relative quantity of its linked products (F372, F378). She stated, 'Since this (O_3) decreases, since this (O_2) is removed. It (O_2) becomes 2.1 times 10^{-5} molar. I think something like this' (F372) and 'I think it should be like that. This (C_2H_4O) becomes 1.1 does not it? Because this one (O_3) is decreasing and that (O_2) is removed' (F378). These statements seemed to indicate that she believed that because the concentration of ozone gas decreased and oxygen gas was removed from it, the concentration of oxygen gas formed had to be 2.1 times 10^{-5} molar and, because the remaining concentration is 1.1 times 10^{-5} molar, then the concentration of C_2H_4O had to be 1.1 times 10^{-5} molar. She seemed to think that as the reaction proceeds, ozone gas split into two parts, one part of which is removed as oxygen gas and the remaining part is the oxygen atom (which joins in the molecule of C_2H_4O). This finding also points to that she is not familiar with the linkage amongst the relative quantity of the compounds and their coefficients in a balanced equation. From this point on, the mediator joined into the dialogue and provided some assistance.

Passage III. The student F's constructing and building with action.

First Part: *R474: Let us talk about the reaction equation. Let us read this reaction together. One ethylene molecule reacted with one molecule of ozone. Is that correct?*

A475: Yes.

R476: After that, one molecule of this (referring to C_2H_4O) and one oxygen gas is formed. Is that correct?

A477: Yes.

F478: Yes.

R479: Is there any leftover of this gas (referring to C_2H_4) and this gas (referring to ozone gas)?

A480: No

F481: No

R482: Of course, they do not disappear. What happens to them is that they converted into products. Like when ice converted into water, was there any ice leftover.

F483: No

R484: Then, reactants.

A485: Equal to products.

R486: Of course, if their concentrations are equal to one another, and if one of them is not more than the other. Let's look at the equation, if we had 10 for each of these (reactants), what would happen?

F487: Similarly, there would be 10 of this (referring to C_2H_4O) and another 10 of oxygen.

A488: There would be 10 of each and 20 as a total.

Second Part

F489: We had already checked the reaction equation and it was balanced.

R490: Now, let us look at the amount of ozone consumed. How much of it is consumed?

A491: 2.1

F492: 2.1 times 10^{-5}.

R493: molar consumed.

F494: Yes.

R495: How much of oxygen is formed? What is the amount of oxygen formed?

A496: Then, one oxygen 2.1 times 10^{-5}, in other words, it decreased.

R497: Let us think this way. If there are 10 of this (referring to C_2H_4) and this (referring to ozone gas), after they react, how many of this (referring to C_2H_4O) and this (referring to oxygen gas) would be formed?

F498: Then, oxygen is 2.1 times 10^{-5} molar over second.

R499: Are you talking about rate or concentration?

F500: I mean concentration. That is 2.1 times 10^{-5} molar.

R501: Then, this (1.1 times 10^{-5}) is wrong, is not it?

F502: I thought based on your comments.

R503: Are you sure with your explanation?

F504: I am not exactly sure.

In this passage, the mediator provided with a series of foci (R474 – R549), which seemed to facilitate the students to focus on particular, and previously unnoticed elements of the activity setting (Van Oers, 2001). In this focusing, the students' attention were drawn on such recognizable aspects of the setting as the coefficients of the compounds, reaction equation, quantity of products and reactants, simultaneous conversion of ice into water, and leftover. In this part, the students were also pointed to how these elements are interlinked to one another in a meaningful way. They were pointed to how the coefficients in a balanced reaction equation indicate the number of compounds consumed or produced (R474-R482). At one point of the dialogue (F487), the student F's utterance, 'similarly, there would be 10 of this (referring to C_2H_4O) and another 10 of oxygen' provides evidence that she had been able to construct the important connection amongst the coefficients of entities and their relative quantities in a balanced equation.

In the second part, the activity turned into recognizing the novel structure within the new setting and building with it to a solution. In this activity, rather than constructing a new more complex structure, the student F recognized and built with the novel knowledge structure to a solution. Her solution, 'Then, oxygen is 2.1 times 10^{-5} molar over second (F498) provides evidence that she was able to recognize the novel knowledge structure within the new problem setting (F490) and build-with it to a solution. However, this novel knowledge structure seems to be still fragile for this particular student because when asked whether she is sure about her solution, she expressed her hesitation in F504. To Monaghan and Ozmantar (2006), this novel structure is still weak and needs to be consolidated in further activities.

DATA ANALYSIS

An analysis of the students F's utterances indicated that she initially thought that as ice melting down, it simultaneously converted into water. She later on believed as the reaction proceeds, ozone gas split into two parts, one part of which is detached as oxygen gas and the remaining part is the oxygen atom, which joins in the molecule of C_2H_4O. This understanding led her to mistakenly conclude that the decrease in the concentration of ozone gas is equal to the increase in the concentration of oxygen gas and the remaining concentration of ozone is equal to the concentration of C_2H_4O. This notion soon after changed into the conception that as the reaction proceeds, ozone gas simultaneously converted into oxygen gas and the molecule of C_2H_4O. And the remaining is still ozone gas. This novel understanding led to her putting forward an accurate solution for the question. She ascertained that the concentration of ozone gas consumed is equal to the concentration of oxygen gas and of C_2H_4O formed.

In Passage II, the student F seemed to believe that as the reaction proceeds, ozone gas split into two parts, one part of which is detached as oxygen gas and the remaining part is the oxygen atom, which joins in the molecule of C_2H_4O. This belief however provided her with an inappropriate point of view and led to her possessing an improper conception that ozone gas split into two parts, one part of which is detached as oxygen gas and the remaining part is the oxygen atom. This belief however led her to bring in a mistaken solution for the problem. She confidently claimed that the concentration of oxygen gas formed was 2.1 times 10^{-5} molar and that of C_2H_4O was 1.1 times 10^{-5} molar.

In Passage III, the mediator discursively focused the students' attention on some particular elements of the activity setting. He focused the students' attention on such 'sensorily perceivable' elements as the reaction equation, the coefficients of the compounds, the symbols of C_2H_4 (ethylene gas), O_3 (ozone gas), O_2 (oxygen gas), and C_2H_4O, the relative quantity of the compounds (R474, R476, R479), and also on a 'sensorily unperceivable' element (a prime knowledge structure), simultaneous conversion of ice into water (R482). With this assistance, the student F in respond seemed to recognize the elements of the activity setting, contemplate the elements from the point of view (the coefficient of a compound signifies its relative quantity in a balanced equation) provided, and ultimately cognize how those elements are meaningfully interlinked. She cognized there is an important connection between the coefficient of an entity and its relative quantity in a balanced equation. Her utterance, 'Similarly, there would be 10 of this (referring to C_2H_4O) and another 10 of oxygen' (F487) provide evidence that she was able to establish the internal connection, a novel structure, that the number of reactants consumed is equal to the number of products formed.

In this constructing activity, the student F's initial notion of that as melting down, ice simultaneously converted into water changed to the conception of that as the reaction proceeds, ozone gas simultaneously converted into oxygen gas and the molecule of C_2H_4O. From a Davydovian perspective, in this change process, her conception altered from one form to another in a constant flux, but retaining everything positive. Her prime conception (as melting down, ice is simultaneously converted into water) passed into its own other (ozone gas simultaneously converted into oxygen gas and the molecule of C_2H_4O), but retaining everything positive (simultaneous conversion into products). Therefore, the idea of 'simultaneous conversion into products' were retained in both conceptions, and the student F's latter conception is interrelated to her former one in this way. That is, what-is-retained continued to exist within the subsequent conception and her succeeding conception is related to the preceding one in this way. Because every conception is related to a preceding one through what-is-retained, through a core element, the change process happens in an evolutionary developmental way.

DISCUSSION AND CONCLUSION

The data signified that conceptual growth is an evolutionary constant development rather than a revolutionary drastic change. In Passage II, for instance the student F seemed to believe (idea 2) that as the reaction proceeds, ozone gas split into two parts, one part of which is detached as oxygen gas and the remaining part is the oxygen atom (which then joins in the molecule of C_2H_4O). This belief however provided her with an inappropriate point of view and caused her possessing an improper conception that ozone gas split into two parts, one part of which is detached as oxygen gas and the remaining part is the oxygen atom. Whereas, in Passage III her notion changed into the conception (idea 3) that as the reaction proceeds, ozone gas simultaneously converted into oxygen gas and the molecule of C_2H_4O. At this point, an advocate of conceptual change model would argue rightly that this change is radical and therefore revolutionary.

However, this point is in fact where the advocates of conceptual change are mistaken. They compare a student's initial and after-instruction conceptions on a particular matter of concern. Nevertheless, this comparison is indeed erroneous.

When the present data is examined, in the constructing action the student F focused on the elements of the activity setting and simultaneous conversion of ice into water (idea 1) was one of those elements. This idea served as a prime structure for the construction of idea 3. Therefore, the idea 1 (as melting down, ice is simultaneously converted into water) altered into idea 3 (ozone gas simultaneously converted into oxygen gas and the molecule of C_2H_4O), but retaining everything positive (simultaneous conversion into products). And because what-is-retained (simultaneous conversion into products) continued to exist within the idea 1 and 3, both ideas are interrelated to one another in this way. Therefore, the student F's conception altered from one form to another in an evolutionary way rather than in a revolutionary drastic one. In this course, one's prime structure passed into its own other, but retained everything positive. And what-is-retained continued to survive within the subsequent conceptions and every succeeding conception was related to the preceding one in this way. Accordingly, a former structure is always a prerequisite and has to be recognized first and foremost for the construction of a further more complex structure.

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APPENDIX A

Interview Protocol

Phase I:

1. If a racehorse were able to run 2 km between 4th and 20th minutes, what is the average speed of the horse meter per second?
2. Now, let us try to find out the melting rate of an ice cube. Please discuss and design an experiment in order to find out the melting rate of an ice cube at human body temperature. Note that required materials will be provided to you.
3. In the following reaction, molecule A converts into molecule B. During the first 90 seconds of the reaction, the concentration of A declines from 1.2 M to 0.75 M. Calculate the rate of reaction in terms of the change in concentration of A and B separately, and then compare the values you have obtained.

$$A \rightarrow B$$

Phase II:

4. According to the following equation, ethylene gas reacts with ozone. During the first 10 seconds of the reaction, ozone concentration decreased from $3.2 * 10^{-5}$ M to $1.10 * 10^{-5}$ M. Express the rate of reaction in terms of the change in concentration of each of the reactants and products and compare the values you have obtained.

$$C_2H_4(g) + O_3(g) \rightarrow C_2H_4O(g) + O_2(g)$$

5. Hydrogen gas reacts with oxygen to form water according to the following equation. Between 5th and 25th seconds, the concentration of oxygen decreases from 1.0 M to 0.8 M. Express the rate of reaction in terms of the change in concentration of oxygen, hydrogen, and water?

$$2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$$