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If a Reaction is Spontaneous, May it Be Endothermic? Perceptions and Creation of an Acceptable Mental Model

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Abstract

Energy changes in chemical reactions, is one of the topics that students struggle most to understand. Students have alternative models that comprise the relationships between the concepts of heat of reaction, change in internal energy and spontaneity. They have strong opinions about how an endothermic reaction cannot be spontaneous or that if a reaction is spontaneous then it is exothermic. Their experiences with chemical changes in their daily life support these ideas. The aim of this research is to identify perceptions about an endothermic and spontaneous reaction ($NH_4Cl + Ba(OH)_2$) that challenges the alternative models students have, to suggest a solution for creating the suitable model and to analyze their thinking processes in model creation. Both qualitative and quantitative research paradigms are used in conducting the study. The research group is constituted of the first year undergraduate students taking general chemistry lab course in the faculty of education of a state university in Turkey. The research had two phases. In the first stage, students (N:86) specified their hypotheses before they observed the reaction and they specified their conclusions after observing the reaction. This is done through a scale that consists of multiple choice and open-ended questions. Some students exhibited confirmation bias, they did not change their initial hypothesis and they looked for elements in the phenomenon to support their hypothesis. Students who changed their perspective were followed in the new model creation process and it was observed that they highly struggled in this process. In the second phase of the study the process of model creation of students (N:30), who attended a guided inquiry type experiment, was supported and examined. Students' data explanation and model creation procedures were interfered with argumentation and scaffolding for reasoning. Students explained in writing their thinking process in creating the model, which explains the internal energy change based on the measurement of the decrease in system's temperature. Written statements of students were analyses qualitatively. It was identified that in creating their new models, students use especially the cognitive processes of reasoning, imagination, analogical thinking.

Keywords**:** *chemical energy, inquiry, creativity, mental model;*

1. Introduction

Energy changes in chemical reactions is one of the most difficult topics for students [1]. Most of the reactions that maintain itself after initiating it are exothermic reactions. On the other hand, an external continuous heat source is needed in order most of the endothermic reactions to maintain themselves. Therefore, most students may not have encountered an endothermic reaction without an external heat source.

Such students might establish an erroneous relationship between reaction energy and spontaneity, which is all exothermic reactions are spontaneous and all endothermic reactions are nonspontaneous [2]. Observing that a reaction known to be endothermic has occurred by itself can be regarded sufficient to eliminate this erroneous relationship. However, students might not change their initial conceptions with unexpected observations; instead, they seek for evidence to validate their current understanding of the phenomenon observed [3].

Creativity is defined as producing something new and appropriate [4]. Students need to perform creative thinking in order to design a mental model that explains a reaction occurring without a heat source, unlike the exothermic reactions that they observed previously. Many researchers ascertain that students need to change their initial understanding and to reconstruct the problem situation for creative problem solving [5]. Reconstruction is a time-consuming process which also requires coping with several mental fixations [6]. In addition, the reconstruction of the problem is the first stage of a creative problem solving [7].

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1.1 The importance of the research
Students' model development activities in science education are often a subject of conceptual change studies in which the new model is introduced along with the existing model [8]. While hiding the new model, creative model development has emerged as a contemporary field of research in science education [9]. Studies on such creative thinking activities might reveal useful information about students' use of some cognitive structures such as reasoning, imagination, and analogical thinking.

1.2 Aim of the study
This study aims to propose a way guiding students to develop creative models of energy changes in chemical reactions and to investigate their thinking strategies. Answers to these questions were sought in the study:

1. What are students' predictions regarding the spontaneity of an endothermic reaction, and their subsequent decisions after observing the reaction?
2. What are students' thinking processes regarding the energy change in a reaction occurred in an inquiry experiment where a temperature decrease is observed in the reaction container?

2. Method
2.1 Participants
Freshmen enrolled in the General Chemistry Lab course in the education faculty of a state university in Turkey constituted the participants. The opinions of a total of 86 students were obtained regarding the spontaneity of an endothermic reaction, and the model development activities of a different group of 30 students participated in the inquiry experiment regarding the energy change in this reaction were investigated.

2.2. Research procedure
The research comprised of two stages.

The spontaneity of an endothermic reaction: The participants' (N:86) predictions regarding the spontaneity of an endothermic reaction were determined. Then, they observed the temperature change during the reaction. They made decisions regarding the energy change during the reaction and the spontaneity of the reaction.

Developing a model of the energy change in the reaction: Different participants (N:30) attended in an inquiry-type experiment in which energy change of the relevant reaction is investigated. The students were not informed that the reaction is an endothermic reaction at the beginning of the experiment. The students explained their measurements indicating a temperature decrease in the reaction container in terms of the reaction energy. An argumentation session was held out in order to give up their erroneous mental models. An initiative reasoning was presented for their restructure the problem situation. The participants maintained their reasoning processes, developed new models, and explained their thinking processes during the development of the models.

2.3 Data sources and analysis
Prediction and decision of the reaction thermodynamics: Multiple-choice and open-ended questions were used in order to determine the participants' (N:86) predictions regarding the spontaneity of the endothermic reaction and their subsequent decisions after observing the reaction. The content validity of the scale was confirmed by the science education experts, and the correlations between the related items were found to be in the acceptable range.
Students' laboratory reports: The result and discussion parts of the students' (N:30) lab reports were investigated in order reveal the students' models. The students' decisions regarding the reaction energy were revealed using the results parts of their reports, and their models were revealed using the discussion parts of the reports. In addition, the participants wrote the thinking strategies they used in developing the new models. Their texts of the thinking strategies were separately analyzed by the two researchers.

3. Results

The students' (N:86) predictions regarding the spontaneity of the endothermic reaction and their subsequent decisions after observing the reaction were showed in Fig. 1. Only some participants (N:28) thought that endothermic reactions might be spontaneous. Most of the participants (N:58) thought that an external heat source is needed in order for the reaction to occur. After observing the reaction, most of the participants (N:44) changed their decision to that the reaction occurred by itself. The remaining participants (N:14), on the other hand, sought for the evidence to validate their current understanding of the phenomenon observed and protected their initial opinions. Even though the participants were given enough time at the end of the implementation, they had difficulties in developing new models without any help.

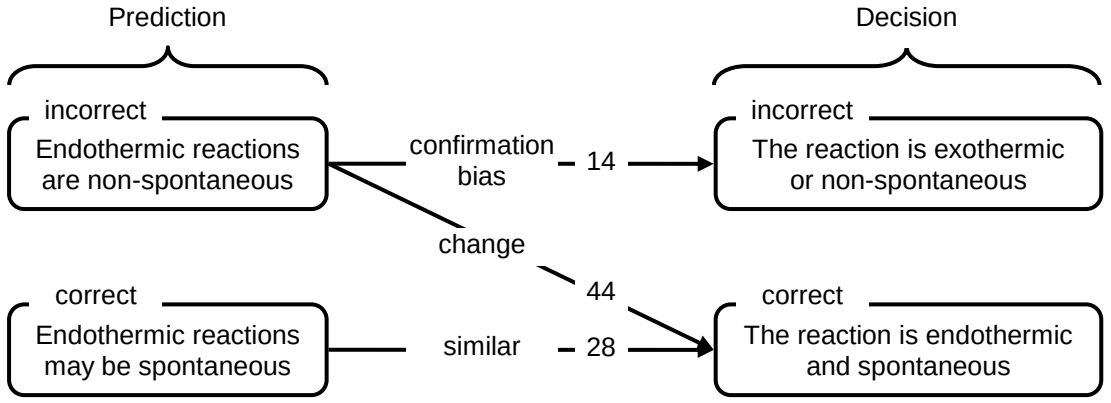

Fig. 1. Students' predictions and decision about an endothermic-spontaneous reaction

Most of the participants (N:24) who attended in the inquiry-type experiment (N:30) did not think that this reaction that erroneously occurred by itself is endothermic. Following the argumentation and reasoning sessions, they developed their models indicating that the reaction is endothermic and that the potential energy of the species is increased. The types of thinking determined in the model development were as follows:

- **Deductive reasoning:** Two types of the deductive reasoning were encountered in the model development. The first was that according to the law of conservation of energy, the potential energy of species must increase if their kinetic energy decreases. The other was that if the kinetic energy of the species decrease and there is no energy transfer from the system to the surroundings, the generated energy is stored in the system/products or transformed into another energy type, according to the law of conservation of energy.
- **Abductive reasoning:** Some students further suggested thoughts in order to explain their inference that the potential energy of the species increased and that the energy is stored in the system. The rupture of the bonds, the storage in products' bonds, the storage in products, the excessive energy stored in products, and the transformation to the chemical energy were among the students' ideas.
- **Analogical reasoning:** Some of the participants were benefited from analogies while developing their models. The change in the attraction forces of water's change of state, the change of potential and kinetic energy during a ball's movement, the change of attraction force between particles in different states of matter and temperature were among the students' analogies.
- **Imagery:** Some of the participants used imageries based on the reaction container and chemical reaction equation. For example, they imagined the reaction equation, the difference of the products from the inputs, the structure and movement of the particles, their interaction with each other, and chemical bonds.

4. Conclusion

The study first revealed that a vast majority of the participants thought that endothermic reactions are nonspontaneous and that observing an endothermic reaction which is spontaneous changed their initial decisions. However, most of the participants did not classify this reaction under the heading as endothermic reactions in a non-informative situation. Argumentation among them was effective in changing their decisions; the reasoning support reconstructing the problem initiated their thinking process for the model development. The participants who abandoned their initial understanding and reconstructed the problem developed new models without any difficulty. In addition, many structures that can be related to the creativity were encountered in the model development.

This study proposed an effective way of developing creative models [7, 10]. Based on the results, this way was recommended to be used in inquiry activities in science education in order to help students to develop models.

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