Education and Science

Original Article

Vol 48 (2023) No 215 31-53

Supporting 7th-Grade Students' Model-Based Explanations about Energy Transformations through Design Thinking *

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Abstract

Learning environments should give opportunities for students to learn the topic of energy transformations that include interdisciplinary, and difficult to understand concepts meaningfully. For this purpose, design thinking, an innovative approach, was employed in the present study. In this context, a module based on design thinking on energy transformations was developed and implemented to 7th-grade students. In addition, the development of students' model-based explanations on the topic of energy transformations was examined. In the study designed as a design-based empirical research, pre- and post-model-based explanations created by students were used as data collection tools. Two rubrics were developed for components and sequences as elements of model-based explanations, benefiting from expert opinions for data analysis. As a result of the implementation of design thinking, it was revealed that the level of the components that the students used in relation to the concepts falling under energy transformations and of the sequences they established, in short, their model-based explanations improved. The current study contributes to the literature by providing information on how the design thinking approach supports the development of middle school students' model-based explanations about energy transformations.

Keywords

Design thinking
Energy transformations
Middle school students
Model-based explanations
Science lessons

Article Info

Received: 02.02.2022
Accepted: 02.03.2023
Published Online: 07.03.2023

DOI: 10.15390/EB.2023.11605

* This article is derived from Ayşe Çiftçi's PhD dissertation entitled "Development and implementation of a design thinking based energy transformations module", conducted under the supervision of Mustafa Sami Topçu. Additionally, it is orally presented at the National Association of Research in Science Teaching (NARST) in 2021.

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Introduction

Design thinking (DT) is a human-centered approach that includes the stages of generating idea and creating an invention through prototype development for this idea (Hehn & Mendez, 2022; Melles, Anderson, Barrett, & Thompson-Whiteside, 2015). DT approach has gained importance in education as an approach that develops the learning and teaching skills necessary for the 21st century (Cook & Bush, 2018; Çiftçi & Topçu, 2020; Retna, 2016). In addition, DT approach also contributes to the development of students' experiential learning and the learning of interdisciplinary content (Canestraro, 2017; Cook & Bush, 2018; Kwek, 2011). In the DT approach, empathize, define, ideate, prototype, and test stages are followed cyclically, and this allows the stages to review the information existing in mind (Deepa, 2020). The fact that iterative processes, not linear processes, contribute to students' learning the topics effectively (Nordine, Krajcik, & Fortus, 2011) can be the reason for why DT approach supports learning. Similarly, in the literature it has been emphasized recently that design-based approaches are very effective in learning science (Çiftçi & Topçu, 2020; Chusinkunawut, Henderson, Nugultham, Wannagatesiri, & Fakcharoenphol, 2020; Ladachart, Radchanet, & Phothong, 2022; Nichols, Musofer, Fynes-Clinton, & Blundell, 2021; Yang, Kim, & Kang, 2020).

Contributions of DT approach involve supporting students' model development skills thanks to sketching and prototyping stages of it (Nickerson, 1994; Vial, 2013). Modeling is considered as the language of DT (Andreasen, 1994; Baynes & Norman, 2012; Cross, 2006). Besides, model development is one of the seven science and engineering practices involved in Next Generation Science Standards (Next Generation Science Standards [NGSS] Lead States, 2013). Accordingly, it is important to examine the development of students' model-based explanations (MBEs). In addition, since DT involves an iterative process as in modeling and MBEs (Bressler & Annetta, 2022; Razzouk & Shute, 2012; Tellioğlu, 2016), it is expected from the present research that students' MBEs will improve.

In the current research, the topic of energy transformations, which has an interdisciplinary content (Heron, Michelini, & Stefanel, 2009; Kurnaz, 2011; Nordine & Lee, 2021), is studied through DT approach. Energy and related concepts are among the fundamental and important concepts in international exams such as TIMSS (Trends in International Mathematics and Science Study) and PISA (Programme for International Student Assessment) and Science Education Standards in the world (Duit, 2014), and are among the 7 crosscutting concepts determined by NGSS (2013). Since crosscutting concepts support the comprehension of science and engineering practices and the basic ideas in these fields, it is important to learn these concepts (NGSS, 2013). As the topic of energy transformations contains abstract concepts and concepts that are difficult to understand by students (Bezen, Bayrak, & Aykutlu, 2016; Chen et al., 2014; Duit, 1984; Hartley, Momsen, Maskiewicz, & D'Avanzo, 2012; Kurnaz, 2011), teaching of this topic requires using innovative education approaches (Aydın & Balım, 2005; Güven & Sülün, 2018; Fortus et al., 2019; Fry, Dimeo, Wilson, Sadler, & Fawns, 2003; Kurnaz, 2011; Küçük, 2022; Trumper, 1990, 1991). In line with the above-mentioned statements, a DT-based module was developed for the energy transformations topic in the present study and was implemented to middle school 7th-grade students. In addition, the development of 7th-grade students' MBEs on energy transformations was also examined. In this context, the present study investigates the following research question:

- To what extent does design thinking approach support 7th grade students' model-based explanations related to energy transformations?

Background of the Study and Literature Review

Students' Difficulties in Learning Energy Transformations

It is important to learn about energy transformations in a meaningful way because energy transformations are one of the four basic concepts (energy transformation, energy transfer, energy conservation, energy degradation) treated as forms of energy in physics (Duit, 2014). Moreover, energy is an important, central and comprehensive crosscutting concept utilized in many disciplines (Fortus et al., 2019; NGSS, 2013) and lays the groundwork for many issues (Fortus et al., 2019; Hartley et al., 2012).

For example, biologists utilize energy to define the relationships between organisms in an ecosystem; chemists interpret chemical reactions according to energy changes; geologists use conservation of energy to create models that describe plate tectonics; astrophysicists make use of energy conservation while picturing the shape and structure of the universe (Nordine, 2007). However, studies have shown that at the end of K-12 (12-year preschool, primary and secondary education) education, most students have difficulty in understanding energy and cannot use energy to make sense of various phenomena and issues (Fortus et al., 2019). Moreover, the usage of energy in different disciplines makes it difficult to learn this concept effectively (Güven & Sülün, 2019; Kurnaz, 2011; Liu & Park, 2014). Due to the use of energy in different disciplines with different types and purposes, students can construct different perceptions of energy (Kurnaz, 2011).

The fact that energy has an abstract content (Bezen et al., 2016; Chen et al., 2014; Duit, 1984; Hartley et al., 2012; Kurnaz, 2011) also causes students to face difficulties while learning this topic. For example, students associate energy with materials such as batteries and fuel rather than with abstract structures (Duit, 1984). Similarly, Yürümezoğlu, Ayaz, and Çökelez (2009) state that students can grasp the transformation when there is a situation that can be observed during the process of energy transformations, and that they experience problems in understanding the transformation in situations that cannot be directly observed. Accordingly, it can be stated that students also face problems in the process of learning energy transformations due to its abstract content. In addition, it is argued that the concepts related to energy are structured at a basic level as kinetic and potential energy in the minds of students and that students focus only on the basic concepts rather than the transformation and conservation of these concepts (Kıryak, Candaş, Karanisoğlu, & Özmen, 2019). This result clearly reveals that students have difficulties in the topic of energy transformations.

One reason for these problems is that traditional education (i.e. lecture-based classroom instruction) does not include energy transformations experienced in daily events but rather simple energy calculations (Fortus et al., 2019; Nordine, 2007). The mismatch between the use of energy in daily life and its scientific meaning makes it difficult to learn, too (Brook, 1986; Chen et al., 2014; Nordine, 2007; Solomon, 1983; Wijayanti, Raharjo, Saputro, & Mulyani, 2018). For example, when individual states that sleep gives him energy in daily life (Chen et al., 2014) or an individual says, "I have a lot of energy," it indicates that they associate energy with being strong in a wrong way (Brook, 1986).

In line with the statements given above, it can be said that students experience problems in learning energy and energy transformations. It is important to eliminate these problems because energy and related concepts are the fundamental and important concepts that must be learned effectively in in 6-8th grades (NGSS, 2013) and are among the fundamental concepts that are also included in international exams such as TIMSS and PISA (Duit, 2014).

Design Thinking (DT) in K-12 Education

Design thinking (DT) was first introduced by Simon in his seminal studies on the nature of design in 1969 and was defined by Rowe in 1987 for use in the design world (McCurdy, Nickels, & Bush, 2020). The DT approach has been popularized by Stanford University (Cabello Llamas, 2015; Yang, 2018). The DT approach is a human-centered and empathy-oriented approach aiming to understand problems and offer innovative solutions for them (Aflatoony, 2015; Canestraro, 2017; Taşpınar, 2022; von Thienen, Meinel, & Nicolai, 2014).

The use of the DT approach in education has significant outputs such as facilitating the instruction of interdisciplinary topics (Henriksen, 2017), improving students' 21st century skills (Girgin, 2019; Lin, Shadiev, Hwang, & Shen, 2020; Retna, 2016) and their academic performance (Girgin, 2019; Simeon, Samsudin, & Yakob, 2020), providing real-world experience (Crane, 2018), helping to associate the acquired knowledge with real-life (Mahil, 2016), raising motivation for learning (Yang, 2018), helping students communicate (Yılmaz, 2022), supporting the development of science content knowledge (Fortus, Dershimer, Krajcik, Marx, & Mamlok-Naaman, 2004; Kolodner et al., 2003; Simeon et al., 2020), determining and meeting the needs in educational environments (Aydemir, 2019). Besides, DT approach supports the connection between the existing knowledge and new knowledge and active learning (Kwek, 2011; Özekin, 2006; Simeon et al., 2020). The above-mentioned outputs of DT approach obtained in the literature clearly reveal the necessity of implementing this approach in K-12 learning environments.

There are some models (e.g., 3I (Inspiration, Ideation, Implementation) model, HDC (Hear, Create, Delivering) model, Stanford d.school design thinking model) that will facilitate the implementation of the DT approach in learning environments are available. In the present study, the Stanford d.school design thinking model was employed, because this model contributes to boosting students' motivation for learning, starting with the empathy phase (Cook & Bush, 2018; Henriksen, Richardson, & Mehta, 2017). In addition, since the stages are followed in a cyclical manner in this model while designing, the model enables the topics to be learned more easily with iterative processes (Nordine et al., 2011). Detailed information about the Stanford d.school design thinking model (Figure 1) and its stages (empathize, define, ideate, prototype, test) is given below.

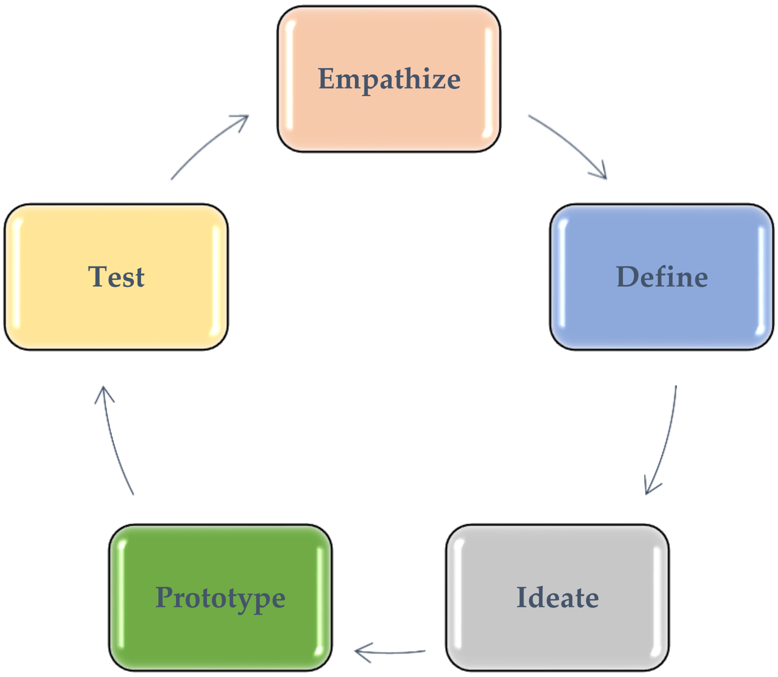


Figure 1. Steps of Stanford Design Thinking Model (adapted from Stanford d.school)

There are 5 stages in the Stanford d.school model. These stages are explained below (Henriksen, Gretter, & Richardson, 2020):

1. The *empathize* stage includes empathizing with individuals through methods such as observation and interview, thus understanding the problem.
2. *Define:* At this stage, the focus is on defining the problem more comprehensively, clearly and succinctly and setting the problem's limits.
3. The *Ideate* stage involves generating as many solution-oriented ideas as possible through brainstorming.
4. In the *prototype stage*, one of the generated ideas is selected and the idea is turned into a concrete model.
5. In the *test phase*, what works and what does not work and what is needed in the prototype are evaluated together with the students.

Models and Model-Based Explanations (MBEs)

In order to develop scientific literacy, students must engage in scientific practices for the development of their conceptual understanding regarding core concepts (National Research Council [NRC], 2012). One of the basic scientific practices that develop students' conceptual understanding of core concepts is modeling (Zangori, 2015). Models are representative of natural systems (Forbes, Vo, Zangori, & Schwarz, 2015). Scientific explanations that students create based on modeling are called model-based explanations (MBEs), and within these explanations, students include cause and effect relationship (Zangori, 2015).

MBEs have some epistemic features, such as components and sequences between these components (see Appendix 2) (Zangori & Forbes, 2016). The *components* of MBEs contain some elements of the topic students select to show, such as potential energy, kinetic energy, velocity, height, rough surface, smooth surface, and friction force. *Sequences*, on the other hand, involve showing relationships between components. In this explanations, students *develop* models and MBEs in response to a question or problem in line with their preliminary knowledge. Components and sequences enable students to *use* MBEs on the topic. As students develop new understandings on the topic, they *evaluate* and *revise* their first models (Peel, Zangori, Friedrichsen, Hayes, & Sadler, 2019). The iterative modeling cycle, which consists of such stages as develop, use, evaluate and revise, enables students' conceptual development (Peel, Zangori et al., 2019; Zangori, Peel, Kinslow, Friedrichsen, & Sadler, 2017).

In the literature, MBEs are used as both a sense-making strategy and an evaluation strategy (e.g. Peel, Zangori et al., 2019; Zangori et al., 2017). In the present research, MBEs were used only as an evaluation strategy (see Peel, Zangori et al., 2019). In this research, the students' MBEs about kinetic and potential energy transformations, the effect of friction force on kinetic energy and the effects of air resistance were evaluated. Components, sequences and rubrics on these concepts are given in Appendix 2.

Method

The design-based empirical research method was adopted in the present study (Brown, 1992; Collins, 1992; Zangori & Forbes, 2016). This method is a systematic but flexible methodology that aims to improve educational practices through design, development, implementation, and analysis based on the collaboration between researchers and practitioners and in an iterative manner (Wang & Hannafin, 2005). In addition, in this method, the emphasis is placed on studying learning through curriculum design and implementation (Design-Based Research Collective, 2006). In this study, the research cycle created by McKenney and Reeves (2013) was used within the scope of design-based empirical research. This research cycle includes of these phases: 1) design and development, 2) implementation and data collection, 3) analysis and results. In this context, a module based on DT approach on energy transformations was developed. The module has been developed according to the learning outcomes regarding energy transformations in Science Teaching Program updated in 2018 by the Turkey Ministry of National Education. A science teacher who volunteered for getting informed and teach about this approach was trained about the developed module and the DT approach; and afterwards, this science teacher taught the energy transformations module to the 7th grade students. In addition, the development of MBEs of students were also evaluated in the research.

Participants

Within the scope of the present study, thirty-six middle school 7th-grade students (thirteen girls, twenty-three boys) took part in the study in the fall semester of the 2018-2019 academic year. Students' age range is 11-14. These students are educated in the center of a province of Eastern Anatolia region in Turkey. Besides, these students did not receive design thinking training before and did not learn about energy transformations. In addition, two students in the pre-implementation and four students in the post- implementation did not answer the "Model-Based Explanations Assessment Scale" (Appendix 1), because these students did not join the class on the day the data collection tools were applied. Apart from these six students, two students did not volunteer to participate in the data collection process. Therefore, the findings regarding the MBEs of twenty- eight students were presented.

The science teacher, who implemented the DT-based module on the topic of energy transformations, was also trained about this approach by researcher (first author) for the first time within the current research scope. The teacher is male and thirty-three years old. Additionally, the teacher has 7 years of teaching experience. The science teacher participated in the present study on a voluntary basis. Moreover, the teacher volunteered to receive and provide training on DT approach. In this context, the researcher (first author) met with the teacher for three hours a day, twice a week for four weeks. The researcher gave training to the teacher on the definition and characteristics of DT approach, the Stanford d.school design thinking model and the stages of empathize, define, ideate, prototype, test. The researcher gave detailed information to the teacher about the activities implemented within the context of the current study and carried out these activities (my roller coaster, I am designing a car and adventure lovers) together with the teacher. In order to determine whether the training given to the teacher was sufficient or not, views were constantly exchanged with the teacher during the implementation of the activities.

Expert opinion on the content of the teacher training was obtained from a researcher who is an expert on the DT approach, a researcher who is an expert in the field of Turkish Language and Literature, a researcher who is an expert in the field of Physics and two science teachers, and necessary corrections were made in line with the feedbacks received from them. Continuous feedback was received from the teacher who was trained in the process, and the process was ensured to progress in an understandable way. When there were points that were not understood, more clear and understandable examples were given to the teacher. For example, the teacher experienced conceptual difficulties related to the DT stages at the beginning and the researcher gave him more explanations on this topic and it was ensured that the resources related to the topic were examined. In addition, the teacher stated that he usually used the lecture-based classroom instruction and stated that he would have difficulties when implementing the module because of the student-centred approach of DT and accordingly the changing teacher and student role. In order to eliminate these concerns and help him get used to the process, the activities in the module were applied to him, he watched the videos of the activities related to the DT and the activities in the module (my roller coaster, I am designing a car and adventure lovers) were examined in detail together with the teacher four times. In addition, suggestions from the teacher were taken into account and revisions were made in the activities. For example, soap would have been used for warm-up activities within the "I am designing a car" activity. The teacher suggested a piece of ice instead. The material list was updated according to the teacher's suggestion.

The Process of Curriculum Design and Implementation

Initially, we considered the learning outcomes of the Ministry of National Education Science Curriculum of Turkey for module design (Ministry of National Education [MoNE], 2018). These learning outcomes are:

1. Categorize energy as kinetic and potential energy by associating it with the concept of work.
2. Conclude that energy is conserved through conversion of kinetic and potential energy types into each other.
3. Express the effect of friction force on kinetic energy with examples.
4. Become aware of the effect of air or water resistance on life.
5. Design a vehicle to reduce the effect of air or water resistance (Ministry of National Education [MoNE], 2018).

In the present study, three basic activities (my roller coaster, I am designing a car and adventure lovers) for DT approach on energy transformations and warm-up activities for these activities were implemented. The activities were developed according to the objectives given above, taking into account the issues in daily life. My roller coaster activity was developed to address the objectives of "Categorize energy as kinetic and potential energy by associating it with the concept of work" and "Conclude that energy is conserved through conversion of kinetic and potential energy types into each other". In the "I am designing a car" activity, the objective of "Express the effect of friction force on kinetic energy with examples" was addressed. On the other hand, the objectives of "Become aware of the effect of air or water resistance on life" and "Design a vehicle to reduce the effect of air or water resistance" were addressed in the activity "Adventure Lovers" activity. While developing the activities in the current study, the activity template given below, which is from the study of Çiftçi and Topçu (2020), was used (See Table 1).

Table 1. Activity template for design thinking (Çiftçi & Topçu, 2020)

Activity Name
Grade Level
Unit Name
Topic
Time
Scientific Concepts
Safety Precautions (if necessary)
Purpose and Summary
Learning Outcomes
Material and Technical Equipment
Warm-up Activities
Scenario-Story
Design-Based Thinking Process
• Empathize
• Define
• Ideate
• Prototype
• Test
Professions related to the Activity
Key Questions
Resources

After the module was developed, expert opinion was obtained from two faculty members who are specialized in science education, a science teacher and a faculty member who is specialized in the field of Turkish Language and Literature, and necessary corrections were made in line with the opinions and suggestions of the experts. In the design and implementation of the activities the stages of the Stanford d.school design thinking model (empathize, define, ideate, prototype, and test) were followed. The implementation process lasted about five weeks, including data collection. During the implementation of the activities, the students worked in groups. In this context, six groups were formed, and there were six students in each group. In addition, the students were asked to decide as a group what the roles of each group member (drawing, supplying materials, group leadership, etc.) would be. The time schedule for the implementation of the activities is illustrated in Figure 2.

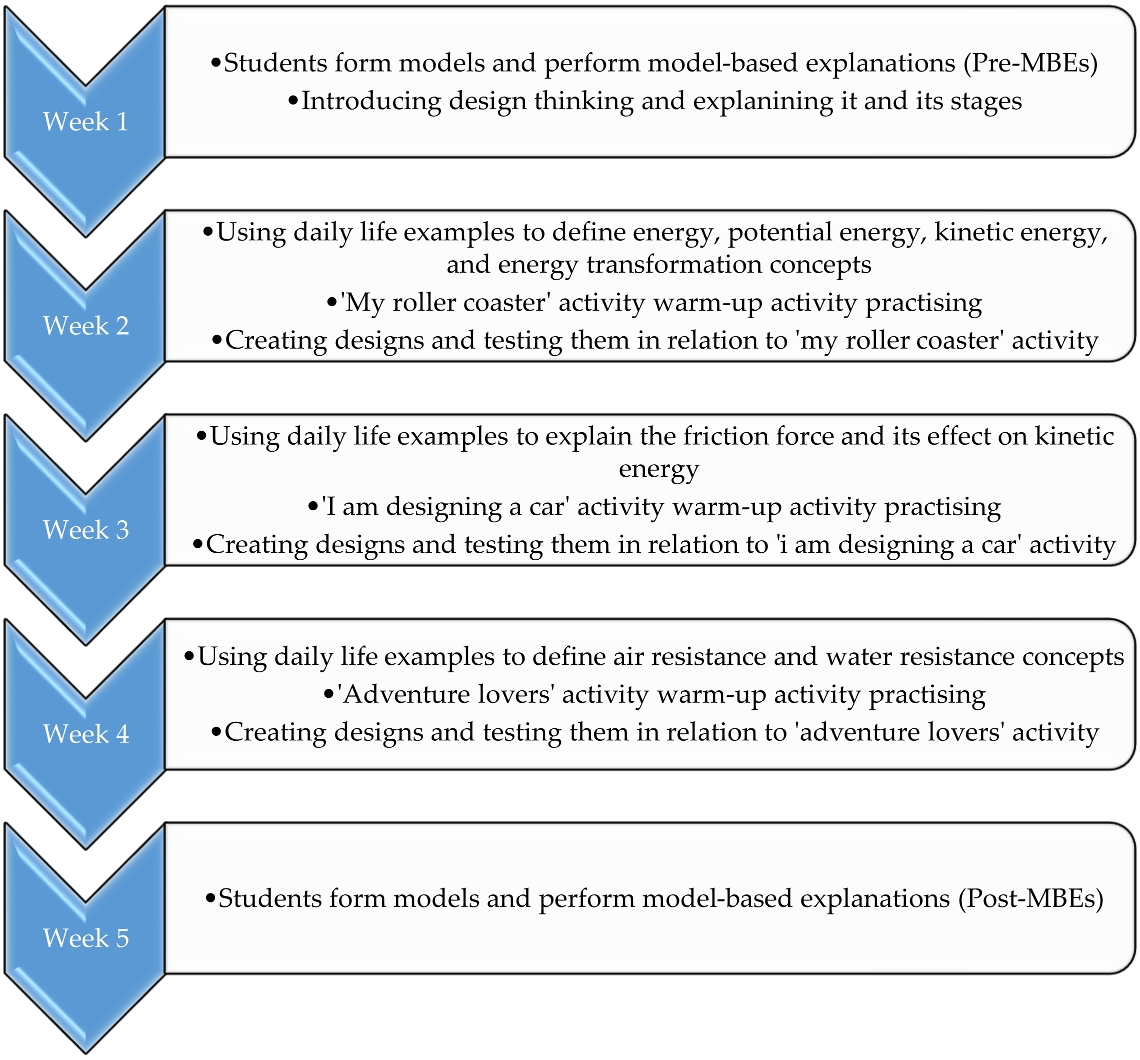
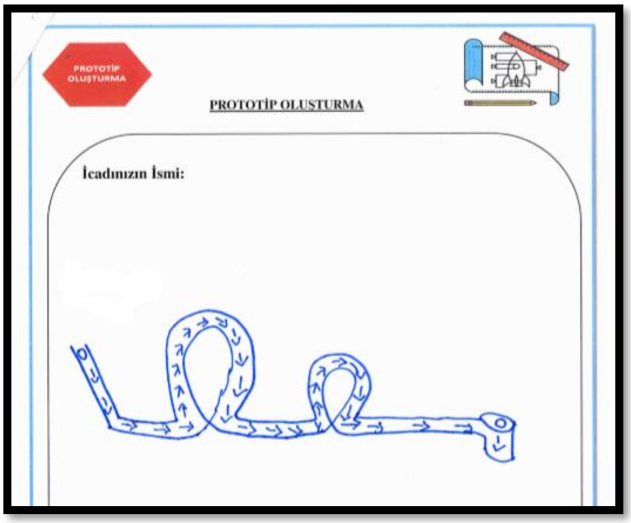
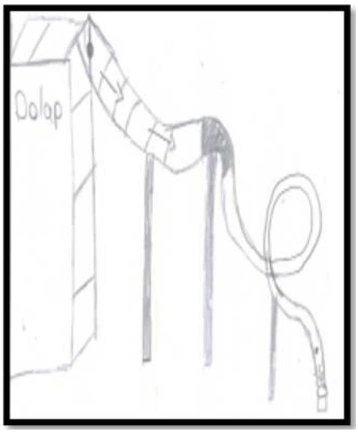


Figure 2. Content of Implementation

In this research, while developing activity according to the Stanford d.school design thinking model, the five stages described above were followed iteratively. For example, in roller coaster activity (Figure 3), the aim was to determine the needs and wishes of the students regarding the rollercoaster to be designed by interviewing other students at the empathy stage (*Empathize*). The groups interviewed a student and asked him/her how he/she wanted to feel (excited or calm) on a roller coaster. During the *define* stage, students were guided to define the boundaries of the current problem clearly. In the *ideate* stage, brainstorming was used to generate solutions and ideas for the problem. Then, the students made a prototype of the idea they produced through brainstorming (*Prototype*). Then, roller coasters designed by the groups were evaluated according to some criteria (e.g. being suitable for the needs of the student selected as a customer) (*Test*). In the designs that failed in the test phase, the students went back to the other stages and tried to improve their designs. In Figure 3 below, a picture of the first and last prototype drawings of a group and their designs are given.



a) The first drawing of the prototype



b) The last drawing of the prototype

c) Picture of the design

Figure 3. Pictures related to the roller coaster activity (Some images in Figure 3 were also used in Çiftçi and Topçu (2020))

Data Sources

The data source of the research was model-based explanations (MBEs). Detailed information about the data source is provided below.

Model-Based Explanations (MBEs)

Data collection source of the research was the model-based explanations (MBEs) of the students. Accordingly, the students' pre-MBEs and post-MBEs were collected through scenarios regarding 'kinetic and potential energy transformations', 'effect of friction force on kinetic energy' and 'effects of air resistance, and questions requiring students to explain events in the scenarios. The scenarios were taken from the studies by İdin and Aydoğdu (2016) and Aktaş (2017) and were revised and questions were prepared by authors. After these questions were prepared, expert opinions were received from a faculty member working on modeling, a faculty member who is an expert in physics, three faculty members working in science education, a faculty member in the field of assessment and evaluation, and two science teachers. In addition, the pilot implementation of the scenario presented and the questions asked was conducted with 41 8th grade students who were learning this topic. Necessary corrections were made in line with the suggestions and criticisms offered by the experts and the answers given by the students during the pilot implementation. The scenarios presented and the questions asked to enable students to produce MBEs are given in Appendix 1.

Data Analysis

The students' responses to the assessment tool consisting of pre-MBEs and post-MBEs about the topics of 'kinetic and potential energy transformations', 'effect of friction force on kinetic energy' and 'effects of air resistance' were evaluated. In order to evaluate the students' MBEs, two different rubrics were developed by the researchers for each topic (kinetic and potential energy transformations, effect of friction force on kinetic energy and effects of air resistance). One of these rubrics was designed to evaluate the related *components* and another to evaluate the *sequences*. While developing the rubrics, expert opinion was received from a faculty member who is an expert in physics, two faculty members who are experts in science education and two science teachers. In line with expert opinions, the rubrics were corrected and finalized. These developed rubrics are provided in Appendix 2.

There is a general tendency in the literature in which a certain percentage of the data is examined by another researcher and this percentage is generally lower than 30% (e.g. Forbes, Zangori, & Schwarz, 2015; Peel, Sadler, & Friedrichsen, 2019). In the current study, thirty percent of the students' MBEs were examined independently by the two researchers according to the rubrics for inter-coder reliability. In this study, inter-coder reliability was found as 95% for the MBEs. Moreover, the two researchers came together and reconciled by exchanging ideas for areas where there was no consensus. Therefore, the other data (70%) were analyzed by the first author. The students' MBEs were evaluated at 4 levels in line with the components and sequences. These are: Level 0, Level 1, Level 2 and Level 3. What was attached importance in each level is explained in detail in Appendix 2. Besides, in order to calculate the mean scores of the students, 0 points were given to Level 0, 1 point to Level 1, 2 points to Level 2, and 3 points to Level 3.

An example of Student 13's pre-model, post-model and MBEs are provided below to demonstrate how models and MBEs related to 'kinetic and potential energy transformations' are analyzed.

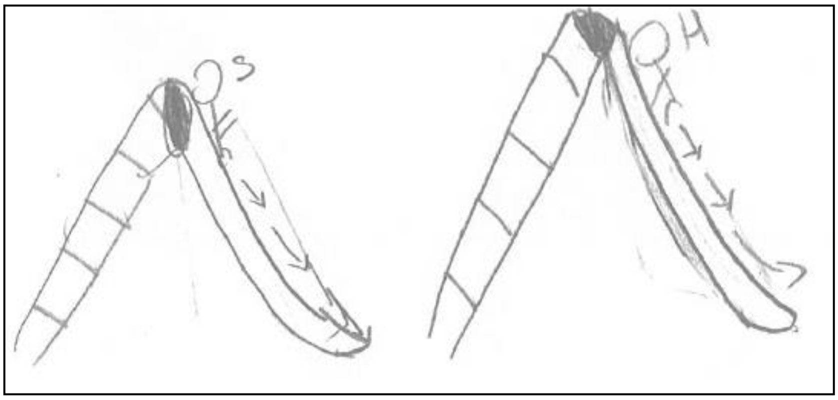


Figure 4. Student 13's Pre-Model on Kinetic and Potential Energy Transformations

Student 13's explanation regarding the pre-model:

"Serkan touches the ground before Hakan. Serkan spends less kinetic energy."

In her explanation for the pre-model (Figure 4), Student 13 only included the kinetic energy component and did not establish any connection between components. For this reason, components fall into Level 1 according to the rubric and Level 0 according to the sequences rubric. The post-model of the same student and her explanations for this model are given below.

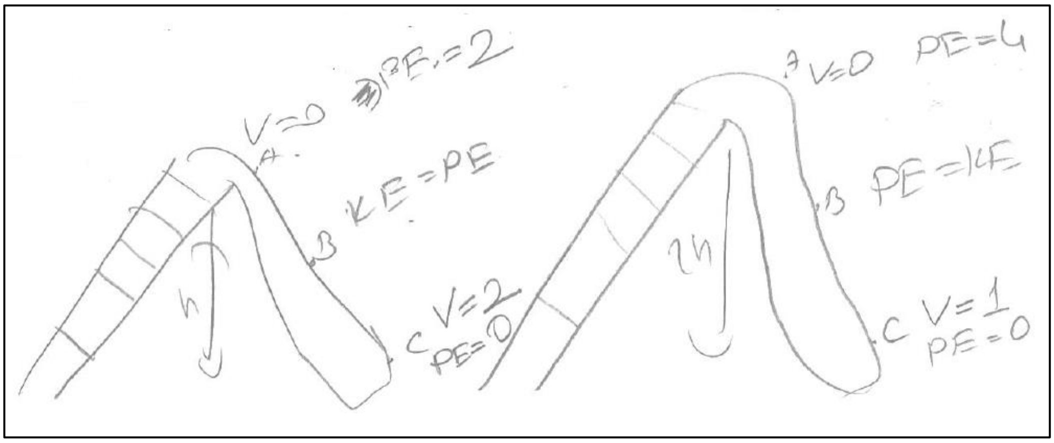


Figure 5. Student 13's Post-Model Regarding Kinetic and Potential Energy Transformations

Student 13's explanation:

"At point A, the velocity of the two [Hakan and Serkan] is zero. There is no kinetic energy because there is no velocity. At point B, potential energy decreased and kinetic energy increased in both. Thus, at point B, potential and kinetic energy became equal. At point C, potential energy decreased further and became zero. Kinetic energy increased more and velocity increased 2 times more than the one at point A."

It is seen that Student 13 included *components* of kinetic energy, potential energy, height, velocity and energy transformation in her post-model (Figure 5) and in her explanation. In addition, this student included the *sequences* of the relationship of potential energy with height, the relationship of kinetic energy with velocity, and the transformation of potential energy into kinetic energy. Therefore, this explanation of Student 13 corresponds to Level 3 according to the two rubrics (*components and sequences)*.

Results

In this section, findings regarding the components and sequences present in the pre- and post-MBEs of the students, and findings regarding at which level they present components and sequences are provided.

In the present research, how the MBEs of middle school students about kinetic and potential energy transformations, the effect of friction force on kinetic energy and the effects of air resistance change over time were analyzed. The level of the components that the students used and that of the sequences they established were evaluated separately. The change in the components of the students' pre- and post-models related to this topic and these concepts is given in the table below. To this end, the frequency for the levels in which the components are found is calculated.

Table 2. Findings Regarding the Levels of the Components

Concept/Topic	**Pre-MBEs& Post-MBEs**	**Level (f)**			
		Level 0	**Level 1**	**Level 2**	**Level 3**
Kinetic and Potential Energy Transformations	Pre-MBEs	11	14	1	2
	Post-MBEs	1	5	7	15
Friction Force and Kinetic Energy	Pre-MBEs	5	6	10	7
	Post-MBEs	0	0	6	22
Air Resistance	Pre-MBEs	10	13	2	3
	Post-MBEs	1	6	11	10

When the Table 2 is analyzed, it is seen that the level of the components that the students included in their models in relation to 'kinetic and potential energy transformations', 'effect of friction force on kinetic energy' and 'air resistance' improved. Findings regarding the levels of the sequences that the students established related to this topic and these concepts are shown in the Table 3 below.

Table 3. Findings Regarding the Levels of the Sequences

Concept/Topic	Pre-MBEs& Post-MBEs	Level (f)			
		Level 0	**Level 1**	**Level 2**	**Level 3**
Kinetic and Potential Energy Transformations	Pre-MBEs	28	0	0	0
	Post-MBEs	7	13	5	3
Friction Force and Kinetic Energy	Pre-MBEs	10	14	4	0
	Post-MBEs	2	7	15	4
Air Resistance	Pre-MBEs	18	8	2	0
	Post-MBEs	4	13	7	4

When Table 3 is analyzed, it is seen that the level of the sequences between the components that the students established in relation to 'kinetic and potential energy transformations', 'effect of friction force on kinetic energy' and 'air resistance' in their models improved. In order to evaluate the change in the students' pre- and post- models regarding this topic and these concepts more precisely, the mean score for components and sequences was also calculated separately. The results revealed that the students' mean scores for both components and sequences increased over time (Figure 6).

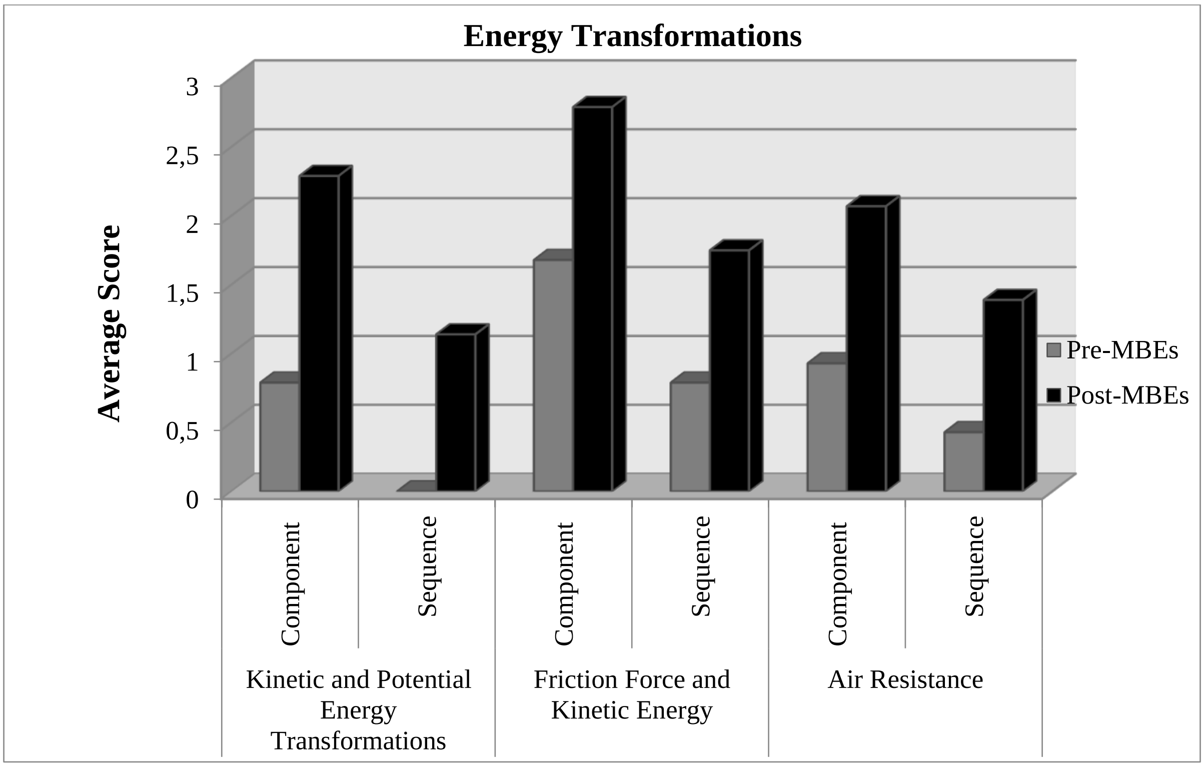


Figure 6. Pre- MBEs and Post-MBEs Scores.

While the mean score of the students regarding the components about 'kinetic and potential energy transformations' in the pre-model was 0.79, it was 2.29 in the post-model. The mean score for the sequences was 0 in the pre-model while it was 1.14 in the post-model. The mean score of the students regarding the components was 1.68 in the pre-model about 'effect of friction force on kinetic energy' while it was 2.79 in the post-model. The mean score for the sequences was 0.79 in the pre-model while it was 1.75 in the post-model. The mean score of the students regarding the components was 0.93 in the pre-model about 'effects of air resistance' while it was 2.07 in the post-model. The mean score for the sequences was 0.43 in the pre-model while it was 1.39 in the post-model. Besides, it is a striking finding that when the mean scores of students regarding their pre-MBEs are compared, the highest mean score is on the "effect of friction force on kinetic energy." In addition, it is seen in Figure 6 that the mean scores of the students for the components are higher than the mean scores for the sequences.

Discussion, Conclusion and Suggestions

The purpose of current research is to explore how middle school 7th-grade students' MBEs of energy transformations change after implementation of the DT-based module on energy transformations. For this purpose, students' MBEs were evaluated. The results show that, as a result of the implementation of the module for DT, the MBEs about the concepts within the scope of energy transformations improve over time when the pre-MBEs and post-MBEs are compared. Similarly, in the related literature, it is emphasized that the DT approach contributes to more effective learning of science topics (Chusinkunawut et al., 2020; Çiftçi & Topçu, 2020; Ladachart et al., 2022; Nichols et al., 2021; Yang et al., 2020). In the current study, apart from the studies on the DT approach in the literature, learning about energy transformations was addressed and model-based explanations were examined. For example, Çiftçi and Topçu (2020) focused on the views and experiences of middle school students on the DT approach in science teaching. Ladachart et al. (2022), on the other hand, carried out DT applications on the topic of pulley with the participation of middle school 8th grade students and determined that DT facilitated the conceptual learning of the students about the topic of pulley. Chusinkunawut et al. (2020), in their study where they carried out design-based science applications with the participation of ninth-grade students, revealed how students learned science, had productive conversations and solved problems. In another study, Yang et al. (2020) conducted DT-based chemistry classes with high school second grade students and concluded that their empathy, problem solving and science and design competences improved. In summary, no study could be found on how the MBEs of middle school students are supported by teaching based on the DT approach in the literature. In future studies, students' MBEs related to different science topics can be examined by integrating the DT approach to different science topics.

The fact that the Stanford d.school design thinking model embodies iterative and nonlinear stages may be a factor that promotes the development of MBEs. Students followed the empathize, define, ideate, prototype, and test stages cyclically and iteratively while designing. For example, in the process of testing the prototype, in cases where the design failed to meet the predetermined criteria, students returned to other stages and had the opportunity to review their knowledge. This provides important opportunities for designer students to review, question, and improve their initial assumptions, knowledge, and understanding (Deepa, 2020). Similarly, in the literature, it is stated that students do not acquire information passively (Simeon et al., 2020). On the other hand, they interpret the acquired information, change it by reviewing, and translate the information into solutions for the problem in applications based on the DT approach (Simeon et al., 2020). These features of the DT approach (being iterative, nonlinear and providing the opportunity to review information) also support students to establish a connection between the existing information and new information and thus to learn meaningfully (Kwek, 2011; Özekin, 2006; Simeon et al., 2020). It is stated in the literature that design-based approaches are very effective in learning scientific concepts (Chusinkunawut et al., 2020; Çiftçi & Topçu, 2020). Therefore, the DT approach can be utilized not only in the topic of energy transformations but also in teaching other science topics. In future studies, DT-based teaching materials, units, and modules can be designed in other science topics.

Another reason in relation to the development of students' MBEs may be that the Stanford d.school design thinking model used in the current study includes empathy and prototype stages. Because it is emphasized in the literature that developing prototypes and establishing empathy can be used as a powerful classroom tool to attract the attention of the students to the lesson (Carroll et al., 2010; Cook & Bush, 2018; Henriksen et al., 2017) and empathy can support their interest in learning science concepts (McCurdy et al., 2020). Therefore, in the present study, empathy and prototype stages may have enabled students interested in learning about energy transformations. Besides, the prototype stage attracts the attention of students by transforming ideas into products (Çiftçi & Topçu, 2020), supports the learning of topics based on learning by doing and experiencing, and the students gain experiences with a hands-on approach (Deepa, 2020). From this point of view, it can be said that the empathy and prototype stages of DT model can be used to enhance students' motivation and interest in learning.

Visualization may be one of the reasons why DT improves students' MBEs. Because visuality is considered as the basic element of DT (Tschimmel, 2012). In this context, sketching and prototyping falling under the stages of DT (Sipe, 2019) which implemented in current research may have contributed to students' skills of model development (Nickerson, 1994; Vial, 2013). In the current research, visuality was provided through sketching and prototyping processes. Students construct models in their minds by sketching and experiencing the prototyping process. This might be an efficient and important factor in the development of students' MBEs. Besides, modeling is considered as the language of DT in the literature (Andreasen, 1994; Baynes & Norman, 2012; Cross, 2006). During the activities we held within the scope of DT, students created models, changed and improved them. Accordingly, it can be said that the activities carried out within the scope of the research contributed to the development of students' models and MBEs. Moreover, in future research, the topic of energy transformations can be taught by integrating the DT approach and modeling applications.

In this research, the mean scores of both components and sequences in the students' MBEs about kinetic and potential energy transformations, the effect of friction force on kinetic energy, and the effects of air resistance increased over time (Figure 6). However, the mean score for the sequences increased less compared to the mean score for the components. This result can be explained by the fact that finding out relationships and establishing sequences between components are more difficult than just specifying components, and require higher levels of cognitive skills. For example, if specifying components is at the remembering level according to Bloom's Taxonomy, establishing sequences or finding out relationships between components is at the analyzing level (Krathwohl, 2002).

It is also a striking finding that the mean scores of the students regarding their pre-MBEs about "Effect of friction force on kinetic energy" are higher than their mean scores for their pre-MBEs on other topics (Figure 6). This result can be explained by the inclusion of learning outcomes related to the frictional force in the Ministry of National Education of Turkey Science Curriculum (MoNE, 2018) in the 5th grade. Since 7th-grade students learn friction force in 5th grade, they have preliminary knowledge on this topic.

In summary, the present research expands the literature by indicating how DT supports students' MBEs regarding energy transformations. Therefore, the development of students' MBEs can be supported by applications based on the DT approach.

Acknowledgements

The present study was completed with the support of the Scientific Research Projects Office of Yıldız Technical University under the Grant Number SDK-2018- 3373.

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Appendices

Appendix 1: Modelling Task

1. **Let's Slide**

   Serkan and Hakan are twins. The height and weight of Serkan and Hakan are equal. They go to a park with their mother. When Serkan runs and occupies the first slide in the park, Hakan takes the other slide. The slides of the twins are of the same width and length. However, Hakan's slide is higher. Serkan and Hakan start to slide at the same time, but they reach the ground at different times.

   a) In this case, show and explain the energy transformations that Serkan and Hakan have undergone until they reach the ground from the top of the slides by drawing a picture. (Frictions will be neglected.)

   Draw a model:

   Explain your model:

....
....
....

   b) Let's assume that the slides of Serkan and Hakan are of the same height and width as well as of the same length. Besides, assuming that the surface of the slide where Serkan slides is rougher and that of the slide where Hakan slides is smoother, which one will reach the ground in a shorter time? Show and explain the reason/reasons by drawing a picture.

   Draw a model:

   Explain your model:

....
....
....

2. The parachutists Cemil and Kemal, whose height and weight are equal to each other, simultaneously make a free jump from the plane which is 12,000 meters above ground level. The opening rate of Kemal's parachute is less than that of Cemil's parachute. After they open their parachutes, it is observed that Cemil lands on the ground after Kemal. Show and explain the reason/reasons for this situation by drawing a picture.

   Draw a model:

   Explain your model:

....
....
....

Appendix 2: Rubrics Designed to Evaluate Model-Based Explanations (MBEs)

1. Rubric for evaluating students' models and model-based explanations about kinetic and potential energy transformations (for the question asked in a)

Level	Description
Components	Potential Energy, Kinetic Energy/Motion Energy, Velocity, Height, Energy Transformations
Level 3	Writing and/or drawing at least 3 components
Level 2	Writing and/or drawing 2 components
Level 1	Writing and/or drawing only one of the components
Level 0	Writing and/or drawing none of the components regarding energy transformations
Sequences between components	
Level 3	Including drawings and/or explanations for at least 3 sequences in Level 1
Level 2	Including drawings and/or explanations for 2 sequences in Level 1
Level 1	Including drawings and/or explanations for only one of the sequences below • Including drawings and/or explanations about the relation of potential energy with height • Including drawings and/or explanations about the relation of kinetic energy with velocity • Including drawings and/or explanations about the transformation of potential energy into kinetic energy • Including drawings and/or explanations related to the decrease of potential energy while kinetic energy increases or vice versa according to the law of conservation of energy.
Level 0	• Not including drawings and/or explanations for any sequences • Or including drawings and/or explanations for a wrong sequence

2. Rubric for evaluating students' models and model-based explanations about the effect of friction force on kinetic energy (for the question asked in b)

Level	Description
Components	Rough Surface, Smooth Surface, Friction Force, Movement, Velocity
Level 3	Writing and/or drawing at least 3 components
Level 2	Writing and/or drawing 2 components
Level 1	Writing and/or drawing only one of the components
Level 0	Writing and/or drawing none of the components about the time that passes until reaching the ground from the top of the slide
Sequences between components	
Level 3	Including drawings and/or explanations for at least 3 sequences in Level 1
Level 2	Including drawings and/or explanations for 2 sequences in Level 1
Level 1	Including drawings and/or explanations for only one of the sequences below • Including drawings and/or explanations about the relationship between friction force and movement • Including drawings and/or explanations about the relationship between the type of surface and friction force • Including drawings and/or explanations about the relationship between the type of surface and the time to reach the ground • Including drawings and/or explanations for the relationship between the type of surface and velocity
Level 0	• Not including drawings and/or explanations for any sequences • Or including drawings and/or explanations for a wrong sequence

3. Rubric for evaluating students' model-based explanations about air resistance (for question 2)

Level	Description
Components	Air Resistance, Contact Surface, Movement, Friction Force, Velocity
Level 3	Writing and/or drawing at least 3 components
Level 2	Writing and/or drawing 2 components
Level 1	Writing and/or drawing only one of the components
Level 0	Writing and/or drawing none of the components regarding air resistance
Sequences between components	
Level 3	Including drawings and/or explanations for at least 3 sequences in Level 1
Level 2	Including drawings and/or explanations for 2 sequences in Level 1
Level 1	Including drawings and/or explanations for only one of the sequences below • Including drawings and/or explanations for the relationship between air resistance and movement • Including drawings and/or explanations for the relationship between contact surface and movement • Including drawings and/or explanations for the relationship between air resistance and contact surface • Including drawings and/or explanations for the relationship between air resistance and the time to reach the ground • Including drawings and/or explanations for the relationship between contact surface and velocity • Including drawings and/or explanations for the relationship between contact surface and the time to reach the ground
Level 0	• Not including drawings and/or explanations for any sequences • Or including drawings and/or explanations for a wrong sequence