Journal of Pedagogical Research
Volume 6, Issue 5, 2022
https://doi.org/10.33902/JPR.202217405

*Research Article*

# Mental model development of preservice science teachers with slow-motion animation and visual material: The case of circulatory system

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This case study aimed to examine whether slow-motion animation and visual materials provide to enhance mental model developments of preservice science teachers (PSTs). A total of 34 PSTs (16 in visual material group and 18 in slow-motion animation group) participated into the study. A mental model application related to circulatory system subject, an observation form, and an open-ended interview form based on the slow-motion animation process were used to collect data. Content analysis was performed to systematically analyze the data. The results showed that the correct model-correct explanation ratios of the PSTs in the slow-motion animation group were higher than those in the visual material group. Based on the observations, the PSTs performed the slow-motion animation in five steps, and the group generally demonstrated these behaviors at the desired level. PSTs expressed their opinions about the slow-motion animation technique in interviews as learning by doing, having fun while learning, and technology supporting and facilitating learning. Using slow-motion animation in education is recommended since it creates an active learning environment for students.

Keywords: Preservice science teachers; Slow-motion animation; Mental model development; Observation; Interview

Article History: Submitted 7 July 2022; Revised 11 October 2022; Published online 12 December 2022

## 1. Introduction

In science, nature and events are systematically examined, the nature of the object is discovered, and unobserved events are predicted. Science lessons are intended to teach scientific concepts, improve learning skills, and teach scientific method processes (Kaptan & Korkmaz, 2001). According to Taber (2002), understanding and explaining abstract concepts is one of the most important reasons for the difficulties encountered in learning and teaching science lessons. By concretizing abstract concepts, this problem can be overcome. The use of models is an effective way to convey abstract concepts in education and ensure students' active participation (Uzun, 2015).

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**How to cite:** Bilginer, E. B. & Uzun, E. (2022). Mental model development of preservice science teachers with slow-motion animation and visual material: The case of circulatory system. *Journal of Pedagogical Research, 6*(5), 153-173. https://doi.org/10.33902/JPR.202217405

Models are defined in a variety of ways in the relevant literature. Günbatar and Sarı (2005) define models as elements that help make sense of how something happens, enable us to see phenomena we cannot see directly with our eyes, and allow us to move from the known to the unknown. Harrison and Treagust (2010) argue that models play an important role in shaping scientific knowledge, communication, and thinking. The purpose of models is to understand the formation of objects, their behavior and the process of their development and to make predictions about them (Ayvacı et al., 2016). Modelling, on the other hand, is the process by which a scientific study creates a model (Justi & Gilbert, 2002). The term *model* refers to a process of bringing an unknown target into understandable terms based on the sources found, and the final product is called the model (Harrison, 2001).

Abstract and complex events are difficult for students to mentally construct in science education (Çökelez, 2015). Therefore, one of the methods for transferring concepts or events in science education is modeling. The history of science has shown us that science can't be thought without a model, and that a science book cannot be prepared without using a model (Matthews, 2007). Examples include the model of the solar system, the model of DNA, the model of the earth, the particle model of light, the atomic model, and the model of a chromosome pair. Additionally, modeling-based teaching stands out as an effective method of creating mental models during the learning phase of science subjects and concepts. Modeling in science education means that students construct the target model by using their existing mental models and similar models or structures that they can grasp and understand more easily than the target model (Çoban, 2021). According to Duit and Glynn (1996), meaningful learning depends on the evolution of the models that students create in their minds based on conceptual models. In this study, we examined the mental models that PSTs developed on the circulatory system with slow-motion animation and visual material. For this purpose, the 5R technique proposed by Hoban and Nielsen (2010) was adopted into the study. Additionally, the PSTs were evaluated in regard to their ability to realize the steps in the slow-motion animation used for teaching the subject of the circulatory system.

### 1.1. Slow-motion Animation

Slow-motion animation is a modeling technique developed by Hoban to build classroom resources. Slow-motion is a new concept in literature that combines the concepts of slow and animation. Slow-motion animation enables students to gain a better understanding of subjects by making the process slower with photos (Hoban, 2005). Slow-motion animation differs from normal animation in that it takes fewer photos per second than normal animation. This makes preparing it easier than preparing normal animation (Çamloğlu, 2014).

According to Hoban and Nielsen (2010), creating an animation involves students creating a sequence of five multimodal representations (5R). This involves creating preliminary information for the models to be created (background notes), sketching the obtained information on a piece of paper (storyboard), then creating 2D and 3D models (models), photographing the small movements of the models (digital photographs), and converting them to video software (animation). In addition to teaching the concept of creating a story using models to explain scientific concepts, slow-motion animation also teaches how easy it is to animate. Furthermore, this technique is thought to be more effective in science education than computer animations (Hoban, 2005).

Although animations have been used for a long time in science education, slow-motion animation technique has a short history (Ekici & Ekici, 2011). Literature reviews reveal that slow-motion animation research is conducted in the fields of biology (Bogiages & Hitt, 2008; Ekici et al., 2014; Hoban & Nielsen, 2012; Hoban et al., 2011; Jablonski et al., 2015; Kamp & Deaton, 2013), chemistry ( Akaygün, 2016; Berg et al., 2019; Chang et al., 2009), physics (Brown et al., 2013; Church et al., 2007; Hoban & Nielsen, 2014; Nordin & Osman, 2018; Uzun & Karaman, 2015; Wilkerson et al. 2018), science (Atalay & Belet Boyacı, 2019; Paige et al., 2016) and multidisciplinary fields (Fleer & Hoban, 2012; Kidman, 2015; Loughran et al., 2012; Vratulis et al., 2011; Wishart, 2017). Studies indicate that this technique facilitates learning and is effective in examining alternative concepts, contributes to the social development of students, facilitates understanding of science concepts, improves learning, creates different learning environments, increases interaction between students and increases students' interest in science (e.g. Hoban et al., 2011; Jablonski et al., 2015). In the dimension of learning and renewal, 21st century skills showed positive improvements in creativity and renewal, critical thinking and problem solving, communication and cooperation skills. The technique also contributes to the understanding of difficult and difficult subjects using simple materials, is effective in understanding abstract subjects, and, at the same time, students actively participate and contribute to their creativity (Atalay & Belet Boyacı, 2019; Chang et al., 2009; Ekici & Ekici, 2011; Fleer & Hoban, 2012; Hoban & Nielsen, 2010, 2012; Karakoyun & Yapıcı, 2018; Uzun & Karaman, 2015). Further, studies have shown that slow-motion animation develops the mental models of students (Akaygun 2016; Church et al. 2007; Mills et al. 2018; Uzun, 2015).

### 1.2. Mental Model

Mental models are mental representations created by individuals as a result of cognitive processes (Güneş et al., 2004). According to Franco and Colinvaux (2000), mental models are internal representations of real situations that people use to understand and perceive events happening in the world. To put it another way, they are mental representations that enable individuals to conceptualize their thoughts, are structured by experience, and include reasoning (Gunning & Marrero, 2017; Lodge-Scharff, 2017). The most important function of mental models is that they provide the individual with opportunities for explaining, evaluating, defining and predicting the systems they represent (Coll, 2008; Ünal & Ergin, 2006). A mental model reflects an individual's perception of a certain concept (Kurnaz & Ekşi, 2015). As a result, mental models can be used to determine whether or not students comprehend a subject (Greca & Moreira, 2001; Kurnaz & Salam Arslan, 2009; Örnek, 2008; Ünal & Ergin, 2006). In spite of the fact that mental models are internalized abstract structures that cannot be directly measured, different methods have been employed to reveal their representations (Akaygün, 2016). To reveal mental models, drawings are the most common data collection tool (Ültay et al., 2017). Through drawing, individuals can easily express their conceptual understandings and make them visible (Zangori & Forbes, 2015). In this study, drawings were used to determine the mental models of PSTs about the circulatory system.

In the science curriculum (Ministry of National Education [MoNE], 2018), the model is intended for use in 21 different acquisitions. Students need to actively provide their own learning in science education in order to learn concepts meaningfully and permanently. Moreover, studies have revealed that the learning environment can also play a role in students' poor learning (Kurnaz & Salam Arslan, 2009). This study uses slow-motion animation to teach the circulation system, allowing students to learn by doing. It is also aimed at making PSTs, who are the teachers of the future, aware of their mental model development by using this technique, since teachers play a vital role in forming students' mental models by providing a meaningful learning environment (Duit & Glynn, 1996).

A review of the literature shows that creating students’ own models are more effective than learning from models created by experts (Kozma & Russell 2005; Wu & Puntambekar 2012). Further, Schwarz et al. (2009) argue that instead of working with models prepared by scientists and teachers, students should be involved in model building, as this makes learning permanent by improving students' mental knowledge through the process of building, using, and evaluating their own models. This study reveals how mental model development differs between the visual material group, which uses ready-made visual models, and the slow-motion animation group, which builds its own models. The study is expected to result in preservice teachers creating their own models, embodied abstract concepts, a learning environment that fosters active participation, and better structured concepts related to the subject. It is thus important for the study to reveal the changes that will occur in the mental models of preservice teachers. Another important aspect of this study is its in-depth analysis of preservice teachers' behavior during the application phase of slow-motion animation. Hence, the research will lead to academic studies that are distinct from similar ones in the literature. The study is also expected to contribute to the literature by including the opinions of preservice teachers regarding slow-motion animation.

### 1.3. Purpose of the Research

The purpose of this research is to examine the mental model developments of PSTs on the circulatory system in an environment enriched with slow-motion animation and visual material. The research seeks to answer the following question: Do mental model developments of PSTs about the circulatory system develop in learning environments that include slow-motion animation and visual materials? Answers to the following questions were also sought:

RQ 1) Do the mental models of the PSTs about the circulatory system change before and after the application in the visual material and the slow-motion animation groups?

RQ 2) What are the reflections of PSTs from the application stages of the slow-motion animation technique?

RQ 3) What are the views of PSTs about the slow-motion animation technique used in teaching?

## 2. Method

A case study research design was utilized for this study, as it aims to define the components that make up a situation or event, to explain a situation, and to evaluate a situation or event (Williams, 2007). To answer the research questions in this study, the researcher used a case study involving limited cases in time and data collection tools containing multiple sources (Creswell, 2007). PSTs' mental model development was compared to the slow-motion animation technique used in the teaching of circulation system in the six-hour study. Further, the preservice teachers in the slow-motion animation group were observed during the application process and their opinions were taken at the end.

### 2.1. Participants

The sample of this research consists of 34 PSTs (5 male and 29 female), in the fall semester of the 2021-2022 academic year. A purposive sampling method was used in sample selection. In purposeful sampling, the most suitable groups are chosen that are believed to serve the research purpose most effectively (Suri, 2011). We chose this method because the Science Teaching Laboratory Applications course and preservice teachers taking it are well suited to the content of the study. On a voluntary basis, preservice teachers who participated in the study were informed about the application process and then divided into two groups as *visual material* and *slow-motion animation*.

### 2.2. Data Collection Tools

In this study, three data collection tools were used: Open-ended drawing questions to measure mental models, an observation form, and a semi-structured interview form to examine the slow-motion process from the perspectives of PSTs.

#### *2.2.1. Drawings of mental models*

Mental model applications consisting of open-ended drawing questions were prepared to examine the mental model development of PSTs on the circulatory system. Mental models focus on revealing the thoughts that individuals create in their minds while they perceive events in the universe (Franco & Colinvaux, 2000).

During the development of the mental model application on the circulatory system, two open-ended questions related to systemic and pulmonary circulation were included considering the 6th grade textbook (Çiğdem, et al., 2021). This question related to the acquisitions of "Explains how the blood travels through the pulmonary circuit, taking into account the structures and organs involved" as well as "Explains how the blood travels through the systemic circulatory system, considering the structures and organs involved." The researcher prepared the questions based on the opinions of two science education experts. PSTs were applied the circulatory system mental model application for one hour before and after their training.

*2.2.2. Slow-motion animation process observation form*

To observe the behaviors of the PSTs who make up the slow-motion animation group during the modeling process related to the circulatory system, we used the Slow-Motion Animation Observation Form. The relevant literature was reviewed and the opinions of the science experts were taken during the development of the observation form. Observation form was prepared considering the 5R suggested by Hoban and Nielsen (2010): background notes, storyboard, models, digital photographs, and animation. The evaluation form rates behaviors as 1 (needs improvement), 2 (moderate), and 3 (good). On the validity of the created observation form and its applicability in the research, two faculty members with expertise in science education were consulted. Based on the expert opinion, it was decided to use the slow transition animation process observation form.

*2.2.3. Slow-motion animation semi-structured interview form*

An interview is a controlled and purposeful process in which detailed questions are asked regarding a predetermined subject, followed by questions based on the answers given (Myers & Newman, 2007). A semi-structured interview form was used at the end of the application to collect data about the problems encountered and the preservice teachers' opinions on this technique. First of all, the interview form was prepared as a draft by the researchers. Afterward, the form was presented to experts in two fields of science education for their opinions and suggestions. In order to ensure content and language validity, form, functionality, and comprehensibility, a pilot study was conducted with five PSTs in the upper class. Based on the results of the pilot study, the interview form was given its final form. Interview form consisted of four open-ended questions. Semi-structured interviewing offers the advantage of allowing more regular information to be provided by using a pre-prepared interview protocol (Bogdan & Biklen, 2007).

**2.3. Implementation Process**

The application process took approximately 12 lesson-hours. The researcher completed all interventions in the slow-motion animation and visual material groups. The process was summarized in Table 1.

Table 1
*The application process*

| *Duration* | *Visual material group* | *Slow-motion animation group* |
|---|---|---|
| 1 lesson hour | Mental model practice | Mental model practice |
| 1 lesson hour | Information about the application | Information about the application |
| 3 lesson hours | Lecturing using powerpoint | Applying the slow-motion animation |
| 1 lesson hour | Mental model practice | Mental model practice |

*2.3.1. Visual material group*

The subject of the circulatory system was taught to the PSTs in the visual material group using PowerPoint. Visual models were used to demonstrate the course content of the circulatory system subject in the textbook, the systemic and pulmonary circulation, and its tasks. The total number of lesson hours for the visual material group was six as shown in Table 1. This included one lesson hour introducing the circulatory system using PowerPoint, one lesson hour explaining the application and introducing the work to be done, and three lesson hours after explaining the circulatory system. The process ended with the mental model practice as post-application, which took one hour.

*2.3.2. Slow-motion animation group*

The second group of PSTs were shown examples of previous slow-motion animation applications to ensure that their prior knowledge of the work was formed. Thus, it is intended to broaden preservice teachers' imaginations for future applications. A total of six lesson hours were required to complete the application, including one lesson hour of mental model preliminary application, one lesson hour of preliminary information about slow-motion animation application, three lesson hours of slow-motion animation technique application, and one lesson hour of mental model final application. The application made to the slow-motion animation group was carried out according to the five multimodal representations of Hoban and Nielsen (2010). These representations of PSTs are presented below.

**Representation 1 – Background notes.** The PSTs in the slow-motion animation group were asked to review literature on circulatory system subjects, systemic and pulmonary circulation structures and tasks. The purpose of the literature review was to provide students with a basic understanding of the subject. During the literature review on the subject, preservice teachers should consult with the researcher on the parts that are unclear to them. In addition, the preservice teachers should acquire pre-knowledge about what they should pay attention to while making animation at this stage.

**Representation 2 – Storyboard.** During this phase, preservice teachers drew the pictures formed in their minds for their upcoming animation and designed the movement flow in their minds. It was expected that preservice teachers would take one week to create their storyboards. Researchers provided assistance if there were difficulties encountered during the process.

**Representation 3 – Models.** In this phase, preservice teachers use slow-motion animation techniques to model the systemic and pulmonary circulations of the circulatory system. PSTs were divided into four groups during the model development phase. Using the storyboards they created after reviewing the literature the previous week, each group modeled their animations. Modeling materials included colored paper, string, clothespins, colored pencils, play dough, straws, etc. The 3D and 2D models are then transferred to a flat surface. As the preservice teachers made models, the researcher guided them, asked questions about the models they made.

**Representation 4 – Digital photographs.** During this phase, the model was photographed after the creation process is complete. A member of each group formed by preservice teachers was responsible for taking a photo. After the model was created, a digital camera was held steady and the models were photographed. Preservice teachers gave the model small movements with their hands at every stage and took at least 20-30 photographs to ensure the fluency of the animation. In the digital photography stage, as in the other stages, the researcher guided the preservice teachers.

**Representation 5 – The animation.** During this stage, PSTs were required to upload all photos taken with their digital cameras to their computers. The photos were transferred to computer software to create slow-motion animation and a photo sequence. Each PTS were required to have animation preparation software with application photos on their computers. During this stage, PSTs were required to upload all photos taken with their digital cameras to their computers. The photos were transferred to computer software to create slow-motion animation and a photo sequence. Each PTS were required to have animation preparation software with application photos on their computers. Groups were instructed to create animations at two frames per second, paying attention to the content of the subject. Animations can be enhanced with optional sound files uploaded during this process.

### 2.4. Analysis of Data

Content analysis was used to analyze the data in this study. The purpose of content analysis is to collect and interpret similar data within the framework of concepts and themes (Krippendorff, 2018). While the content analysis for the mental model application used in the research was conducted, the answers given by the preservice teachers to the questions in the mental model application were categorized into four subcategories: correct explanation, partial explanation, incorrect explanation, and no explanation (see Table 2). The categories were created through the study of literature on structures and organs in the circulatory system.

Table 2
*Analysis framework of mental models*

| | Correct explanation | Partially correct explanation | Incorrect explanation | No explanation |
|---|---|---|---|---|
| Correct model | Explanation that coincides with scientific knowledge- Exactly correct visual drawing | Explanation that partially overlaps with scientific knowledge - Exactly correct visual illustration | Explanation that does not coincide with scientific knowledge - Exactly correct visual drawing | No explanation provi Exactly correct image drawing |
| Partially correct model | Explanation that overlaps with scientific knowledge - Partially correct visual illustration | Explanation that partially overlaps with scientific knowledge - Partially correct visual illustration | Non-scientific explanation - Partially correct visual illustration | No explanation provided - Partially correct visual illustration |
| Incorrect model | Explanation that overlaps with scientific knowledge - Incorrect visual drawing | Explanation partially overlapping with scientific knowledge - Incorrect visual drawing | Explanation that does not coincide with scientific knowledge - Incorrect visual drawing | No explanation provided - Incorrect visual drawing |
| No model | Explanation that overlaps with scientific knowledge - No visual drawing provided | Explanation partially overlapping with scientific knowledge - No visual drawing | Explanation that does not coincide with scientific knowledge - No visual drawing | No explanation provi No visual drawing pr |

The PSTs mental models were analyzed by creating 16 different categories based on their overlap with scientific knowledge and visual drawings in the literature on the circulatory system, as shown in Table 2. For example, when the answers given to the questions in the mental model application of the preservice teachers are examined, the response is classified in the correct model-correct explanation category if it includes an explanation that overlaps with the scientific knowledge in the relevant literature and a perfectly accurate visual drawing. The names of the students were not used when revealing the research findings, but rather a code was assigned to each preservice teacher and noted as S1, S2, S3, ...

PSTs in the slow-motion animation group were observed during the application process. In the observation form, behaviors were categorized as good, moderate, or needs improvement. PSTs were rated as "good" if they fully comply with the observation form, "moderate" if they are partially compliant, and "needs improvement" if they do not comply at all. During the application, the PST groups were assigned codes such as G1, G2, ... and the findings were analyzed. Keywords were determined while analyzing the data obtained from the interview form, and the data obtained from the interview was coded and categorized. The data obtained is presented in tabular form. The interviews lasted approximately 15 minutes for each preservice teacher. As a result of the analysis, the quotations expressing the opinions of the PSTs were cited without identifying their names. We sought the advice of two faculty members who are experts in science education when analyzing the data collected through the circulatory system mental model application, observation form, and semi-structured interview form. Based on the opinions of expert faculty members, the results of the analysis were determined whether they reflect the research topic. Additionally, raw data were constantly provided to confirm the codes and categories obtained from the data collection tools in the findings section.

## 3. Findings

### 3.1. Mental Model Developments of the PSTs

To determine the pre-knowledge of PSTs regarding the systemic and pulmonary circulation, mental model practices were conducted before intervention. In this regard, PSTs were asked to explain how the blood travels through the pulmonary circuit, taking into account the structures and organs involved (First acquisition). Table 3 presents the pre-application data.

Table 3

*Findings from the drawings related to the first acquisition before the implementation*

| *Groups* | *CE* | *PCE* | *IE* | *NE* |
|---|---|---|---|---|
| Slow-motion animation | | | | |
| Correct model | - | - | - | - |
| Partial model | $S_7$ | $S_3$,$S_4$,$S_8$,$S_{15}$,$S_{18}$ | - | - |
| Wrong model | - | - | $S_5$,$S_6$,$S_{13}$,$S_{14}$,$S_{16}$ | - |
| No model | - | - | - | $S_2$,$S_9$,$S_{10}$,$S_{11}$,$S_{12}$,$S_{17}$ |
| Visual material | | | | |
| Correct model | - | - | - | - |
| Partial model | - | $S_{10}$ | $S_9$,$S_{14}$ | $S_{15}$ |
| Wrong model | $S_{11}$,$S_{16}$ | $S_7$ | $S_1$,$S_2$,$S_5$,$S_6$,$S_8$,$S_{12}$,$S_{13}$ | $S_3$,$S_4$ |
| No model | - | - | - | - |

*Note.* CE: Correct explanation; PCE: Partially correct explanation; IE: Incorrect explanation; NE: No explanation

The slow-motion animation group PSTs made 28% incorrect models-incorrect explanations, 28% partially correct models-partially correct explanations, and 33% incorrect models-no explanation in the pre-application of the first question regarding the first acquisition. The visual material group PSTs made 44% incorrect models-incorrect explanations, 13% incorrect models-correct explanations, 13% partially correct models-incorrect explanations, and 13% incorrect models-no explanation. The correct model-correct explanation was not performed by any PSTs in either group. With regard the second acquisition (explains how the blood travels through the systemic circulatory system, considering the structures and organs involved), pre-application data was presented in Table 4.

Table 4

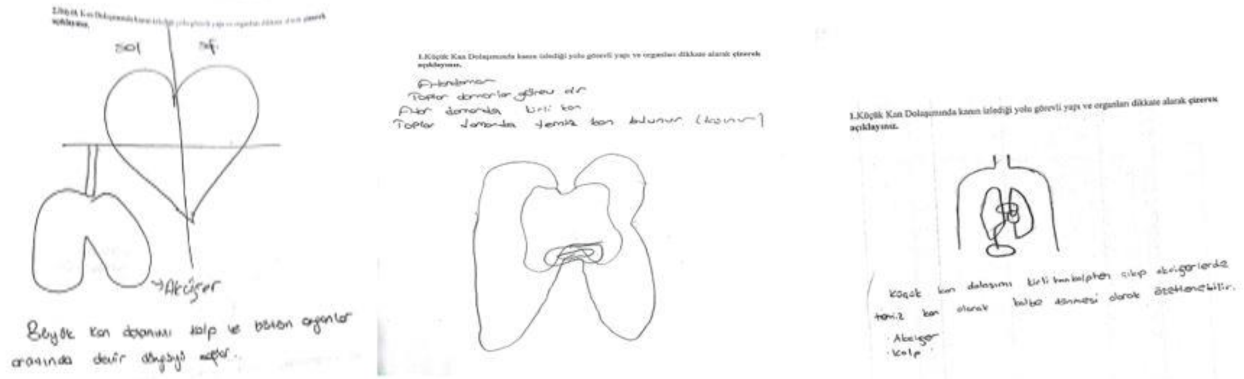
*Findings from the drawings related to the second acquisition before the implementation*

| *Groups* | *CE* | *PCE* | *IE* | *NE* |
|---|---|---|---|---|
| Slow-motion animation | | | | |
| Correct model | - | $S_8$ | - | - |
| Partially correct model | $S_5$,$S_6$ | $S_7$,$S_{15}$ | $S_3$ | - |
| Incorrect model | - | $S_{17}$ | $S_1$,$S_{10}$,$S_{16}$ | - |
| No model | - | - | - | $S_2$,$S_4$,$S_9$,$S_{11}$,$S_{12}$,$S_{14}$,$S_{18}$ |
| Visual material | | | | |
| Correct model | - | - | - | - |
| Partially correct model | - | $S_1$,$S_{10}$,$S_{14}$ | - | $S_{15}$ |
| Incorrect model | - | $S_7$ | $S_2$,$S_3$,$S_6$,$S_7$,$S_8$,$S_9$,$S_{13}$ | $S_4$ |
| No model | - | - | - | - |

*Note.* CE: Correct explanation; PCE: Partially correct explanation; IE: Incorrect explanation; NE: No explanation

As shown in Table 4, the slow-motion animation group PSTs scored 39% incorrect models with no explanation for the second acquisition, 17% incorrect models with incorrect explanations, 11% partially correct models with correct explanations, and 11% partially correct models with partially correct explanations. PSTs in the visual material group made 44% incorrect models with incorrect explanations, 31% incorrect models with partially correct explanations, and 19% partially correct models with partially correct explanations. No preservice teacher provided a correct model-correct explanation in both groups. Figures 1 and 2 show samples of participant responses.

Figure 1
*Visual material group pre-implementation examples*

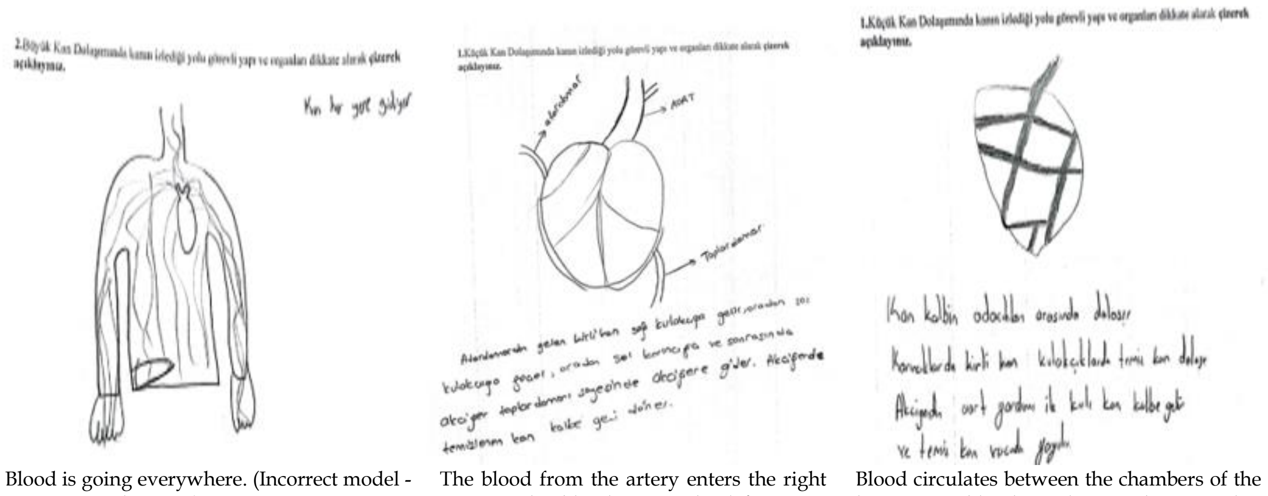


The systemic circulation provides the cycle between the heart and all organs. (Incorrect model - Partially correct explanation)

Arteries and veins take charge. There is dirty blood in the arteries and clean blood in the veins. (Incorrect model – Incorrect explanation)

The pulmonary circulation is the return of dirty blood from the heart to the heart as clean blood in the longs. (Incorrect model – Partially correct explanation)

Figure 2
*Slow-motion animation group pre- implementation examples*



Blood is going everywhere. (Incorrect model - Incorrect explanation)

The blood from the artery enters the right atrium. The blood enters the left atrium and then the right ventricle. Through the pulmonary vein, it reaches the lungs. The heart receives cleaned blood from the lungs. (Incorrect model - Partially correct explanation)

Blood circulates between the chambers of the heart. Dirty blood circulates in the ventricles, and clean blood circulates in the atria. Dirty blood is transported to the heart by the aorta in the lung, and clean blood is transported throughout the body. (Incorrect model – Incorrect explanation)

An application of the circulatory system mental model was carried out as a final implementation to learn the post-application knowledge of PSTs regarding systemic and pulmonary circulation. Taking into account the acquisitions, Table 5 and Table 6 present the data obtained after the application.

Table 5
*Findings from the drawings related to the first acquisition after the implementation*

| *Groups* | *CE* | *PCE* | *IE* | *NE* |
|---|---|---|---|---|
| Slow-motion animation | | | | |
| Correct model | $S_3,S_4,S_5,S_6,S_7,S_8,S_9,S_{13},S_{14},S_{16},S_{17}$ | - | - | - |
| Partially correct model | $S_2,S_{11},S_{12},S_{15}$ | $S_1,S_{18}$ | - | - |
| Incorrect model | $S_{10}$ | - | - | - |
| No model | - | - | - | - |
| Visual material | | | | |
| Correct model | $S_{14}$ | - | - | - |
| Partially correct model | $S_5,S_6,S_9,S_{10},S_{12},S_{15}$ | $S_{14},S_{16}$ | $S_1,S_2,S_8$ | $S_3$ |
| Incorrect model | $S_4,S_{11}$ | $S_7$ | | - |
| No model | - | $S_{13}$ | | - |

*Note.* CE: Correct explanation; PCE: Partially correct explanation; IE: Incorrect explanation; NE: No explanation

Using the results from Table 5, it was determined that preservice teachers in the slow-motion animation group made 61% of correct model-correct explanations, 22% of partially correct model-correct explanations, and 11% of partially correct model-partially correct explanations on the first question relating to the circulatory system mental model application. In the same group, no PSTs made the incorrect model-incorrect explanation. PSTs in the visual material group made 38% partially correct model-correct explanations, 13% partially correct model-partially correct explanations, 13% incorrect model-correct explanations, and 19% incorrect model-incorrect explanations.

Table 6
*Findings from the drawings related to the second acquisition after the implementation*

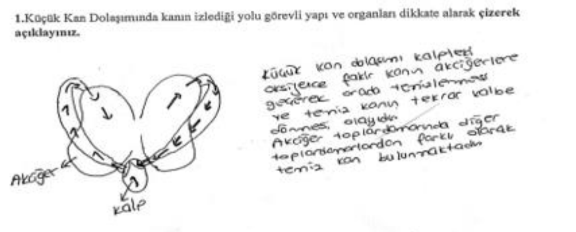
| *Groups* | *CE* | *PCE* | *IE* | *NE* |
|---|---|---|---|---|
| Slow-motion animation | | | | |
| Correct model | $S_3,S_6,S_7,S_8,S_9,S_{13},S_{14},S_{15},S_{17}$ | $S_4$ | - | - |
| Partially correct model | $S_1,S_2,S_5,S_{15},S_{12}$ | $S_{16},S_{18}$ | - | - |
| Incorrect model | $S_{10}$ | - | - | - |
| No model | - | - | - | - |
| Visual material | | | | |
| Correct model | - | - | - | - |
| Partially correct model | $S_6,S_{10},S_{12},S_{14},S_{15}$ | $S_1,S_5,S_{11},S_{16}$ | - | - |
| Incorrect model | $S_9$ | $S_2,S_4,S_7$ | $S_8$ | - |
| No model | - | $S_{13}$ | - | $S_3$ |

*Note.* CE: Correct explanation; PCE: Partially correct explanation; IE: Incorrect explanation; NE: No explanation

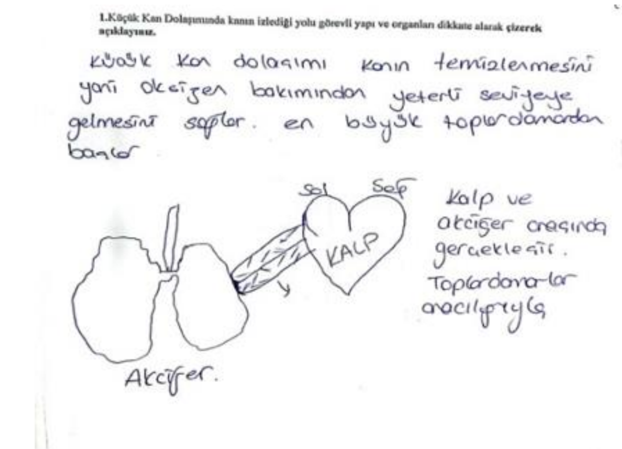
The findings presented in Table 6 reveal that the PSTs in the slow-motion animation group provided 50% correct model-correct explanations, 28% partially correct model-correct explanations, and 11% partially correct model-partially correct explanations for the second question related to the second acquisition. Similar to the other group, no PSTs provided either incorrect model-incorrect explanation or no model-no explanation. Table 6 shows that 31% of the visual material group PSTs made partially correct model-correct explanations, 25% partially correct model-partially correct explanations, and 19% incorrect model-partially correct explanations. No PSTs in this group were performed correct model-correct explanation. Figures 3 and 4 show samples of participant responses.

Figure 3
*Visual material group post-implementation examples*


The dirty blood comes to the right ventricle. It travels to the lungs to be cleaned, and dirty blood is cleaned here. The cleaned blood travels to the left atrium of the heart. This is the pulmonary circulation. (Partially correct model - Correct explanation)




The pulmonary circulation transports oxygen-poor blood from the heart to the lungs for cleansing. Clean blood then returns to the heart. (Partially correct model - Partially correct explanation)

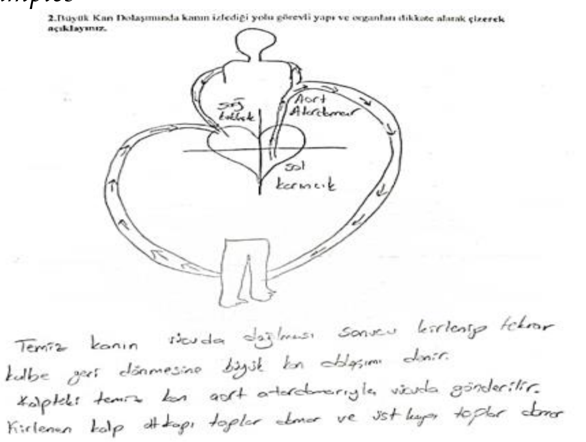



As a result of the pulmonary circulation, the blood is cleaned. During this process, blood passes between the heart and the lungs through the veins. (Incorrect model – Partially correct explanation)

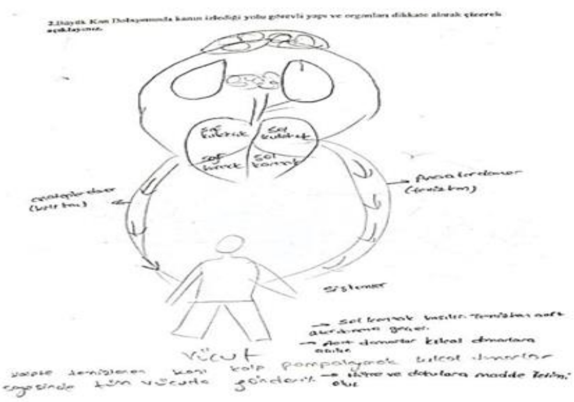

Blood that has been cleaned in the lungs and filled with oxygen is circulated throughout the body, and blood that has been polluted in the body is brought to the heart. (Partially correct model – Partially correct explanation)

Figure 4
*Slow-motion animation group post-implementation examples*

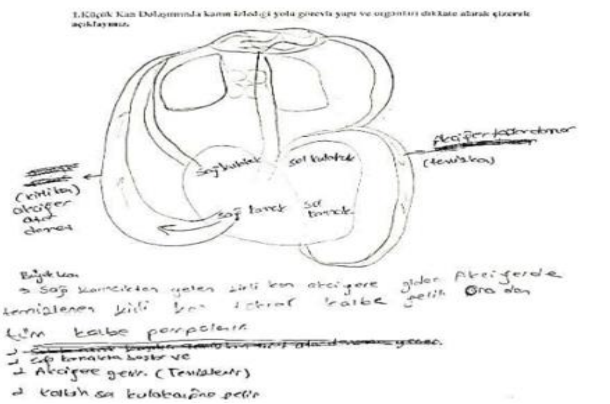

The systemic circulation involves returning clean blood to the heart after it has been polluted and dispersed throughout the body. Through the aortic artery, the heart sends clean blood to the body. (Correct model – Correct explanation)




The right ventricle of the heart receives dirty blood from the body. As the blood travels through the pulmonary artery, it is cleaned by the alveoli, and it is then sent to the left atrium of the heart via the pulmonary vein. (Correct model – Correct explanation)



Dirty blood from the right ventricle goes to the lungs. Lungs clean dirty blood and return it to the heart. The blood is then pumped throughout the body. (Correct model – Correct explanation)



The left ventricle contracts. In the aorta, clean blood passes. Aortas open into capillaries. Through the capillaries, the heart pumps the cleaned blood throughout the body. (Correct model – Correct explanation)

### 3.2. Reflections of PSTs from the Application Stages of the Slow-motion Animation

Considering the multimodal representation of Hoban and Nielsen (2010), the data obtained from the observation form were presented in five stages. In the following section, the findings regarding these stages are presented.

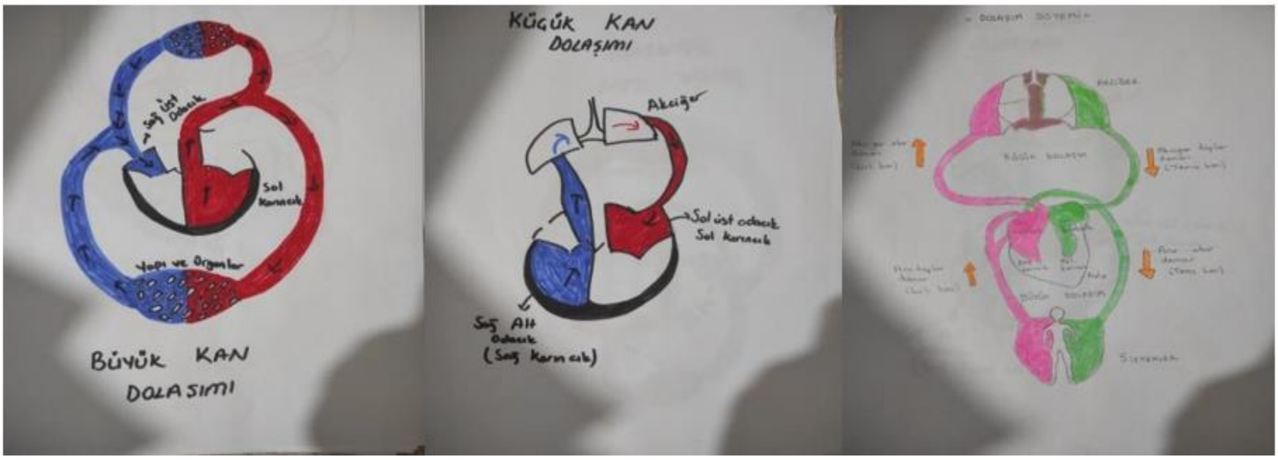
#### *3.2.1. Representation 1 – Background notes*

Based on the observation form, two groups used the internet and textbooks, while the other two used only the internet. Additionally, it was observed that the preliminary knowledge of the three groups on the subject was sufficient during the application process. Before the application, the three groups had sufficient knowledge of the animation design process. Furthermore, all of the groups sought assistance from the researcher before the application for the fields they could not understand.

#### *3.2.2. Representation 2 – Storyboard*

During the storyboarding stage, all groups divided the circulatory system into systemic and pulmonary circulation sections. It was observed that PSTs used colored pencils to create picture sketches. The storyboards of all groups included structures and shapes related to the circulatory system (see Figure 5). In all picture drafts created by the groups, legible, understandable language is used. In addition, the three groups created storyboards that specified the animation steps in each item. Moreover, both groups were observed to have sufficient active participation in creating storyboards.

Figure 5
*Storyboarding practice*



*3.2.3. Representation 3 – Models*

PSTs performed the modeling process according to the order they create in their storyboards at a good level based on the observation form. In the practice of making a visual model, all groups have embodied the abstract concept of the systemic and pulmonary circulation. During the modeling process, the members of the group received assistance from the researcher about the content of the subject. In addition, during the modeling process of the groups, colored pencils, play dough, colored paper, etc. were used. The group members also benefited from the materials and engaged in effective communication by taking an active role. The groups produced 2D and 3D models of their storyboards and created the structures and organs. By examining the responsibilities of group members in the modeling process, such as creating models and moving them, it is revealed that responsibilities of all groups are equally shared and that PSTs in the same groups are actively involved. Figure 6 includes reflections from applications.

Figure 6
*Modelling practice*

*3.2.4. Representation 4 – Digital photographs*

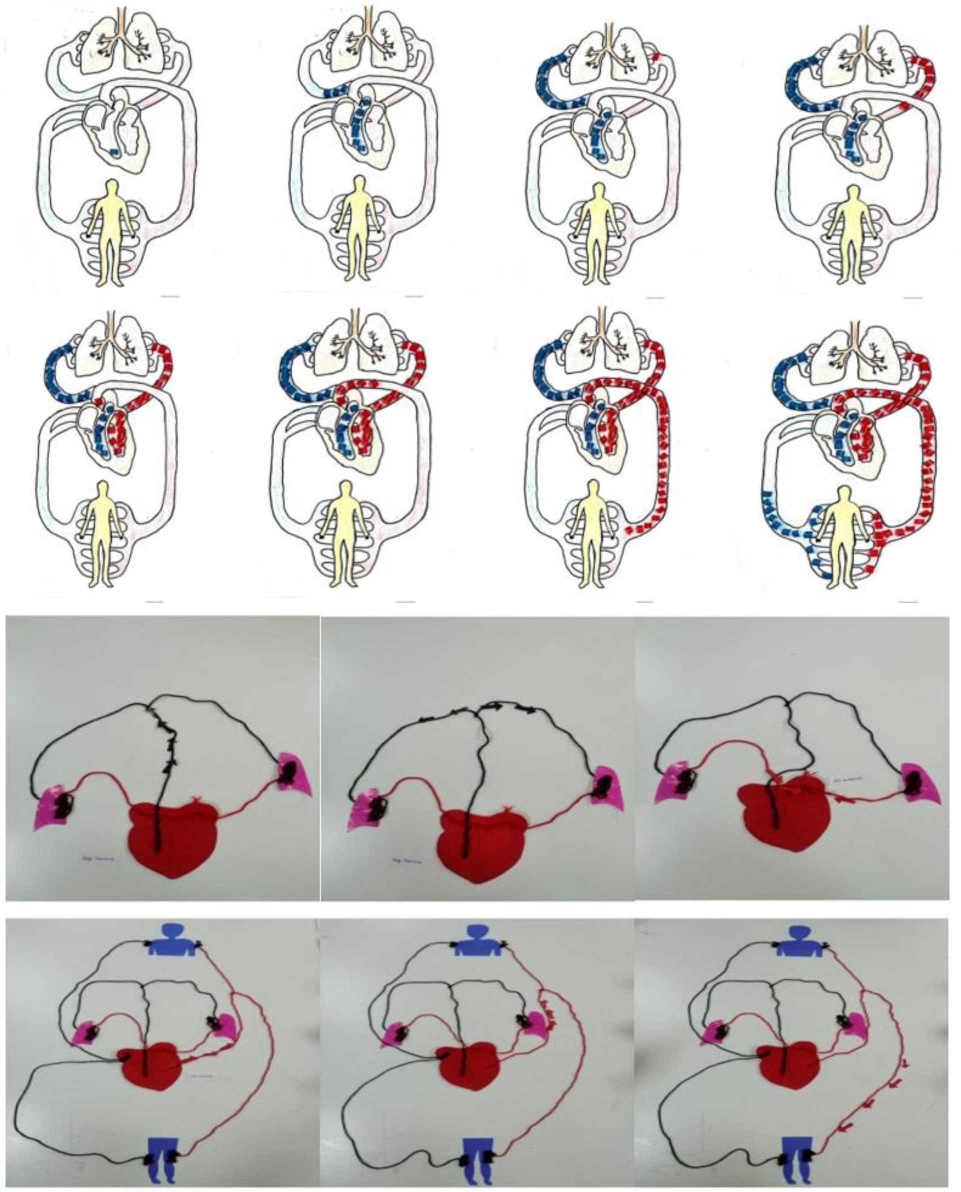
As for the next stage, PSTs did well in validating the model during the digital photography process according to the content of the subject, photographing each movement of the model, holding still during the photo-taking process, and modeling in moving situations. During the digital photography process, the three groups demonstrated a high level of effective communication and cooperation within the group. As the model movement progressed, members shared responsibilities and took an active role. All groups in the application photograph all structures and organs of the circulatory system, including the heart, parts of the heart, lungs, and vessels. In this stage, PSTs took 25-30 photos for each subject content (see Figure 7).

Figure 7
*Reflection from the digital photography process*

### 3.2.5. Representation 5 – The animation

According to observation form data, the animation created in all groups is appropriate for the circulatory system content. All structures and organs related to the circulatory system are included in these groups, including the heart, parts of the heart, lungs, and vessels. Two groups used sound effects in their animations, while the other groups displayed their animations visually only. Across all animations created by preservice teachers, the subject handling and animation speed are at a good level. After the slow-motion animation activity, each group produced one animation, resulting in a total of four animations. In class, the animations were shared and presented. Figure 8 includes the reflection from this stage.

Figure 8
*Model studies*



## 3.3. The Views of PSTs about the Slow-motion Animation Technique

In the last research problem, the aim was to determine preservice teachers' opinions about slow-motion animation through semi-structured interviews. To this aim, firstly, they were asked whether they liked this technique, then how they perceived this technique, and finally, they were asked about the difficulties they encountered. The results were presented in Table 7, 8 and 9, respectively.

Table 7
*Likes and dislikes regarding the slow-motion animation technique*

| *Category* | *Code* | *f* |
|---|---|---|
| *I liked, because the techniques provides…* | Practical training | 1 |
| | Learning by making videos | 1 |
| | A different learning style | 1 |
| | Learning with fun | 2 |
| | An easy animation | 1 |
| | Learning by doing | 2 |
| | Permanent learning | 3 |
| | Making learning easier | 3 |
| | Technology supported education | 2 |
| | A quite useful content | 1 |
| | Helps to rejuvenate | 1 |
| | Bringing visual intelligence to the fore | 1 |
| *I partially liked, because the technique is…* | Time consuming | 1 |
| *I didn't like* | - | - |

According to Table 7, all PSTs emphasized the advantages of the techniques, and none expressed dissatisfaction with the technique. The views of S1 regarding this issue are as follows.

> I like it. Making an experiment on a subject can help one determine whether students understand it in a practical way. We were able to understand our learning level through this activity. As a result of this course, we learned how to prepare presentations and videos for students in the future. The lessons we learned were put into practice.

In a similar manner, S11 asserted that:

> I partially liked it. Due to its generally fun and enjoyable nature, the information provided is more permanent. The existence of necessary technologies can only make it a little more challenging to create an application that is easy for students and teachers to use.

With another question, the participants were asked whether they had experienced slow-motion animation before, and 10 of the PSTs had never experienced, while three of them had only heard about it. Another question asked participants to define this technique based on their experience in the application to determine how they perceived it. The data obtained are shown in Table 8.

Table 8
*Perceptions of PSTs on slow-motion animation technique based on the application*

| *Code* | *f* |
|---|---|
| Photographing every moment | 4 |
| An implementation | 1 |
| A Three-dimensional model | 1 |
| Creating video | 2 |
| Placing photos one after another | 2 |
| Making sth. more understandable | 2 |
| Photographing from the same spot | 1 |
| Making learning easier | 2 |
| Memorability | 3 |
| Show step by step | 1 |
| Easier learning | 1 |
| Providing convenience | 1 |
| Help with education | 1 |
| Merge sequential photos together | 1 |
| Support with information technology tools | 1 |
| A technique used in education | 2 |

According to Table 8, the preservice teachers defined the slow-motion animation technique as photographing every moment, a technique used in education, combining sequential photos into a video, capturing it, facilitating learning, memorability, and photographing from the same point. For instance, S2 stated that, "By placing these photos one after another, you can create a video of the movement performed on the three-dimensional model." In another PST, S10 pointed out that, "With this application, teachers and students can learn a certain event or a subject explained in a lesson more effectively and more permanently." Likewise, S13 stated that "slow-motion animation is a technique used in education to support knowledge and skills while emphasizing visual structures of information." The participants were also asked about the difficulties they encountered during slow-motion animation and the results are summarized in Table 9.

Table 9
*Difficulties experienced during the application*

| *Code* | *f* |
|---|---|
| I had no difficulties | 5 |
| Photo shooting | 3 |
| Moving materials | 2 |
| Group communication | 2 |
| Selecting material | 1 |
| Lack of prior knowledge | 1 |
| Transitioning photos | 1 |
| Lack of materials | 1 |

Table 9 shows that five preservice teachers did not experience any difficulties. Other preservice teachers discussed the difficulty they had with applications such as photo shooting, moving materials, group communication, selecting materials, and transitioning photos. For instance, S1 asserted that, "We challenged our imaginations by brainstorming and deciding what materials we would need and how we could use them to bring our topic to life. We struggled to communicate with bandmates, but eventually, we found common ground." Similarly, S3 stated that, "During the application, we had difficulty taking photos from a fixed angle. Apart from that, we had no difficulty applying." Finally, S7 pointed out that, "There was a strain from myself, that is, from the group. The material was limited, but despite this, the work was excellent."

## 4. Conclusion and Discussion

In this study, slow-motion animation was used to examine mental model developments of PSTs on the circulatory system. By comparing these results with similar studies in the literature, conclusions were drawn in this direction.

PSTs' mental models were determined pre- and post-implementation in the circulation system mental model application. Two open-ended questions were included in the mental model application. According to the results, the slow-motion animation and visual material groups could not provide the correct model and explanation for the two acquisitions of the circulatory system before implementation. Following the implementation, it was observed that 61% of slow-motion animation group PSTs constructed correct model-correct explanation for the first question, while 50% built correct model-correct explanation for the second question. On the other hand, it was observed that 38% of the visual material group PSTs gave partially correct model-correct explanations to the second question and 31% of them were after the implementation. No teacher candidate in the visual material group gave the correct model-correct explanation for both questions. From these results, it can be concluded that PSTs in the slow-motion animation group have a higher correct model-correct explanation ratio. Similar results have also been found in previous studies. As a result of her study, Uzun (2015) concluded that photoelectric simulations positively influence the modeling of the phenomenon in the mind using slow-motion animation. It is evident from this result that the technique is important for understanding and concretizing abstract ideas. Further, the literature indicates that students create their own models rather than using them for demonstrations, which helps them develop mental models more accurately (Leenaars et al. 2013; Lehrer & Schauble, 2006; Schwarz et al., 2009). Several studies have shown that slow-motion animation facilitates conceptual understanding by improving students' mental models (Akaygun, 2016; Brown et al., 2013; Church et al., 2007; Fleer & Hoban, 2012; Hoban & Nielsen 2012; Loughran et al., 2012). Using the slow-motion animation technique, Uzun and Karaman (2015) conclude that incomprehensible subjects and concepts are comprehensible to students and that their mental models are improved. Furthermore, slow-motion animation has been shown to improve academic success, retention, learning, 21st century skills, and social development for students (Atalay & Belet Boyacı, 2019; Hoban & Nielsen, 2012; Hoban & Nielsen, 2010; Jablonski et al., 2015; Paige et al., 2016; Uzun & Karaman, 2015; Wishart, 2017).

Slow-motion animation process observation form was prepared considering the five multimodal representations of Hoban and Nielsen (2010). The current study considers each representation as a stage. In the first stage (background notes), it was determined that PSTs obtained sufficient information about the subject from the internet and textbooks. This shows that participation in the implementation will help students develop their research skills. Atalay (2015) concluded in his study that slow-motion animation techniques improve students' research skills. According to Ekici and Ekici (2011), students should have sufficient knowledge to design a subject in different phases or sections, and research on the subject is necessary for this. As part of the second step of creating a storyboard, preservice teachers incorporated the Turkish science curriculum (see MoNE, 2018) into topics such as the circulatory system, systemic circulation, and pulmonary circulation. When creating the storyboards, the majority of groups used colored pencils to indicate the important points about the subject. In addition, all storyboards included figures, and the language was legible and scientific. Placing the shapes formed in the minds of the students about the subject on paper gives them more meaning. Consequently, any negative situations that PSTs may encounter during the modeling process are avoided. As Uzun (2015) pointed out in her study, students can also use their imaginations during the storyboarding process. The importance of creating a storyboard was also emphasized in order to prevent any negative outcomes during animation.

In the 3rd stage, which refers to the modeling phase, PSTs designed their models based on the storyboard. As a result, the abstract concept has been realized by making a visual representation of the systemic and pulmonary circulation in all groups. Models were created in 2D and 3D by the groups. Their models also included colored paper and pencils. During this process, it was observed that the PSTs in the groups were involved in effective communication. Students need to realize their mental shapes by modeling them and making them more understandable. Additionally, various materials can be used to make models of structures and organs in the subject to facilitate learning. In the fourth step, which refers to digital photographs, it was observed that the preservice teachers animated their models based on the content of the lesson. The cameras were fixed at an angle during this process. For each of the subject contents, they obtained 25-30 photos, and the group members took part actively by fulfilling their responsibilities while photographing. It was observed that the preservice teachers photographed all the organs and structures in the pulmonary and systemic circulations. In the process of creating slow-motion animations, Hoban and Nielsen (2012) found that students engage in social communication and cooperation. According to Brown et al. (2013), this technique enhances classroom discussion and cooperative learning skills. According to the results of the 5th stage which refers to the animation, each animation created by the preservice teachers was appropriate for the subject matter. The animations included all the structures and organs of the systemic and pulmonary circulation. There have also been animation groups that use sound effects. All groups found animation speed and subject handling appropriate. Using an animation software, Uzuner and Aker (2019) noted that photos can be transferred to the computer and music, comments, and sounds added to the animation during the animation phase. According to Wilkerson et al. (2018), slow-motion animation would improve students' mechanical reasoning skills. This technique is also believed to improve early childhood technology skills (Fleer & Hoban, 2012).

In the interview, PSTs expressed their opinion about slow-motion animation, which provides a learning environment by doing, entertains while learning, is technology supported, facilitates learning, and provides a permanent learning environment, in contrast to classical learning environments. In her study, Uzun (2015) observed that preservice teachers believed that this technique helped concretize abstract concepts, develop creativity with the help of imagination, and increase fun and memorability. According to their definition of slow-motion animation, this technique involves photographing every moment, putting each photo next to one another, creating a video, increasing memorability, facilitating learning, making a subject more understandable, and assisting in education. Slow-motion animation technique was defined by Uzuner (2018) as an exciting and fun method for students to better understand. This technique has also been shown to increase motivation in a body of literature (Bogiages & Hitt 2008; Brown et al. 2013; Hoban 2005; Hoban & Nielsen 2010; Jablonski et al. 2015). In response to the interview, the majority of PSTs reported that they had never seen this technique before, while those who had, stated that the technique they saw did not relate to education and that they did not take an active role in the animation production process. Additionally, they reported difficulty fixing the camera in the application's digital photography section. Furthermore, preservice teachers had difficulties with materials movement, group communication, material selection, photo transitions, and materials-related difficulties. A number of preservice teachers also stated that they had no difficulty applying. This method has a number of positive aspects, including facilitating the understanding of complex and difficult subjects through simple materials, facilitating the understanding of abstract concepts, and enhancing student participation. Negative aspects of this technique include that it takes time, is tiring, and is difficult to implement in crowded classrooms.

### 4.1. Recommendations

Following are some recommendations based on the results and conclusions of this study:

- Considering the positive effects of slow-motion animation on PSTs' mental models, these implementations are suitable for today's classrooms.
- The effectiveness of revealing and improving mental models of students in other subjects of science can be investigated in similar studies.
- Preservice teachers in the study found the slow-motion animation application to be fun based on their opinions. To enable students to learn slow-motion animation by having fun and using it, the number of lesson hours for science education applications can be increased.
- In order for prospective teachers to use their own materials in lessons during their professional lives, slow-motion animation lessons can be given in their preservice periods.
- Using slow-motion animation helps students learn by doing and experiencing, and develops their creativity skills. Hence, it can be used not only in science lessons, but also in other subjects.
- In order to develop the teaching and learning process, it is necessary to make different applications that will enable students to develop their creativity, have in-group interaction, increase cooperation, and develop problem-solving skills.

**Acknowledgements:** This research is based on the Master’s thesis submitted by the first author, under the supervision of the second author.

**Author contributions:** All authors are agreed with the results and conclusions.

**Funding:** No funding source is reported for this study.

**Declaration of interest:** No conflict of interest is declared by author.

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