Designing, Developing, and Evaluating an Interactive E-Book Based on the Predict-Observe-Explain (POE) Method

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Abstract
Teaching materials can increase efficiency in learning environments. One type of materials with proven effectiveness is interactive e-books. Interactive e-books based on certain learning strategies are known to be more effective. This study focuses on analyzing, designing, developing, and evaluating an interactive e-book based on the predict-observe-explain method. The design-based research method is adopted in the study. Firstly, two physics education experts, four instructional technology field experts, and ten physics teachers were consulted about the developed interactive e-book. The pilot study with 20 high school students involved non-participant observations. Two physics education experts and four instructional technology field experts graded the developed e-book based on interactive e-book evaluation criteria. The second phase involved the determination of the platform where the interactive e-book would be developed as well as the software and tools to be used for creating multimedia materials. In the third phase, within the scope of the predict-observe-explain method, the kinds of multimedia materials and activities to be included in the e-book were designed with a physics education expert and an instructional technology expert. The interactive e-book was prepared in accordance with the target audience and subject, and design arrangements were made considering the recommendations given. The study can contribute to designers on key points to consider when creating the content of interactive e-books to be developed based on a learning method and designing and developing materials such as video, audio, and animation to be included in them. Furthermore, it can guide designers through principles and rules to be considered in designing the materials contained in interactive e-books.

Keywords Predict-observe-explain · Design-based research · E-book · Interactive e-book · Physics · Multimedia

Introduction

E-books are similar to printed books in terms of texts and images they contain but differ from them in terms of audio reading texts, animations, sound effects, videos, and interactive games (Wang & Yang, 2016). Especially with the development of technology, e-books, where different multimedia or interaction elements can be integrated for individualized learning, offer more flexibility and access than printed books thanks to the ability to link to websites (Huang et al., 2012; Wilson et al., 2002). Log records keeping students’ behaviors in e-books allow teachers to learn more about students. Thanks to such features, e-books can support student engagement and learning outcomes more than printed books (Connor et al., 2019). Wu and Chen (2018) state that the different types of media contained in e-books increase students’ interest. The inclusion of more visual and auditory elements in e-books compared to printed books allows students to understand what they are reading and to learn while having fun (Liang, 2015). In addition to providing students with interesting, challenging, and stimulating experiences, e-books raise their interaction with learning content and increase their participation in the lesson by allowing them to take notes on the e-book (Gong et al., 2013). According to Bozkurt and Bozkaya (2015), interactive e-books are essentially digital book formats in which the user, the digital book, and the environment can interact at a high level, digital book elements can communicate and interact among...
themselves as well as with the environment and users, and many communication channels are put in use at one and the same time (p. 60).

Research shows that interactive e-books based on certain learning strategies are more effective on learning outcomes (Connor et al., 2019). E-books developed without integration with appropriate learning strategies or methods may be insufficient to meet learning-related expectations (Peng et al., 2009) and to support high-level thinking processes such as analysis, evaluation, and synthesis (Batoon et al., 2018). Well-designed interactive e-books can support students’ higher-order thinking skills (Bozkurt & Bozkaya, 2015). Sung et al. (2019a, b) argue that student-centered e-books should include appropriate strategies and methods to guide learning. Students will only use e-books that are developed without taking a specific learning theory or strategy as a basis for reading purposes, and such cases may result in rote learning, which is often seen in learning with traditional textbooks (Wang et al., 2020). Accordingly, this study will focus on the analysis, design, development, and evaluation phases of an interactive e-book developed by the predict-observe-explain (POE) method.

POE is a three-phase teaching strategy, method, or model (Sarah et al., 2021). At the prediction phase, students predict the results of an experiment, demonstration, event, or question related to learning outcomes (Arminas & Sopandi, 2020; Pujiwati & Susilaningih, 2020). In other words, students make assumptions or hypothesize based on their pre-knowledge or pre-experiment (Venida & Sigua, 2020). At the observation phase, students observe the process relating to their predictions. At the explanation phase, that is the last phase, students compare their predictions and observations, so they reach an explanation relating to learning outcomes. Through this method, students reconstruct their knowledge or ideas (Teerasong et al., 2010). This method adopts the constructivist approach (Hilario, 2015), makes students active in the learning process (Jasdilla et al., 2019; Sarah et al., 2021), and lowers teachers’ role (Pane et al., 2020). At the same time, POE is effective in supporting critical thinking (Alfiyanti & Jatmiko, 2020). Critical thinking contains similar components: examining claims or hypotheses, using different ways for making inferences, determining, and arriving at a decision (Lai, 2011). Critical thinking can foster students’ conceptual understanding (Akmam et al., 2018).

The phases of POE facilitate students’ understanding of concepts (Alamsyah et al., 2021; Astiti et al., 2020; Baydere, 2021). Concepts are defined as abstractions of various events, objects, and facts with specific qualities (Harjono et al., 2020). Defining concepts differently from what is considered scientifically correct are called misconception (Haryono & Aini, 2021). It is often stated in the literature that prior knowledge, daily life experiences, teaching method, and materials are effective in creating misconceptions (Astiti et al., 2020; Suhandi et al., 2020).

POE reveals students’ incomplete or incorrect prior knowledge about the concepts by enabling them to make predictions about the presented facts or events through the use of their prior knowledge at the prediction phase. POE involves steps to provide conceptual change, as it allows students to doubt their prior knowledge, make efforts to eliminate such doubts, and reconsider the concept by comparing their old and new knowledge and reviewing their knowledge of the concept (Nalkıran & Karamustafağlı, 2020). At the prediction phase in POE, cognitive dissonance is also created when a situation or case that may cause a mistake about the concept is presented so that the student can focus on the concept. At the observation phase, opportunities are provided for students to test their predictions and experience concept construction. At the explanation phase, students reach explanations for constructing the concepts correctly. In other words, in the process, it is tried to make students learn concepts and get rid of misconceptions by engaging in critical thinking.

There are few studies using the POE method in a technology-supported way. Akpınar (2014) investigated the effect of using POE-based interactive animation on students’ understanding of static electricity concepts. Hong et al. (2014) tried to determine how elementary school students’ attitudes were related to learning interest, and intention to continue learning using mobile applications based on the POE method. Hong et al. (2017) examined how POE affected the cognitive-emotional learning process through an application called “WhyWhy.” Hsiao et al. (2017) determined that the elementary students who used POE inquiry-based learning FPOEIL model (a five-stage prediction-observation-explanation inquiry-based learning model) with technology-assisted learning improved their learning performance in the science course. Hong et al. (2019) modified the learning process based on POE steps to POQE (prediction, observation, quiz, explanation) and built an e-learning environment to provide students with knowledge about green energy. Hsu et al. (2011) investigated the effects of a computer game based on the POE method on facilitating preschoolers’ acquisition of scientific concepts about light and shadow. Alfiyanti and Jatmiko (2020) examined students’ critical thinking skills by using POE and PhET simulations. Siswoyo (2019) prepared a guide for teachers on the use of PhET simulations in POE. Choowong and Worapun (2021) explored the effect of using the 5E model with the POE method on scientific reasoning skills. Yang and Chen (2021) investigated elementary school students’ academic achievement and learning retention levels in digital game environments based on the POE method. However, the literature review found no studies on e-books based on POE.
The Rationale of the Study

Teaching materials can increase efficiency in learning environments, which can be achieved by the use of correctly, appropriately designed materials (Heinich et al., 2002). Presenting content in an impressive way can motivate students to pay more attention to reading it (Tsai et al., 2017). While designing a visual that will also be included in interactive e-books, attention should be paid to attract the attention of those reading the interactive e-book, to facilitate the recall of given messages, and to create an interactive environment in which information can be easily understood (Boynukara, 2019). Otherwise, hyperlinks, color images, animations, and voice narratives in e-books can cause distraction, cognitive load formation, difficulty in understanding the subject (Pearman & Chang, 2010), inability to transmit the desired message, and loss of content when not planned well (Heo & Hirtle, 2001; Murray, 2004). This study will focus on the analysis, design, development, and evaluation processes of the interactive e-book developed on the basis of the POE method. The study may serve as a guide for interactive e-book designers taking any teaching method as a basis. The study addresses the rules to be considered and the process to be followed in the design of interactive e-books based on POE. The study can contribute to designers on key points to consider when creating the content of e-books to be developed based on a learning method and designing and developing materials to be included in them. Furthermore, it can inform and guide designers through principles and rules to be considered in designing the materials contained in e-books. In this direction, the aim of this study is to determine the processes that are considered in the analysis, design, development, and evaluation phases of interactive e-book design based on POE. The research questions are as follows:

1. What are the processes experienced during the analysis phase of interactive e-book design based on POE?
2. What are the processes experienced during the design and development phases of interactive e-book design based on POE?
3. What are the processes experienced during the evaluation phase of interactive e-book design based on POE?

Method

This study was based on the design-based research method (DBR). Wang and Hannafin (2005) define design-based research as a systematic but flexible method of research conducted in collaboration of participants and researchers in a real practice environment. The context-sensitive method aims at developing design principles and educational practices through the phases of analysis, design, development, and implementation cyclically (p. 6–7). Conducting design-based research in a real-world context is important to evaluate the results of the developed application in at least one context, for seeing the functionality of the product (Design-Based Research Collective, 2003) and developing the product (Anderson & Shattuck, 2012). In this method, researchers report different aspects of design using both quantitative and qualitative methods (Wang & Hannafin, 2005). In design-based research, researchers base the product on a theory for learning and teaching and present the relationships between the product developed, the application made, and the theory (Design-Based Research Collective, 2003). The researcher systematically designs and implements interventions, reviews, improves, and re-applies the initial design based on the results of the application. The researcher continues this process cyclically until s/he believes that the application made from a utilitarian point of view has sufficiently improved the product (Kuzu et al., 2011). In this study, the analysis, design, development, and evaluation phases of the e-book based on the POE method are explained by the design-based research method.

Sample

The study involved 2 physics education experts (2 female) to evaluate the developed e-book in terms of content, 4 instructional technology field experts (1 female, 3 male) to evaluate the e-book in terms of message design, and 20 9th grade students (15 boys, 5 girls) to evaluate the suitability of the developed book for the target audience. In addition, 10 physics teachers’ (8 male, 2 female) opinions were received concerning the presentation of content, topics, activities contained in the interactive e-book, and multimedia materials.

Data Collection Tools

Interview

The study employed the interview method, a qualitative data collection tool. Interviews are important for capturing the ideas, thoughts, and experiences of the sources of information in their own words (McGehee, 2012). The interviews allow participants to discuss how they perceive the world and to evaluate the situations they face from their point of view (Cohen et al., 2017). This study used interviews to
get the views of physics education and instructional technology experts on the content and design of the developed interactive e-book and specifically to determine in detail the characteristics the material should have. The interviews with experts in the field of physics education asked the following questions:

- Were concepts about the “heat and temperature” unit properly addressed in concept cartoons, videos, and animations?
- Was the content about the “heat and temperature” topic addressed clearly?
- Are the activities in the POE parts sufficient in terms of detecting and eliminating misconceptions?

Some of the questions asked to experts in the field of instructional technology are as follows:

- How do you find the colors and symbols used in the POE parts in terms of drawing attention to the subject?
- How do you find page designs in terms of attracting students' attention?
- Are the concept cartoons, videos, and animations designed appropriately in terms of learning the subject?
- How do you find the materials in the interactive e-book in terms of motivational design principles?
- How do you find the materials in the interactive e-book in terms of conceptual learning?

Instructional technology experts evaluated the e-book on the basis of the message design principles determined by Fleming and Levie (1978), and questions were created in that direction. Physics teachers were asked the following questions:

- What do you think of the activities involved in the prediction phase of the interactive e-book?
- What do you think of the content and design of multimedia materials such as animations, graphics, concept cartoons, and videos contained in the interactive e-book?

**List of E-Book Evaluation Criteria**

The e-book evaluation criteria developed by the researchers were used as a data collection tool in the study. The criteria list was used to evaluate the e-book in terms of content compatibility with the determined learning outcomes, student level and physics course curriculum, language usage, teacher-student communication, types of materials to support the content, content compatibility with the student level, information provided for e-book use, interface usage, navigation in the e-book, effective usage of POE method in structuring content, student-content interaction, how feedback is given, storage of student responses, and clarity of information and directions. The list included criteria that could serve determining whether the developed e-book achieved the targets set. After creating the criteria list, the list was edited by taking the opinions of 4 instructional technology experts. The criteria list consists of 36 items. The Cronbach's alpha of the criteria list was calculated as 0.80.

**Observation**

Observation has a great benefit in providing a holistic view of the subject being investigated in order to identify the situations that participants are not aware of or do not want to express (Patton, 2018: p. 262). This study used non-participant observations to determine positive or negative situations that occurred during students’ use of the developed interactive e-book. In non-participant observation, the researcher focuses on events/situations to be observed directly by being in the environment (Creswell, 2017: p. 191–192). In the pilot study, the researcher recorded students’ behaviors and conversations in notes during the use of the interactive e-book, thereby determining how much time it took to use the material and what assistance students needed when using the material.

**Process**

The first phase involved the determination of the subject, content, and learning outcomes to be addressed in the interactive e-book with a physics education expert. In the second phase, the platform where the interactive e-book would be developed and the software and tools to be used to create multimedia materials were decided on. In the third phase, with in the scope of the POE method, the kinds of multimedia materials and activities to be included in the interactive e-book were designed with a physics education expert and an instructional technology expert. While designing, multimedia design principles, cognitive load theory, and message design principles related to motivation, perception, and concept teaching were taken into account. In this way, following the completion of the designs for each topic title, the development phase was started.

After the development of interactive e-book parts for each topic, interviews were conducted with 2 physics education experts to evaluate the content and 4 instructional technology field experts to evaluate the interactive e-book in terms of message design. Before the interviews, the field experts examined the developed unit and provided their design recommendations. Following the completion of all the topics, 4 physics teachers and 2 instructional technology field experts reviewed all the topics and evaluated the e-book by taking into account
the e-book evaluation criteria developed by the researchers. Also, using the developed interactive e-book, a pilot study was carried out with 20 9th graders. During the 4-week pilot study carried out with 9th graders, non-participant observations were made. Students used the e-book in the computer laboratory of a high school for 2 h of lessons in a week.

Data Analysis

Data from interviews with experts in physics education, instructional technology, and teachers were subjected to descriptive analysis. Themes and categories were created by examining the opinions stated by the experts. Descriptive statistical techniques were applied to the data collected using the e-book evaluation criteria list. Observations made during the pilot study were subjected to descriptive analysis.

Findings

The Processes Experienced During the Analysis Phase

This section describes the process considered in the analysis phase. At this stage, the topic and content of the interactive e-book to be developed and the platform on which it would be developed were determined.

Determining the Topic and Content

The field of physics contains many complex concepts (Irawati & Sofianto, 2019). The literature suggests that students have difficulty understanding the concepts in the physics course and have misconceptions about many topics (Bozzi et al., 2019; Fenditasari & Istiyono, 2020; Oktavianty et al., 2018; Soeharto et al., 2019). Today, developments in instructional technologies make it possible to develop materials in new forms to increase students’ interests and learning (Brooks et al., 2014). The disadvantages experienced in the field of education during the COVID-19 pandemic also revealed once again that students need materials to help them learn concepts and eliminate misconceptions in both distance education and face-to-face education. As a matter of fact, during the pandemic period, the Turkish Ministry of Education was able to provide teachers with materials contained in the Educational Information Network and the General Directorate of Secondary Education (https://ogmmateryal.eba.gov.tr/panel/Default.aspx). In the Educational Information Network, an academic support system was created for the 11th and 12th grade levels. Physics experiments, questions, animations, and interactive books were included on the material page of the General Directorate of Secondary Education. Some animations and questions presented in the form of videos were placed in the materials called interactive books. Multiple choice, short answer, and drag-and-drop were used as the question type. However, the fact that the resources offered are not collected on a single platform and are not based on a teaching method/model may limit the use of these materials. As Clark and Kozma point out, media in the learning process alone may not be effective. For this reason, the media should be designed with a method likely to render it effective (Clark, 2002; Kozma, 1994).

After determining the discipline in which the e-book would be developed in the study, the “heat and temperature” topic, on which students are stated to have misconceptions (Sofianto et al., 2020), was selected. Students have early conception created through interaction with their environments (Latifah et al., 2019). Their conceptual frameworks are constructed from their experiences in everyday life (Alwan, 2011; Kartal et al., 2011). This topic (heat and temperature) has many examples from everyday life (Alwan, 2011; Ratnasari et al., 2017). Thus, students already have thoughts regarding concepts related to this topic when they come to the classroom (Haryono, 2018).

The “heat and temperature” topic in the 9th grade curriculum in Turkey includes many learning outcomes. All the learning outcomes in the “heat and temperature” topic in the 9th grade physics curriculum were included in the study. First, the curriculum and textbook were examined, and detailed information about the scope and limits of the “heat and temperature” topic was obtained. From among the learning outcomes contained in the textbook on the “heat and temperature” topic, those determined to be closely related to each other were grouped, and 8 sub-topics were created (Table 1). Those 8 sub-topics were taken as basis for content in the interactive e-book to be developed. Table 1 below presents the sub-topics created, the learning outcomes of the basic physics course, and the materials used in the prediction-observation phases for these outcomes.

Selection of the Platform

For the development of the interactive e-book, platform was searched first. Such search started with Kotobee and iBook Author. iBook Author provides its users with various e-book templates such as 3D object, interactive presentation, visual, video, audio, and interactive quiz. However, problems would be encountered in offering the e-books developed in this environment to the target audience of the study, mainly because public schools in Turkey do not have MAC computers, which are needed for iBook Author. Kotobee, on the other hand, has certain limitations, relative to iBook Author, in terms of interactive elements and flexibility. For this reason, it was decided to develop the e-book on the web using the HTML5, CSS3, Bootstrap, Java Script, PHP, and...
| Topics                          | Related outcomes                                                                                                                                                                                                 | Materials used in the prediction phase | Materials used in observation phase | Materials used in the evaluation phase                                                                 |
|--------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------|-------------------------------------|--------------------------------------------------------------------------------------------------------|
| Heat and temperature          | Explains the concepts of heat, temperature, and intrinsic energy. Compares the types of thermometers in terms of their use. Makes calculations about temperature units.                                              | Drag-drop                              | Animation                           | Interactive drop-down box There are explanations, visuals and evaluation questions about the concepts of heat and temperature. |
| Specific heat and heat capacity | Relates the concepts of specific heat and heat capacity. Gives examples from daily life (such as late warming and late cooling of the seas from land). Analyzes the variables that depend on the change in temperature of pure substances that are endothermic or exothermic. | 3 different concept caricatures         | 3 different interactive videos      | There are explanations, visuals, video and evaluation questions about specific heat and heat capacity. |
| Thermal equilibrium           | Analyzes the relationship of the concept of thermal equilibrium with the concept of temperature difference and heat.                                                                                              | 3 different interactive videos         | 3 different interactive videos      | There are explanations, visuals, video and evaluation questions about thermal equilibrium.              |
| Change of State               | Analyzes the variables that depend on the amount of heat required for state change in pure substances.                                                                                                          | 6 different concept caricatures         | Animation                           | 3 different interactive graphics There are explanations, interactive lecture videos, graphics, infographics and evaluation questions about the change of state. |
| Energy transmission routes    | Explains energy transmission ways with examples.                                                                                                                                                                   | 3 different concept caricatures         | 3 different interactive videos      | There are explanations, visuals and evaluation questions about energy transmission routes.              |
| Energy transmission routes of solids | Analyzes the variables that affect the energy transfer rate in solid matter.                                                                                                                                 | 5 different concept caricatures         | Video                              | There are concept explanations, visuals and evaluation questions on the energy transmission routes of solids. |
| Global warming                | Develops a project on measures to be taken against global warming.                                                                                                                                               | 2 different concept caricatures         | Animation                           | There are explanations, visuals and evaluation questions about global warming.                        |
| Expansion                     | Interprets the effects of expansion and contraction in solids and liquids in daily life.                                                                                                                                 | 4 different concept caricatures         | 4 different videos                  | There are explanations, visuals, graphics and evaluation questions on the subject of expansion.         |
MySQL programming languages. A web-based interactive e-book was developed, which students could easily access from any computer with internet connection. In this way, it would also become possible to develop an interactive e-book having virtual classroom features such as teacher and student sessions, teacher listing and scoring student responses. iBook Author and Kotobee do not offer these opportunities to their users. Therefore, they were not used in the study.

The study used the Camtasia Studio program to create the videos contained in the prediction, observation, and explanation sections of the e-book. The Adobe Illustrator program and the Freepick site were used for the design of all images contained in the e-book, and the Adobe Animate program was used for the development of animations.

The Processes Experienced During the Design and Development Phase

This section describes the process followed in the design and development phases. At these phases, scenarios were prepared on how to integrate the POE method with the interactive e-book. In line with the scenarios, materials to be included in the interactive e-book were developed. Design decisions were made on how to present the learning outcomes aimed to be introduced by the interactive e-book to students more effectively.

The Development of the Interactive E-Book Based on POE

The literature contains many studies showing the effectiveness of POE on many variables. These variables can be listed as analytical skills (Sarah et al., 2021), misconceptions (Astiti et al., 2020; Latifah et al., 2019), critical thinking skills (ArSY et al., 2020), and conceptual mastery (Furqani et al., 2018). In this case, it can be said that POE is an effective method in eliminating misconceptions and supporting conceptual learning. Hence, it could be beneficial to take POE as basis during the development of instructional materials related to physics, which has many abstract subjects and concepts.

This study took POE as basis, as it allows students to be more active in the learning process and has many advantages. In addition, there is no sufficient research about POE-based interactive e-book. When the advantages of POE and opportunities of interactive e-book are combined, learning is expected to be more effective.

In the study, scenarios were created with a field expert about what might happen at the phases of the POE method, taking into account the learning outcomes that would be addressed within the scope of each sub-topic (Fig. 1, Table 1). When creating scenarios, the following items were planned as a whole:

- Prediction by students based on the kind of materials presented for the intended learning outcomes group
- How they can observe what they predict
- How to explain their observations and predictions by comparing them

At the prediction phase, matching questions were used only for the learning outcomes groups related to concepts (Fig. 2a). On the other hand, open-ended questions were employed for the learning outcomes groups related to a law of physics or phenomenon (Fig. 2b). Open-ended questions were presented in the form of videos, animations, or concept cartoons. When the concept cartoons were used, the students were asked to indicate the characters they agreed with in the concept cartoons prepared in the form of dialogs and why they agreed with their opinion. They were expected to watch the video or animation.
During the observation phase, animations and graphics were employed in general. When the situation presented at the prediction phase contained an event that could be observed, animations were used. If the relationship between the two variables was displayed simultaneously, graphs were used. Graphs are often used for situations involving computation. They were used to observe how the factors included in the calculations changed simultaneously. For example, the following item of the curriculum states that a mathematical model should be given in its learning outcome, no mention should be made of how the calculations should be made: “Analyzes the variables that depend on the amount of heat required for change of state in pure substances.” In this case, graphs showing how the relationship between any two of the variables in the formula $Q = mc\Delta T$ changed were used. When two of the four variables contained in the formula were kept constant, how the other two changed was shown by drawing separate graphs. The following learning outcome states that examples from daily life should be presented: “Correlates the concepts of specific heat and heat capacity with each other.” In this case, events involving situations related to substances whose specific heat and heat capacity are different were presented with animations. For example, animations were used in cases where the relationship between only two variables was observed, such as the effect of surface area on the heat conduction rate in solid materials. When animations were used in the observation phase, students were asked to answer the open-ended questions given by observing the events involved in the animation (Fig. 3a). In the graphs, changes in the heat and temperature of substances were reflected by time, and the students were asked to examine the graph and answer the questions asked (Fig. 3b).

The explanation phase involved a short explanation (Fig. 4a), summarizing physics information, and evaluation...
questions (Fig. 4b) for the answers of those presented in the prediction phase. Verbal and visual content, video narration, drop-down menu, back-and-forth buttons, infographics, tables, graphics, and photo galleries were used to explain physics information. In this phase, explanations, visuals, and evaluation questions about each topic were presented to students, in an attempt to provide them with an idea about whether their predictions and observations were correct. In the evaluation questions, the students were provided with the scores they received after answering the questions and the correct answers.

Multimedia Design Principles Considered in Interactive E-Book Design

In order to achieve the learning outcomes determined in the developed e-book, information about heat and temperature was presented to the students using multimedia elements such as visuals, videos, graphics, animations, concept cartoons, and sounds. Mayer (2001) defined multimedia as the presentation of a material supported by images and text, in other words, in more than one form. However, in some cases, the resources used to support students’ interest in activities could prevent students from reaching the targeted learning outcomes by causing them to put much more cognitive effort into the learning process (Chandler & Sweller, 1991). At this point, cognitive load theory, which focuses on adapting teaching based on the student’s cognitive capacity, comes to the fore (Schnotz & Kürschner, 2007). Plass et al. (2010) define cognitive load theory as a theoretical framework based on making as much use of long-term memory as possible by effectively designing the learning environment and teaching processes for the most effective processing of complex cognitive processes.

Cognitive load is considered in three dimensions: intrinsic cognitive load, extraneous cognitive load, and germane/effective cognitive load. The intrinsic cognitive load is related to the inherent complexity of knowledge that needs to be understood and of material that needs to be learned (Schnotz & Kürschner, 2007). It is not influenced by instructional issues, such as how knowledge should be presented or what activities students should take part in to maximize
learning (Sweller, 2010). Extraneous cognitive load is a load that negatively affects the learning process as a result of the learning environment containing information and content that is not appropriate for the subject content (Paas et al., 2003). Germane/effective cognitive load can be defined as a load related to activities and content supporting learning and schematic creation (Schnotz & Kürschner, 2007). Cognitive load theory recommends reducing the extraneous load, balancing the intrinsic load, and increasing the germane load in order for teaching to be more effective. Due to the limited structure of working memory, the extraneous cognitive load should be taken as a subject to be considered during the instructional design, so that it does not negatively affect learning, recalling, and transferring (Kıraç, 2019). In this way, the germane/effective load that positively affects learning can be increased, and the intrinsic load can be managed through the schemas and mind structures created by the effective cognitive load (Paas et al., 2003). The extraneous cognitive load should be reduced by using appropriate teaching methods, as it directly reveals situations in which learners experience learning difficulties and is an element that negatively affects learning (Erdoğmuş, 2020).

As a result of many years of experimental research, Mayer revealed multimedia design principles for the use of three types of cognitive loads. Therefore, in the developed interactive e-book, the principles of multimedia design put forward by Mayer (2009) were taken into account. According to the multimedia principle, especially in the description section of the e-book, supporting texts, descriptive images, videos, and animations were included (Fig. 5a). Taking into account the principle of coherence, explanations and visuals were not included on each page of the e-book, except for the targeted learning outcomes. Based on the principle of signaling, icons reflecting each phase of POE were included, and the colors of important texts were set to red and thickened in the explanation phase (Fig. 5a). By the redundancy principle, texts and visuals or visual and audio elements were included in the e-book, especially in videos and animations. The use of the three elements together was avoided (Fig. 5b). In accordance with the spatial contiguity principle, relevant images and texts were placed simultaneously and closely together (Fig. 5c). Attention was paid to the human voice and daily language use in all voice statements made in accordance with the principle of personalization and voice. According to the temporal contiguity principle, attention was paid to present audio narration and visuals together, especially in animations. Based on the principle of segmentation, the “heat and temperature” topic was divided into 8 sub-topics, and the POE activities related to each sub-topic were presented separately (Fig. 1).
In the development of the interactive e-books, both multimedia design principles and message design principles put forward by Fleming and Levie (1978) were considered. In order to arouse the students’ interest and willingness, attention was paid to the symbols in the prediction, observation, and explanation phases and to the colors used to evoke the subject being processed. Various materials such as animations, concept cartoons, and videos were used in the POE phases. To activate cognitive willingness, concept cartoons containing different views on the subject of physics were used, and it was ensured that the students expressed the views they supported (Fig. 2c). Thanks to focusing on examples from daily life (such as the heat and temperature of a boiling dish in a pot), the students could relate their previous and current knowledge. Virtual classroom logic was used to give students feedback on their responses in the POE phases. A classroom was created with e-mail addresses and passwords. Each student’s answers in the sessions logged in with their own personal accounts are recorded and sent to the teacher’s panel. Here, the teacher can also evaluate and score based on the answers of each student and give feedback to the students. To gather and maintain the students’ attention, e-book page designs had a comfortable appearance to work with, only one learning outcome was targeted on each page, and easy-to-read fonts and natural language were used (Figs. 2, 3, 4, and 5). Coloring was done by considering the figure-ground relationship so that the texts could be easily read, and the elements contained in the pages could be easily perceived. Back-and-forth arrows and orientation buttons were used to facilitate the guidance of the material. In order for the student to easily read the e-book pages, sections were made on the pages, and symbols were used (Figs. 2 and 3). The content was presented to the students by dividing it into sub-topics so that they were related to each other.

Apart from the above information, educational video design recommendations of Moussiades et al. (2019) were taken into account in the design of the videos contained in the e-book. In this direction, the videos were prepared for 2–3 min long in order not to bore the students. Attention was paid to ensure the compatibility of the colors, visuals, and sounds contained in the videos as well as that the images used were two-dimensional and simple. Close-up shots and sounds compatible with the subject were included in the videos. The principles proposed by Weiss et al. (2002) were considered in the design of the animations in the interactive e-book. In the animations, effects such as zoom-in and zoom-out were used to attract the students’ attention and allow them to examine the images more closely. Animations were not used for the presentation of information but for the embodiment of concepts and events in the design of concept cartoons, and Kabapinar’s (2009) suggestions for using and naming characters were taken into account.

The Processes Experienced During the Evaluation Phase

Opinions were received from field experts regarding the interactive e-book content and design developed in this phase.

Expert Views on the Interactive E-Book

The physics education experts’ (E1, E2) and 4 instructional technology field experts’ (E3, E4, E5, E6) views on the content and message design of the developed interactive e-book were generally positive, and they had some suggestions to make it more effective. One of the physics education experts (E1) made suggestions, such as the following, only to make questions and texts more understandable:

- Instead of saying, ‘according to you, observe how the movements of the particles of the heat-generating substance change’, it would be more accurate to say, ‘observe how the movements of the particles of the heat-generating substance change.’

Another physics education expert (E2) also made suggestions for more accurate and understandable questions and texts. Some of these suggestions are as follows:

- “Isn’t there a semantic shift when saying ‘we can put the soup in a bowl with cold water in it?’ It sounds like there will be a mixture. Instead of that, it would be more logical to put the soup in a bigger bowl with water in it or support it with a visual”. “In the animation, instead of asking, ‘What could be the temperature units Cem?’, a question like ‘Do you know the temperature units?’ should be more proper because the answer doesn’t involve a possibility. The same goes for ‘calorie and joule could be’ because it is already ‘calorie and joule’.”

E2 suggested that the ranking of speech bubbles in the two concept cartoons should be changed: “The ranking of speech bubbles should be adjusted.” “Again, the cartoon ranking is not right in my opinion, the conversation should go from top to bottom.” The expert with the statement “There are more striking visuals on global warming,” suggested that better visuals should be used for the situation/event. As for the videos and animations, it was suggested to organize them in a way that could be observed more easily: “Can’t we make pans bigger? It is difficult to observe, or a stopwatch may be placed on the side to measure both pans.” “Let’s either increase the diameter of the arrows or make the room smaller.” All instructional technology experts stated that the interactive e-book complies with the elements and principles of material design. Only two of the experts (E5, E6) suggested a more detailed presentation of introductory information for the use of the interactive e-book:
“Students could be informed more about its use.” “Information about the use of materials could be presented in the introduction of the interactive e-book.”

Teacher Feedbacks on the Interactive E-Book

After the development of content and materials related to all topics was completed, in interviews with physics teachers, all teachers stated that the developed interactive book was prepared in accordance with the subject, the method used, and the student audience: “It was prepared in accordance with the curriculum.” “Well thought. I really like it. It’s overlapping.” “Suitable for student level.” Two teachers stated that the number of questions and activities in the prediction and observation phases should be increased: “Examples could be increased in the prediction phase.” “There could be more prediction and exemplification.”

Three teachers said that the number of questions should be increased: “I think that the comprehension part is good,

Table 2 Compliance with e-book evaluation criteria according to expert views

| Items                                                                 | Mean |
|----------------------------------------------------------------------|------|
| It allows teacher-student communication.                              | 4.60 |
| There is a dictionary section that explains words and concepts that students do not understand. | 3.00 |
| There are different types of materials to support the content.        | 4.83 |
| Content is suitable for learning outcomes.                           | 4.83 |
| Content is appropriate to student level.                             | 4.66 |
| The content consists of accurate information.                        | 4.83 |
| Current information/examples are included in the content.            | 5.00 |
| The content is presented in an interesting way.                      | 4.66 |
| The content is compatible with the physics course curriculum.        | 5.00 |
| In the presentation of content, the principle of simple to complex is followed. | 4.66 |
| Activities that require high-order thinking are included.            | 4.16 |
| Teachers and students can easily access the e-book.                  | 4.66 |
| An education is required to use the e-book.                          | 2.00 |
| Information required for the use of the e-book is provided.          | 3.83 |
| Sufficient information is provided about the use of the e-book.       | 4.16 |
| The e-book is easy to use.                                           | 5.00 |
| E-book gives you the opportunity to navigate in it.                  | 4.83 |
| E-books can be easily used in a classroom environment.               | 3.66 |
| Instructions/guidance on the pages is clear and comprehensible.      | 4.50 |
| Attention was paid to copyright in the development of elements.      | 4.66 |
| The POE method was used effectively in structuring the content.      | 5.00 |
| The virtual classroom is used to provide interaction between the student, teacher, and content. | 4.83 |
| It includes interactive applications that make it easier to achieve learning goals. | 4.83 |
| Teachers can give immediate feedback to students’ answers.           | 4.16 |
| Students can instantly see the feedback given by teachers.           | 4.16 |
| Teachers can easily follow which practices students perform.          | 5.00 |
| The answers that students give throughout the applications can be stored. | 5.00 |
| There is an evaluation phase suitable for determining the status of students’ attainment. | 5.00 |
| The strategy/method/technique used activates the students.           | 4.83 |

| Items                                                                 | Mean |
|----------------------------------------------------------------------|------|
| It stores data for process evaluation.                               | 5.00 |
| A method/strategy/technique that can be effective in eliminating students’ misconceptions is used. | 5.00 |
| It includes interactive applications that make it easier to achieve learning outcomes. | 4.83 |
| It contains elements that will motivate students to learn.           | 4.16 |
| Different types of media related to content (text, audio, images, graphics, video, etc.) are used. | 4.83 |
| The icons of the buttons used clearly demonstrate their function.    | 4.33 |
| The names of the menus clearly demonstrate their function.           | 5.00 |
| Colors are used to provide emphasis.                                | 4.66 |
| Elements are placed in interfaces to create formal/informal balance. | 4.33 |
| It’s easy for students to log back in when they log out of the e-book. | 4.83 |
but there is a lack of questions. It is useful to diversify and increase the number of questions.” “There are not many disadvantages. Only maybe in the last part, there may be more questions.” “Extra questions could be added.” A teacher stated that some of the images are not appropriate for the high school student level: “The characters are quite interesting, but I think some visuals are not appropriate for the 9th grade students.”

**Results of the Pilot Study with Students**

Twenty students voluntarily participating in the study were first introduced to the interactive e-book and the POE method. Then the students registered in the system. Introduction and registration took 50 min. It took an average of 40 min for each section related to the sub-topics in the interactive e-book to be used by the students. The students did not have problems using e-books and understanding the content. The problems can be listed as follows: Not every student had a computer, internet infrastructure and computer hardware in laboratories were insufficient, and there were infrastructure-related failures.

**Compliance with the E-Book Evaluation Criteria**

After the development of content and materials related to all topics was completed, 2 physics education and 4 instructional technology experts were asked to express their views by rating them in the range of 0–5 points using the e-book evaluation criteria. They indicated at what level they agreed with the statement specified in each item presented in Table 2. The average scores given by the experts for each item are presented in Table 2.

As can be seen from Table 2, the experts expressed their views on the suitability of many features in the developed material for the e-book criteria by rating them higher than 4.00. The average scores given to the criteria for the comfortable use of the e-book in a classroom environment \((X = 3.66)\) and presentation of information required for the use of the e-book \((x = 3.83)\) were less than 4.

**Conclusion and Discussion**

**The Processes Experienced During the Analysis Phase**

This study covered the development process of an interactive e-book based on the POE method by choosing “heat and temperature” from among physics topics. In the literature, a limited number of interactive e-books have been developed on physics, and they are related to energy sources (Hasan et al., 2018), static liquids (Adam & Suprapto, 2019), rotational dynamics (Adawiyah et al., 2019; Harjono et al., 2020), momentum (Septikasari et al., 2021), and earthquakes (Perwita & Fauzi, 2021). However, the literature review found no interactive e-books developed for the “heat and temperature” topic. Irsyad et al. (2018) determined that students found the topic of temperature difficult and had misconceptions about heat and temperature. One of the topics that students have the most misconceptions about science is heat and temperature (Bozan & Savaş, 2019; Fenditasari & Istiyono, 2020; Rizaldi, 2021). Irsyad et al. (2018) detected that the reasons for misconceptions about heat and temperature are previous learning and the teaching methods used. As Suprapto (2020) notes, the teaching methods and materials used by teachers play an important role in eliminating misconceptions. Saparini and Rizaldi (2021) suggested developing materials to support learning about heat and temperature and eliminating misconceptions. For this reason, the interactive e-book developed on the “heat and temperature” topic, where there are many misconceptions, may contribute to the practice of physics education. As a matter of fact, the developed interactive e-book offers teachers and students an alternative resource that can be used both at school and in individual study times outside of school.

Since the “heat and temperature” unit, which is one of the subjects of the 9th grade physics course, was addressed, the target audience of the research was high school students. As research sample, previous studies in the interactive e-books field covered university students (Almekhlafi, 2021; Kao et al., 2019), preschool students (Li et al., 2020; Mouri et al., 2018; Sung & Wu, 2017), or primary school students (Huang & Liang, 2015; Hwang & Lai, 2017; Sung et al., 2019a, b; Umarji et al., 2020). There were a limited number of studies on physics subjects with high school students (Adam & Suprapto, 2019; Adawiyah et al., 2019; Harjono et al., 2020; Hasan et al., 2018; Perwita & Fauzi, 2021; Septikasari et al., 2021). In this sense, the interactive e-book developed in the study contributed to the literature on physics education at the high school level.

**The Processes Experienced During the Design and Development Phases**

As Kuczmann (2017) states, the improvement of critical thinking can be effective in preventing misconceptions. Experimental studies in the literature demonstrated that one of the methods supporting critical thinking is POE (Furqani et al., 2018; Muhibuddin et al., 2020). There is a positive relationship between critical thinking skills and success (Arsy et al., 2020). For this reason, the material developed by adopting the POE method is likely to help increase students’ success and eliminate misconceptions. Several studies indicated that the POE method supports conceptual learning related to heat and temperature and helps eliminate misconceptions (Anarki et al.,
2016; Baydere, 2021; Khatoon, 2019; Latifah et al., 2019). However, in those studies, the POE method was not utilized in a technology-supported way. The developed material may contribute to the literature on the teaching of the “heat and temperature” topic and the use of the POE method.

The interactive e-book developed within the scope of the study used videos, animations, concept cartoons, graphics, and matching questions. The literature suggests that animations embody abstract concepts, and hence students’ perception and understanding can improve (Akcay et al., 2005). Aththibby (2021) confirmed, with an experimental study, that the use of animation in physics positively affects both success and motivation. Educational videos may provide a better understanding of concepts and recall from the memory than printed sources (Jackman & Roberts, 2014; Tiernan, 2015). Educational videos are argued to be important course materials for concretizing difficult and complicated situations by supporting them with some elements such as graphics and shapes (Bates, 2005). Concept cartoons are effective in identifying (Sertaş & Türoğlu, 2020) and eliminating (Baysan, 2007) misconceptions in science teaching, and the use of animated concept cartoons contributes to students’ better understanding of science concepts (Dalacosta et al., 2009).

Evaluating materials in terms of cognitive load in the development process of materials often used in learning-teaching environments not only support meaningful learning but also help in the effective design of teaching environments (Tuğtekin, 2019). According to cognitive load theory, the success of instructional designs performed without taking into account the cognitive capacities of individuals will depend on probabilities (Schnoz & Kürschner, 2007). It is important for instructional designers to consider cognitive load when preparing multimedia materials. For this reason, multimedia design principles based on cognitive load theory and message design principles put forward by Fleming and Levie (1978) were taken into account when designing the materials contained in the interactive e-book. Expert opinions confirmed that the use of the developed material complies with multimedia design principles and message design principles, and hence, it can positively affect the teaching process.

The Processes Experienced During the Evaluation Phase

Based on the views of the physics education and instructional technology experts, attention was paid to ensure that the questions in the interactive e-book serve a clear and understandable purpose, that the focus is on a single learning outcome on each page of the e-book, and that animations and videos clearly reflect the concept or event addressed. Thus, as Fleming and Levie (1978) stated in the message design principles, misunderstandings were forestalled, and it was ensured that each student would infer the same meaning from the questions in the e-book. In the concept cartoons, the speech balloons were sorted, orientation buttons were placed, and the images used in the explanation phase were kept consistent with the texts next to them. Hence, students’ easy navigate through the e-book was assured. As Paivio (1991) noted in his dual-coding theory, texts and images supporting each other were aimed at raising the memorability for students by making it easier to understand concepts. While developing the interactive e-book based on the views of physics teachers and the results of the pilot study with high school students, more activities were included in the POE phases, and the number of evaluation questions was increased, thereby allowing the better determination of students’ misconceptions and facilitating their comprehension of the subjects. Indeed, Fleming and Levie (1978) also suggested that the number of examples in concept teaching may have an effect on learning.

Declarations
Conflict of interest The authors declare no competing interests.

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