STUDENTS’ UNDERSTANDING OF THE GREENHOUSE EFFECT: A CROSS-AGE STUDY

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ABSTRACT

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This study aimed to investigate high school students’ and final-year pre-service teachers’ mental models of the greenhouse effect at different age levels (Grade 9, Grade 11, and the pre-service teachers). This study further investigated the relation between students’ mental models and academic achievements. In this regard, the study identified the components and properties of the mental models of each participant about the greenhouse effect and explored how the main constituents of these models progressed across different grade levels. Secondly, the mental models of the greenhouse effect were examined based on the participants' academic achievement. For this purpose, individual interviews were conducted with high school students: Grade 9 (n=18) aged between 14-16, Grade 11 (n=24) aged between 17-19, and pre-service physics and chemistry teachers (n=19), who were 18-29 years old. This study used qualitative data from semi-structured interviews and sketches to identify the participants' mental models about the greenhouse effect. The constant comparative method was used to analyze student answers to questions about the greenhouse effect. The data was iteratively coded to generate the codes corresponding to students’ mental models about the mechanism of the greenhouse effect. The features of greenhouse effect mechanisms and ten different mental models were identified. The Macro Models without particulate level explanations outnumbered the Micro Models in which the properties of particles are explained across all participant groups. Pre-service teachers have significantly progressed toward a scientific greenhouse effect model compared to the other groups. Alternative conceptions of the students about the greenhouse effect were also identified. Each student’s academic accomplishment based on their grade point average was related to the type of their mental model. No correlation was found between academic achievement and the types of mental models of the Grade 9 students’ mental models. However, there was a moderately significant correlation between the mental models of the Grade 11 students and the pre-service teachers.

ÖZET

LİSE ÖĞRENCİLERİNİN VE ÖĞRETMEN ADAYLARININ SERA ETKİSİNE İLİŞKİN ZİHİNSEL MODELLERİNİN İNCELENMESİ

Bu araştırma, lise öğrencilerinin ve öğretmen adaylarının farklı yaş düzeylerinde (9. sınıf, 11. sınıf lise öğrencileri ve son sınıf öğretmen adayları) sera etkisine ilişkin zihinsel modellerini araştırmayı amaçlamaktadır. Bu çalışma aynı zamanda öğrencilerin zihinsel modelleri ile akademik başarıları arasındaki ilişkiyi de incelemektedir. Bu bağlamda, bu çalışma, her bir katılımcının sera etkisine ilişkin zihinsel modellerinin bileşenlerini ve özelliklerini belirleyerek, bu modellerin ana bileşenlerinin farklı sınıf seviyelerinde nasıl ilerleme gösterdiğini araştırmaktadır. Bununla birlikte, katılımcıların akademik başarılarının sera etkisine yönelik zihinsel modellerinin gelişimi arasındaki ilişki incelemektedir. Bu amaçla, araştırmaya katılmaya gönüllü 14-17 yaş arası 9. sınıflardan 18 öğrenci, 11. sınıflardan 24 öğrenci ve fizik ve kimya öğretmen adaylarından ise 18 yaş üstü 19 öğrenci ile bireysel görüşmeler yapılmıştır. Bu çalışmada, sera etkisi ile ilgili çeşitli zihinsel modelleri ortaya çıkarmak için yarı yapılandırılmış görüşmeler ve öğrencilerin oluşturduğu çizimlerden elde edilen nitel veriler kullanılmıştır. Öğrencilerin sera etkisi ile ilgili sorulara verdikleri yanıtların analizinde sürekli karşılaştırma yöntemi kullanılmıştır ve sera etkisi zihinsel modellerinin mekanizmasına karşılık gelen kodlar tespit edilmiştir. Sera etkisi mekanizmalarının özellikleri belirlenmiş ve 10 (on) farklı zihinsel model oluşturulmuştur. Tüm gruplardan toplanan verilere bakıldığında, parçacık düzeyinde açıklamalar içeren makro modellerin, parçacıkların özelliklerinin ve davranışlarının açıklandığı mikro modellerden daha fazla sayıda olduğu tespit edilmiştir. Öğretmen adaylarının, diğer gruplara kıyasla bilimsel sera etkisi modeline daha yakın modellere sahip olduğu belirlenmiştir. Öğrencilerin sera etkisi ile ilgili sahip oldukları alternatif kavramlar tespit edilmiştir. 9. sınıf öğrencilerinin akademik başarıları ile sera etkisine ilişkin göstermiş oldukları zihinsel modellerinin türü arasında anlamlı bir ilişki bulunamamıştır; ancak 11. sınıf öğrencileri ve öğretmen adaylarının akademik başarıları ve sera etkisine ilişkin zihinsel modelleri arasında istatistiksel olarak orta düzeyde anlamlı bir ilişki bulunmuştur.

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DESD	Decade of Education for Sustainable Development
G9	Grade 9 students
G11	Grade 11 students
GHE	Greenhouse Effect
IPCC	Intergovernmental Panel on Climate Change
MoNE	Ministry of National Education
MDG	Millennium Development Goals
NASA	National Aeronautics and Space Administration, Science Mission Directorate
NGO	Non-Governmental Organizations
OECD	Organization for Economic Cooperation and Development
PST	Final year pre-service teachers
UN	United Nations
UNESCO	United Nations Educational, Scientific, and Cultural Organization

1. INTRODUCTION

Global temperatures inevitably rise as greenhouse gases continue to be emitted into the atmosphere due to human activities, resulting in climate change (NASA, 2010). The intensification of greenhouse gases consequently leads to an increase in greenhouse effect, which is the main reason for climate change (IPCC, 2007). We are currently living with the consequences of climate change. Some of the impacts that have been linked to climate change are extreme weather incidents, ocean acidification, reduced oxygen levels, coral bleaching in hydrosphere, erosion, drought, losing wetlands, changes in animal species, wildfires, and melting ice caps (IPCC, 2007; IPCC 2021). Thus, climate change poses problems to plants, animals, hydrosphere, weather, human health and agricultural activity. As the consequences of climate change occur more frequently, there is a need to increase individuals' environmental literacy and take pro-environmental actions all around the globe. For instance, using renewable energy, sustainable transportation and political commitment to these pro-environmental actions should be provided. International organizations highlighted education as an effective strategy for developing environmental literacy and raising environmental consciousness. The goal of environmental education was affirmed in the Tbilisi Declaration in 1977 as a result of an international conference of the United Nations Educational, Scientific, and Cultural Organization (UNESCO) in 1976. Since then, education has been shown as an indispensable stakeholder of climate action to build resilience against global warming due to greenhouse effect and consequently climate change. Many countries have started to place environmental education on their agenda urgently. The goal of environmental education was to make individuals understand the nature and effect of their continuous interaction on the environment, gaining the attitudes and practices to manage environmental problems (ICEE, 1977).

The United Nations continued to take steps to be sure of the educational aspect of sustainable development by publishing declarations. For this purpose, ensuring environmental literacy took place among the eight Millennium Development Goals (MDG) for 2015 that were set in the Millenium Summit of the UN in 2000. In the World Summit on Sustainable Development, the resolution 'Decade of Education for Sustainable Development

(DESD)' was proposed by Japan and supported by 46 other countries in 2002 (UNCED, 2002). In the PISA 2006 assessment, it was found that 98% of students in the Organization for Economic Cooperation and Development (OECD) countries attended classes about environmental topics such as pollution, biodiversity, and conservation of resources (OECD, 2009). In 2014, the United Nations Climate Change Conference affirmed a declaration as a complement for the DESD. In the UN Sustainable Development Summit 2015, seventeen sustainable development goals were set to be achieved by 2030 (UN, 2015). Since then, countries have been making educational revisions on environmental and sustainability education by considering these goals.

It is crucial to improve environmental literacy among students, responsibility and hopefully, protective behavior for both today's world and future generations since the ecosystems and Earth's sources are ruined each day. Mohan et al. (2009) stated that environmental literacy encompasses the need for people to know specific information about environmental events, such as the transformations of matter that occur in the carbon cycle, mechanism of greenhouse effect in order to make responsible environmental decisions. Research in science education has identified at which level students comprehend the basic concepts in relation to these topics to adjust the curriculum, building instructional plans to educate students on the greenhouse effect and climate change (Driver et al., 1994; Osborne & Freyberg, 1985). In order to set light to the current knowledge level of high school students and student teachers, this study focused on students' mental models of the greenhouse effect and explored how these models progress across different grade levels.

1.1. Environmental Education in Turkey

According to the constructivist view of learning, students are influenced by informal and formal sources about environmental subjects, in particular visual media and social interactions are highly influential besides the formal education students take at schools. The OECD (2012) defined non-formal learning as out-of-school activities with a plan. There are voluntary-based non-governmental organizations (NGOs) that work for generating solutions for the environmental problems and raise environmental awareness in Turkey. As Ors (2012) stated, some of these kinds of NGOs are: The Environment Foundation of Turkey (Türkiye

Çevre Vakfı), Turkey's Nature Conservation Society (Türkiye Tabiatını Koruma Derneği), World Wildlife Association, Turkey (Doğal Hayatı Koruma Derneği, Türkiye) and The Turkish Foundation for Combating Soil Erosion, for Reforestation and the Protection of Natural Habitats (TEMA Vakfı).

Formal education in Turkey is planned in accordance with the needs of the citizens and society as well as the demands of the times. Curricula and textbooks of primary school to secondary school are updated in line with these demands. The long-term educational aims of all curricula were stated to be complementary throughout pre-school, primary, and secondary education (MoNE, 2017e). The educational aim concerning the secondary education was stated as “to develop their competencies gained in primary and secondary schools, transform the national and spiritual values and embrace as the lifestyle, be productive and active citizens, contributing to country's economy, social and cultural development, acquired skills and competencies in the "Turkey Qualifications Framework" and are ready for a profession, higher education and life in line with their interests and abilities” (MoNE, 2017e). The educational aims are known to be encircling various aspects of life, and this educational aim covers long-range individual and societal issues for all groups of students. Curriculum developers expect a vast majority of students to undergo similar learning experiences and achieve the educational goals of the curricula.

Science curriculum at the Grade 5 level includes objectives in relation to the greenhouse effect, which are linked to the propagation and reflection of light (MoNE, 2017a). The unit "Heat and Matter" is one of the course objectives for the science classes taught in Grade 6. The science course textbooks also address climate change, global warming, and how it affects Turkey in association with the relevant unit at the Grade 6 level (MoNE, 2017b). In the middle school science curriculum, the concept of greenhouse effect is mainly addressed within the context of “Climate and Air Movements” and “Environmental Issues” units in Grade 8 (MoNE, 2017c).

The high school chemistry curriculum has also been reviewed with a similar emphasis on the ideas around the greenhouse effect. In the high school level, environmental concepts and issues are introduced to students within the curriculum framework of different courses in time. High school students may learn about similar environmental subjects in different grade levels and in different courses such as chemistry, biology, and geography. The Grade 9 chemistry curriculum included a subject on “Environmental Chemistry” (MoNE, 2017e). The greenhouse effect, ozone depletion, air pollution, global warming, and sustainable development are among the unit's goals (MoNE, 2017e). The greenhouse effect and other environmental concerns are also included in the chemistry curriculum for Grade 10 (MoNE, 2017e).

In higher education, there are environment-related courses about global climate change, the environmental dimension, and sustainable development for university students to contribute to the improvement of their environmental literacy in Turkey. Tuncer (2008) stated that there are three different environmental elective courses for the students of Faculty of Education at the Middle East Technical University. For instance, there are 6 different environmental elective courses for students at Boğaziçi University (Boğaziçi University Institute of Environmental Sciences, 2022).

1.2. The Greenhouse Effect

The Earth’s climate system, the greenhouse effect, and climate change can be explained by physical concepts and principles. The sunlight consists of a spectrum of electromagnetic wavelengths. When the sunlight reaches the Earth, the shortwave radiation may either be absorbed or reflected back to space by the Earth’s atmosphere (clouds and the greenhouse gases). The radiation with shorter wavelengths might be reflected mostly by the thin clouds but most of them reach the Earth’s surface (NASA, 2010). The ozone layer that resides mostly in the stratosphere absorbs the ultraviolet radiation coming from the sun (Fahey & Hegglin, 2011). The greenhouse effect (GHE) is a phenomenon in which the shortwave radiation (visible light) passes through the atmosphere, is either absorbed or reflected by the Earth’s surface, and then re-emitted as longer wavelengths (infrared radiation). Re-emitted longwave radiation is absorbed by the greenhouse gases, accumulated majorly at the lowest layer (troposphere) of the atmosphere (Prather et al., 2001). The longwave radiation is reemitted once again in various directions into space and Earth, which increases the temperature of the Earth (see Figure 1.1).

According to the basic laws of radiation, during the blackbody radiation, objects absorb all radiation that falls on it and reemit the energy as electromagnetic radiation, and hotter objects emit shortwave radiation (NASA, 2010). The greenhouse gases (e.g., methane, water vapor, carbon dioxide) are not affected by the visible light but they are able to absorb and emit the infrared radiation. This condition is met by all gas molecules with three or more atoms, making them infrared radiation absorbers. The absorptions of infrared radiation are responsible for the vast majority of atmospheric warming (ACS, 2022). As the incoming infrared radiation is absorbed by the greenhouse gas molecules, this increases the energy of the gas molecules, and molecules start to vibrate. When the gas molecules give off the absorbed energy as reemitted infrared radiation, the vibration of the gas molecules end (UCAR, 2022). The lower the vibrational energy of these molecules, the less the number of collisions of gas molecules are (ACS, 2022).

Like the other greenhouse gases, carbon dioxide is unaffected by visible light, but infrared radiation interacts with molecules of carbon dioxide and warms them. If the amount of greenhouse gases decreases, this would result in the fall of the temperature of the globe. Arrhenius (1896) was the first to claim how much the amount of CO_2 in the atmosphere affect the heating of the Earth. He conducted an experiment by halving the amount of carbon dioxide in laboratory conditions and observed the temperature was lowered by 4-5 Celsius degrees. He also found out that when he doubled the amount of CO_2, the temperature had risen about 5-6 Celsius degrees. This experiment was the earliest evidence of if the level of carbon dioxide increases, that would increase the temperature of the Earth. The equilibrium between the absorbed solar radiation and reemitted longwave radiation has changed as more greenhouse gases have been emitted over the years, which led to the increase in the equilibrium temperature of atmosphere.

Some of the reemitted radiation by the greenhouse gases turns back to the water, land surfaces, and heat the globe. According to Benestad (2016), at equilibrium, the balance between the solar energy emitted from the sun, absorbed by the Earth, and reemitted by the Earth's surface is maintained. For the global temperature's mean to stay constant, there has to be an equilibrium between the energy that comes from the sun and the outgoing energy reemitted by the Earth, as first stated by Joseph Fourier in 1824 (Fleming, 1999; Mitchell, 1989).

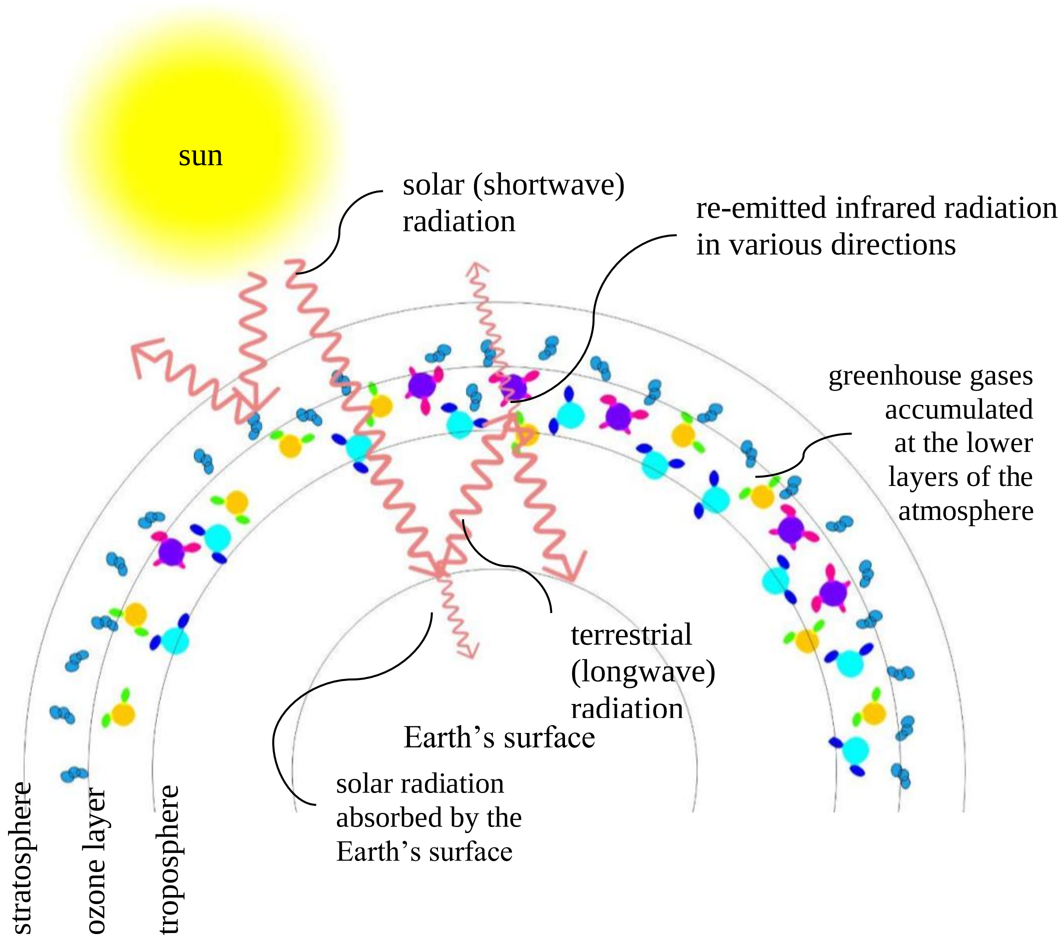


Figure 1.1. The mechanism of greenhouse effect.

According to the American Chemical Society, greenhouse gases (water vapor, carbon dioxide, methane, ozone, and nitrous oxide) are both naturally occurring and man-made or in other words anthropogenic gases. Chlorofluorocarbons, hydrochlorofluorocarbons, bromofluorocarbons (halons), perfluorocarbons, nitrogen trifluoride, and sulfur hexafluoride are the only greenhouse gases generated artificially. Because of their chemical structures, they have different abilities to radiate and absorb energy. The mutual characteristics of these gases are being radiatively active and thus, strongly absorb the infrared radiation (Hansen et al., 2005). Pierrehumbert (2011) stated that the structures of the greenhouse gas molecules enable them to rotate and vibrate in multiple directions. The gas molecules with more vibration modes are more likely to interact with the waves of radiation. For instance, CO_2 is the most efficient in capturing the longwave IR radiation because it can vibrate better compared to the other gases in the atmosphere. Even nitrogen and oxygen gases that are abundant in the atmosphere do not have absorption properties at longer infrared wavelengths because their vibration modes are limited (Zhong and Haigh, 2013).

The average surface temperature would drop to around -21 degrees Celsius without the greenhouse effect (Lacis et al., 2010). Even though the greenhouse effect is necessary in order to maintain the average habitual temperature of the globe, it poses problems to the Earth because the abundance of greenhouse gases has increased tremendously since the Industrial Revolution (Michelle, 1989). Burning fossil fuels increases the amount of CO_2 in the atmosphere, which strengthens the process for capturing the terrestrial radiation and increases the earth's temperature (Anderson et al., 2016). Not only does fossil fuels elevate the amount of the greenhouse gases, but also the increase in cement production, flaring in which natural gas is burned off, forestry and land use among human activities pollute the atmosphere (IPCC, 2014). Concentrations of methane and nitrous oxide have been increasing remarkably since the 1750s. The major drawback of the greenhouse effect is climate change because increased amounts of greenhouse gases contribute to greater absorption and emission of long-wave radiation. Since the greenhouse gases trap heat, that leads to an increase in the radiative heating of the globe (Hansen et al., 2005).

1.3. Theoretical Framework of the Study

This study was guided by a constructivist view. Constructivism, as a research theoretical framework, focuses on understanding a phenomenon from the eyes of those who experience it (Schwandt, 1994). The perspectives of individuals are at the center of constructivist investigation, assuming that meaning making processes occur uniquely for each individual. Constructivist researchers are suggested to clearly explain how people derive meaning from their experiences. Individuals perceive the physical world through a series of mental activities and using symbolic language (Bruner, 1986). Verbal expressions and drawings are suitable ways individuals use to express their perceptions and meanings that they derived from their experiences (Holstein & Gubrium, 1994). Verbal and drawn expressions are indicators of which features of the subject are more prominent and important to students for construction of meaning. In line with these notions, this research employed pictorial and verbal format of self-expression to learn the scope of students' conceptions of greenhouse effect.

Patton (2002) suggested that the meaning that students make cannot be separated from the mental models they create through their experiences with the context of events and people around them. Schwandt (1994) claimed that each day, we build models and schemes of an event, and revise it if we have new knowledge or experience related to it. Hence, he asserted that models are doomed to change (Schwandt, 1994). Observing how student thoughts within a subject could evolve over time is essential to understand learning progression and conceptual change. The roles of prior knowledge and everyday experiences cannot be ignored in the development of students' mental models because the main idea behind the conceptual change theory views learning as a process consisting of revising new information and fitting them into the preexisting mental models (Driver et al., 1994). Prior knowledge affects how students perceive, interpret, and remember new information (Alexander, 1996). Driver (1985) stated that conceptions are constituted based on unique experiences of each individual. Students come to class with their understanding of the scientific concepts they built themselves and progress through a sequence of intermediate conceptions to a refined level of scientific conception (Driver et al., 1994). However, these pre-instructional notions that students initially hold about scientific phenomena often diverge from the accepted scientific explanations, and they are known as alternative conceptions (Barke et al., 2009; Greca & Moreire, 2000).

The conceptual change framework has come to signify science learning from constructivist viewpoints. Alternative conceptions are enormous obstacles to reaching a conceptual understanding for students. Primitive conceptions that students hold are typically unstructured and loosely organized (Vosniadou et al., 2008). Nonetheless, conceptual understanding requires coherent and sequentially arranged concepts in students' minds (Stevens et al., 2010). For the comprehension of the desired science concepts, the learners' pre-instructional conceptions must be extensively reconstructed (Treagust & Duit, 2003).

Further description of conceptual change learning and what conceptual understandings are can be found in Chapter 2.

1.4. Significance of the Study

As students take science courses at school and are exposed to the greenhouse effect and climate change content outside classrooms (e.g., news, articles, social interactions, everyday experience), they interact with new information from multiple channels. Since climate change is a trending topic on the news, there are higher chances that students acquire information on climate change and greenhouse effect from the media rather than science lessons (Arto & Meira, 2011). Consequently, there is a need to know the process of how students connect the new and existing information to develop more scientific mental models. Correspondingly, this study was designed as a cross-age study, which examined the mental models of students about the mechanism of greenhouse effect across multiple age groups. The cross-age design of the study helped us describe whether students attain levels of sophistication of various ages, as mentioned by Driver et al. (1996).

Besides enlightening students’ learning progressions across the age groups, this study is significant in terms of contributing to the literature by revealing scientific and non-scientific concepts that high school and undergraduate students hold. Examining students' mental models about the mechanism of greenhouse effect at different grade levels provides information about how the current secondary school curricula and higher education programs contribute to students’ understanding of this particular concept. Therefore, instructional practices and the present secondary and higher education curricula can be reviewed to challenge students’ mental models about the mechanism of greenhouse effect and the related concepts.

1.5. Purpose of the Study

The main purpose of this study was to identify Grade 9 (G9), Grade 11 (G11), and final year pre-service teachers' (PST) types of mental models of the greenhouse effect. As a result, the study examined how the primary features of these models progress over grade levels. This study also aimed to uncover alternative conceptions regarding the greenhouse effect. The third focus of this research was to see if there was a link between students' academic achievement and the sort of mental models they held about the greenhouse effect.

1.6. Research Questions

The following research questions guided this study:

(i) What are students' mental models of greenhouse effect across different grade levels (G9, G11, PST)? What is the nature of their mental models?

(ii) What are students' alternative conceptions on the greenhouse effect across different grade levels (G9, G11, PST)?

(iii) Is there a relationship between students' academic achievement and the type of their mental models on greenhouse effect?

2. LITERATURE REVIEW

The main purpose of this study was to investigate the conceptual progression of different groups of students' understanding of the mechanism of greenhouse effect through describing their mental models. This research examined how the main constituents of these models progressed over grade levels and determined the components and features of such models. Secondly, the participants' alternative conceptions emerged while explaining their mental models were also identified. Finally, the relationship between students' mental models of the greenhouse effect and their academic achievements was tested if there is any significant association between the two variables.

This section initially explains the learning progressions, then mental models, following with the nature of student conceptions and alternative conceptions. Subsequently, the nature of mental models is defined and their use in assessing student understanding is described. Then, the literature on the greenhouse effect and students' understanding of the greenhouse effect is summarized.

2.1. Learning Progressions

Learning progressions are defined as ''descriptions of the successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time'' (Duschl, Schweingruber, & Shouse, 2007). Learning progressions in science education represent the extent to which scientific concepts can be understood in succession over time (Smith, Wiser, Anderson, and Krajcik, 2006), and it further represents advanced paths of reasoning about a specific domain (NRC, 2007). The sophistication level of understanding indicates being able to use central concepts of a particular domain and eliminating inert knowledge or not having a collection of separate ideas (Anderson, 2007). The fundamental concepts of a particular area are expected to be initially used in their simplest form, refined and enhanced as being exposed to formal education (Smith et al., 2006).

Central to most of the learning progression definitions, there are steps which indicate the levels of sophistication of a particular topic. The developmental approach in student learning is based on a growth expectation as students are introduced to instructional practices. The first stage of the learning progression is students' initial understanding of the subject, which they bring to classes. The first level is followed by multiple intermediate stages, and then comes an upper level that is the targeted and desired level of understanding (Upahi & Ramnarain, 2022). Based on the hierarchical order of these steps, students are expected to grow up towards scientific conceptions. However, Duschl et al. (2007) stated that "all students may not follow one general order of learning process, but multiple sequences''.

Learning progression emphasizes inquiry skills as well as focusing on content knowledge, which is an important element of scientific literacy (Duncan, 2009). Learning progression research addresses fundamental concepts of a subject as it is grounded in theories of cognition as well as building upon progression variables (Duschl et al., 2011). A progression variable describes an aspect of students' learning about a scientific concept in the entry, intermediate, and advanced levels of an iterative process (Jian-Xin Yao et al., 2017). The current study reviewed the literature on students' existing ideas of the greenhouse effect to identify progress factors. In this sense, this study delved into the current learning paths that students take by initially focusing on the key ideas and utilizing the cognitive development theory of Piaget (1968) to describe how students develop a scientific conception about the greenhouse effect.

Learning progression was shown as a valuable tool to align curriculum objectives and goals, instruction, and assessment (Duschl et al., 2011). Learning progression at each level is helpful to assessment design since they provide a mastering level of students. Instruction that is aligned with the levels of learning progression would stimulate students' progression towards a sophisticated level. As Mohan et al. (2009) mentioned, some learning progression research in science education utilizes instructional interventions to embody progressions empirically, while some cross-sectional studies merely analyze the domain to search for the initial progressions of students from different grade levels.

Adopting the developmental perspective without the application of an additional instructional intervention in this study, led to a cross-sectional approach to documenting students' understanding of the greenhouse effect and met the goal of identifying progress in students' mental models.

2.2. Mental Models

Mental models are internal representations of the learning content that facilitate researchers and instructors to have an insight into student learning (Opfermann, Schmeck & Fischer, 2017). Internal representations are related to knowledge and construction in the memory in various configurations. Gilbert and Boulter (1995) demonstrated the mental model as a representation of a notion, phenomenon, system or thought. Duit and Treagust (2003) stated that a model's main purpose is communication rather than idea exploration. Mental models may not be explicitly understood; mainly gestures, speech, and writing of the owner may be used to infer them (Justi & Gilbert, 2010).

When students are learning they are fed both by textual and pictorial content (Treagust et al., 2017). According to Mayer (2009), because textual and pictorial contents are different by their nature, both types of information sources are combined in the learner's mind and create a single consistent mental model. In order to enable students to express combined information in their minds, they should be expected to explain their understanding in both ways when expressing their mental models. In this way, the possibility of revealing all aspects of students' mental models increases.

In science, "mental models are used to describe a system and its components and states, to explain its behavior as it moves from one state to another, and to predict the future states of the system" (Franco & Colinvaux, 2000, p. 105). Teachers initially utilize mental models for conveying the accepted scientific/conceptual models and secondly, for delineating scientific phenomena (Duit, 1991). Likewise, Coll (1999) proposed that mental models help visualization and explanation of a scientific phenomenon. Research supported that mental model have a significant role in science education (Boulter et al., 2000; Coll, 1999). Harrison and Treagust (2000) suggested that scientific models are learned by the students after seeing those models during science instructions. Students create their own mental models by making sense of the scientific models they encounter in the lesson and certainly from the experiences they have with nature from an early age (Driver et al., 1996).

Experts are seen as more knowledgeable than novices in building mental models. The main difference between the experts and novices is that experts are able to construct their own representations by categorizing fundamental concepts, while novices are not able to construct a certain model (Kozma & Russell, 1997). Such activities as explaining the mental models, making detailed explanations, and connecting different concepts meaningfully, are an indication of learning, while fragmented ideas are showing weak levels of understanding. Sophisticated explanations have to be logically consistent with the current scientific explanations. Moreover, some hidden mechanisms, such as including explanations of particulate behavior of matter, is an indicator of a scientific explanatory model (Cheng & Brown, 2015). According to Gabel, Briner, and Haines (1992), chemistry may be explained at the sensory, atomic, and symbolic levels. However, students usually handle chemical issues on only one level, for instance, by utilizing merely symbolic level representations. This is mostly due to students' incapability to express themselves at the comprehensive level.

Weighing the review above regarding mental models, this research chose to use mental models to monitor students' learning progressions from the beginning of high school to higher education, as mental models are rich resources of information. As stated, mental models are eligible to examine multiple forms of knowledge as textual and pictorial. Therefore, using mental models provides researchers with a variety of aspects of students' knowledge level of the subject matter. On the other hand, this research utilized mental models to see the discrepancies between the scientific models and students' mental models. Elucidating the differences between them can uncover evidence of emerging alternative conceptions. Lastly, the reason for choosing mental models is that the dynamic nature of mental models matches well with the learning progression observation.

Building of mental models depends on how complicated the learners' current conceptions on a certain subject are (Libarkin et al., 2003). While poorly built non-scientific mental models may be quickly adjusted in response to new knowledge, well-established mental models which are close to the scientists' models allow students to integrate new information into current models more easily. Detecting loosely connected ideas in mental models is a crucial strategy because students should create scientifically valid mental models that connect the various aspects of the subject in point (Schraw et al., 2006).

2.3. The Nature of Student Conceptions and Conceptual Change

Stevens et al. (2010) identified the conceptual understanding based on the constructivist view as being able to organize ideas, connect them in a meaningful manner, and use them in problem-solving in another context. Adadan et al. (2010) stated the importance of meaningful learning: "Meaningful science learning entails conceptual understanding rather than rote memorization" (p. 1005). While novices may hold fragmented ideas about a concept, a sophisticated level of knowledge is understood from organized ideas around the central concepts. If one has inert knowledge that is not well-organized and ill-connected with the other concepts in mind, making use of knowledge is difficult for them. In contrast, experts with more well-established conceptual understandings can straightforwardly relate and use their knowledge in various contexts.

Based on the constructivist view, learning is a process that requires adapting or changing pre-existing knowledge to new scientific knowledge, resulting from both individual and social processes (Driver et al., 1994). Posner et al. (1982) stated that conceptual change starts as learners are dissatisfied with their existing ideas, then the availability of understandable new concepts, the persuasiveness and the fruitfulness of these new concepts are prerequisites of conceptual change. In the conceptual change process, students first use their existing knowledge to deal with the new knowledge. Then, if the new knowledge seems understandable and persuasive to them, they either assimilate or accommodate the new one into their knowledge framework.

According to Posner et al. (1982), one of the prerequisites of conceptual change approach is students' *dissatisfaction* with the existing knowledge because it is no longer helpful to explain or solve a problem. Secondly, seeing the new knowledge as *plausible*, which is having a meaningful logic in students' minds—evaluating new knowledge as *intelligible* that students express the new concept in a language to which they are already accustomed; finally, *fruitful* to solve potential problems in similar domains. The conceptual change process involves a constant change in students' conceptions. However, new and old concept networks should be restructured meaningfully for new conceptions to be sustainable.

2.4. Alternative Conceptions

Alternative conceptions are a popular topic of research interest in science education. Although alternative concepts are generally thought to exist separately in students' minds, they can be interrelated, as well as being in a structured form (Chi, 2008). Therefore, individuals may hold consistent but scientifically incorrect beliefs in their minds, as also Reinfried and Tempelmann (2014) suggested. If students have multiple preconceptions that are not in line with the accepted scientific knowledge, consequently this leads to the formation of mental models with distortions.

Mental models are subjected to change and dynamic as students encounter scientific and non-scientific content or notions and experiences in time (Greca & Moreire, 2000). In fact, if novices construct a mental model that is not parallel to a scientifically accepted conceptual model, then the deficient model must be reconstructed (Shepardson et al., 2017). How to change those mental models falls within the scope of conceptual change research.

Synthetic models might be created by simply adding new information via strategies of constructive enrichment to previously known but inconsistent knowledge (Vosniadou et al., 2008). When prior knowledge contains alternative conceptions, focusing on identifying those concepts becomes important, as they can create an obstacle to conceptual change (Vosniadou, 2002). Brown (2014) also highlighted that when alternative ideas are present, making sense of the new knowledge becomes harder for people. In other words, to provide a shift from synthetic models/alternative conceptions to scientific models, researchers first need to determine whether alternative conceptions exist.

2.5. Research on Students' Understanding of Greenhouse Effect

Niebert and Gropengiesser (2014) compiled the findings about students' and scientists' understanding of global warming to sum up the related research. They stated that people from primary school students to scientists exhibited similar perspectives about global warming and climate change. The first common finding was the notion of entrapment of solar energy in a specific layer of the atmosphere, which consists of the greenhouse gases, causing rise in temperature. The second common finding among students was that they were not able to explain the difference between sunrays, ultraviolet radiation, and heatwaves (Khalid, 2003; Niebert & Gropengiesser, 2014; Papadimitriou, 2004; Pruneau et al., 2001; Shepardson et al., 2011). Another frequent finding for younger novices was the lack of knowledge to propose a proper explanation about the mechanism for global warming or pointing out the pollution as the major cause of it (Pruneau et al., 2001). Some students, however, show the heat emitted from industrial activities and natural disasters like volcanic eruptions as the cause of global warming (Papadimitriou, 2004).

Harris and Gold (2017) stated that the ability of greenhouse gases to absorb light was widely explained by utilizing the word 'trap' in their study with students who are not experts on greenhouse effect models. However, some novice participants think that the energy is trapped in the clouds and cannot be released as another form of energy or could not leave the area between the atmosphere and the Earth's surface. Therefore, using the word 'trap' can create undesirable ideas in students' minds that energy cannot be transferred and may be misleading.

Christidou and Koulaidis (1999) suggested that in order to teach the greenhouse effect, students should first understand that longwave (infrared) radiation is the cause of the GHE. The greenhouse gases principally absorb the longwave radiation reflected from the Earth. Coulson (2012) explained the terrestrial radiation phenomenon as "since natural land and water surfaces, gases of the atmosphere, clouds and similar materials on Earth are at much lower temperatures than that of the Sun, the wavelengths at which they emit significant amounts of energy are longer than the wavelengths of most solar energy" (p.279). However, students from various grade levels do not show the terrestrial radiation as the cause of the greenhouse effect.

2.5.1. Research on Students' Alternative Conceptions of Greenhouse Effect

This section focused on the previous findings in related literature in certain fundamental aspects of the greenhouse effect: (1) confusion of the greenhouse effect with other environmental issues; (2) the definition, role and types of greenhouse gases; (3) explanation of the greenhouse effect phenomenon; (4) the causes of the greenhouse effect; (5) the causes of climate change.

First of all, students may be confused by the phrase "greenhouse effect," as well as the more general ideas of "climate change" and "global warming" (Shepardson et al., 2011). Research revealed a tendency to mix up the greenhouse effect with ozone depletion (Christidou & Koulaidis, 1999). According to research, high school students often mistakenly establish causal connections between climate change and the unrelated phenomena of ozone depletion (Liarakou, Athanasiadis, & Gavrilakis, 2011; Punter, Ochando-Pardo, & Garcia, 2010). Students of all ages showed similar defective causal connections (Karpudewan et al., 2014; Lambert et al., 2011).

One of the students' alternative conceptions about the greenhouse gases is that they could not categorize water vapor and carbon dioxide as greenhouse gases (Boyes et al., 1993; Pruneau et al., 2001). Despite being well educated in the causes and mechanism of climate change, in-service teachers did not accept water vapor as one of the main greenhouse gases, overlooking its heat-trapping ability (Anyanwu et al., 2015). According to the other related studies, students used air pollutants and greenhouse gas concepts interchangeably (Boyes & Stanisstreet, 1997). Another conception about greenhouse gases is the tendency to infer that some specific gases cause the greenhouse effect over others. Libarkin et al. (2015) underlined an issue about people with alternative conceptions that they think atmospheric gases are able to trap energy like the greenhouse gases do. Rubba et al. (1997) found that middle school students have an alternative conception that carbon dioxide is the major greenhouse gas that contributes to the destruction of the ozone layer. Some students thought that the role of greenhouse gases is to form a thin 'layer' in the Earth's atmosphere that captures the sun's rays (Andersson & Wallin, 2000).

According to Christidou and Koulaidis (1999), the alternative conceptions that emerged during the explanation of the greenhouse effect phenomenon are: (i) Students could not differentiate between diverse types of sun rays ; (ii) Some students failed to explain the greenhouse effect entirely, which was associated with lacking knowledge of the Earth's energy balance of incoming and outgoing energy; (iii) Greenhouse gases generate an uneven layer in the atmosphere, the upper surface of this layer permits incoming solar energy to reach the planet. The lower border of the greenhouse gas layer, on the other hand, is significantly less transparent, thus heat trapped in the earth-atmosphere system cannot escape into space; (iv) While traveling through the atmosphere, solar radiation's energy diminishes, at the time it hits the planet and tries to go back to space again, it has degraded to the point that it can no longer pass through the layer generated by greenhouse gases, and is stuck within the atmosphere; (v) The UV light entering the atmosphere through ozone holes amplifies the greenhouse effect.

Similar to Christidou and Koulaidis (1999)'s findings, Harris and Gold (2017) stated that there are two types of naive ideas about global warming because of the greenhouse effect. The first type is that people think there is a reduction in the outgoing energy from the Earth to space. The second type is that people think there is an increase in the incoming solar radiation because of the ozone holes. Christidou and Koulaidis (1999) designated the lack of understanding of solar and terrestrial radiation as the leading cause of these alternative conceptions. Thus, they suggested the terrestrial and solar radiation concepts should be taught in detail to students because the greenhouse gases absorb mainly the terrestrial radiation.

Some students believed that ozone depletion was a significant contributor to global warming and climate change. The ozone hole, according to a widely held view, allows insolation, in other words, more solar energy or ultraviolet radiation to reach the Earth, resulting in global warming and climate change (Boyes et al., 1999; Christidou & Koulaidis, 1999). In line with the findings from multiple research studies, Niebert and Gropengiesser

(2014) also stated that most of their student participants believe that climate change is caused by ozone depletion, as the greenhouse gases cause holes in the ozone layer. According to the students' perspective, greenhouse gases cause holes in the ozone layer as a result of increased solar input. Niebert and Gropengiesser (2014) also found that a diverse range of people, including primary school students and well-educated individuals, believe that solar radiation is trapped right under the ozone layer when they reach the atmosphere and pass through ozone holes. Similarly, Liarakou et al. (2011) also found that 626 students between the ages 13-17 thought that the greenhouse effect is stemming from ozone depletion. In turn, scientists attribute the increase in the globe's temperature to the increased greenhouse effect caused by the tendency of greenhouse gases to trap heat. In addition, some other students from a mock summit class on climate change, who thought ozone depletion was the cause of the greenhouse effect also believed that greenhouse gases were trapped in the atmosphere rather than solar radiation (Gautier et al., 2006). Gautier et al. added that students lack the knowledge of the Earth as a radiating body because they do not insert the longwave radiation in most of their concept maps.

The cause of the climate change that was proposed by the university students were found to be attribution of the increased CO2 levels in the atmosphere, without referral to other abundant greenhouse gases (Fernández et al., 2011). In his study, Kroufek (2014) revealed that the most common alternative concepts among teacher candidates are "the ozone layer must be destroyed for climate change to occur" (p.4071). However, these scientifically literate teachers were able to express that human lifestyle is affecting climate change. Ratinen et al. (2013) conducted a study with primary school teachers, using instruction intervention. They documented that the participants could not relate the increase in greenhouse gas emission and climate change. Altınöz and Topsakal (2010)'s study revealed elementary school pre-service teachers' alternative conceptions on the greenhouse effect. The findings of their study claimed that pre-service teachers mostly have alternative conceptions on the following topics: the necessity of the greenhouse effect for life, the causes of greenhouse effect, anthropogenic and industrial factors' impact on greenhouse effect, and pro-environmental behavior. The majority of the pre-service teacher participants have just rudimentary knowledge of climate change. Teachers have been found to have alternative conceptions about climate change, and they probably pass these factually erroneous notions on to their students (Papadimitriou, 2004).

Prior research generally confirms that despite the attempts to teach the core greenhouse effect and climate change concepts and to inspire action, people continue to have alternative conceptions and are often reluctant to show pro-environmental acts (Niebert & Gropengiesser, 2014; Weber & Stern, 2011). Many students have trouble grasping the basic concepts of the greenhouse effect, and even after teaching, many continue to believe in their everyday perceptions of global warming (Ekborg & Areskoug, 2006; Pruneau et al., 2001; Rubba et al., 1997; Rye et al., 1997).

2.5.2. Research on Students' Mental Models of Greenhouse Effect

Varela et al. (2020) examined the level of sophistication of Grade 7 students' mental models on the greenhouse effect and climate change. They used open-ended questions to collect pre-test and post-test data after they applied instruction. The findings demonstrated that students' mental models became more sophisticated after instruction. To illustrate, the number of students, who associated the cause of climate change to the rise in temperature due to the greenhouse effect, had slightly increased after the instruction. However, students continued to state the most well-known actions to avoid climate change, such as polluting, even though they had been instructed that not all pollutants cause climate change. Besides, participants largely and superficially defined climate change as 'a change in climate'. Lastly, students do not have clear boundaries between the causes and effects of climate change.

In the study with 164 first- and second-year undergraduate students, Harris and Gold (2017) investigated the understanding of the greenhouse effect through explanatory mental models of students. They asked participants to sketch the greenhouse effect, and they were given a guiding line of the Earth's surface. There was a 30-minute instruction about the behavior of the gases at particulate level, and the data were collected before and after the intervention. Participants had also been trained in order to draw scientific sketches for different subjects. They have analyzed the drawings by comparing the students' and scientists' mental models' main features. The findings indicated that the scientific representations were seen more in student sketches after the instruction in a short time. This claimed the dynamic nature of students' mental models. However, a few shifts were seen from a non-scientific model to another inaccurate, novice model.

Shepardson et al. (2009) conducted a cross-age study to examine students' conceptions of the greenhouse effect and climate change by examining their mental models. Their study was based on the constructivist view since they tried to infer meanings from student generated drawings. Shepardson et al. (2009) evaluated the findings on students' knowledge about climate change as simple. The analysis technique used in this study to identify similar themes in drawings underpins alternative methods of classifying works based on predetermined mental models. Different from the results of the previous findings, the participants of Shephardon et al. (2009)'s study did not attribute the cause of climate change to ozone depletion.

Another study in which researchers examined the effect of preconceptions on the 13--year-old students' mental models of greenhouse effect and global warming, was conducted by Reinfried and Tempelmann (2014). The theoretical framework of the study was based on cognitive constructivism. According to this framework, mental models are actively built by students and revised as new knowledge is acquired. They have analyzed how students construct mental models by examining the learning pathways of students. In order to see whether students with similar prior knowledge follow the same learning pathways, students' mental models were compared. The form of the data were video recordings, interview transcripts and sketches. A pre-assessment regarding students' initial knowledge and post-assessment to uncover mental models was conducted. Before the post-assessment, an activity was done with the participants to evoke their prior knowledge and teach new information to them. According to the findings of the study, none of the 14 students had scientifically correct prior knowledge related to the radiation concept. In total, three types of mental models are categorized based on prior knowledge of the participants. Participants with no prior knowledge have built totally new models close to the scientific model. Participants with a certain level of knowledge about the decrease in the outgoing radiation/heat, have reconstructed their models. Finally, students with subjective notions on the incoming radiation to the Earth were challenged to reorganize their mental models.

Understanding the steps students take to integrate new and prior knowledge into their mental models are important to know. Accordingly, different from the related studies in the literature, this study carried out a cross-age investigation of students' mental models, which is consistent with its goal of analyzing learning progression. The study's cross-age design allowed us to determine if student groups reach different ages' worth of sophistication, as suggested by Driver et al. (1996). This study is significant since it contributes to the literature by exposing the scientific and non-scientific beliefs that high school and college students have, in addition to illuminating students' learning progressions and conceptual changes.

2.6. Summary

Steps that denote the degree of sophistication of a given topic are at the heart of the majority of definitions of learning progressions. The learning progressions framework is founded on a growth expectation. In parallel, using mental models provides researchers with a variety of aspects of students' knowledge level of the subject matter. Alternative conceptions of the greenhouse effect in the literature are showing that both pre-service teachers and students have alternative conceptions regarding the greenhouse effect and climate change. These alternative conceptions may be from the similar subject areas of the domain, indicating that the alternative conceptions teachers hold are likely to be conveyed to the students.

Each of the studies on mental models of greenhouse effect were conducted within different focuses. Reinfried and Tempelmann (2014) concentrated on learning pathways and assimilation of prior knowledge when constructing a new mental model after instruction. Similarly, Shepardson et al. (2009) identified mental models of students from different age groups. Harris and Gold (2017)'s focus was on mental models' shift from non-scientific to scientific as instruction is introduced to students. Varela et al. (2020)'s research targeted students' conceptions of greenhouse effect and climate change. However, since these studies focused on certain age groups, they did not respond to the need in learning progressions of students about the greenhouse effect.

This study is significant as it contributes to the literature and sheds light on the students' conceptual growth and learning development. It is crucial to comprehend how students construct their mental models by blending new information with old knowledge in studies of learning progression. As a result, in contrast to similar research in the literature, this study examined students' mental models at various age levels in tandem with its goal of analyzing learning progression. By revealing mental models, the scientific and non-scientific ideas of high school and university students are also being exposed.

Table 2.1. Summary of research on students' mental models of greenhouse effect

	Participants	Findings
Shepardson et al. (2009)	12-13 year-old students	Five mental models with various features were identified.
Reinfried and Tempelmann (2014)	13-year-old students	Three mental models based on prior knowledge and learning paths of participants were identified.
Harris and Gold (2017)	First and second year undergraduates	Seven different mental models including one in particulate level were formed.
Varela et al. (2020)	Grade 7 students	Students' mental models became more sophisticated after instruction

3. METHODOLOGY

The primary purpose of this study was to investigate students' and pre-service teachers' mental models of the greenhouse effect at different age levels [Grade 9 (G9), Grade 11 (G11), and the final year pre-service teachers (PST)]. The study identified the components and properties of each participant's mental models in association with the greenhouse effect and explored how the main constituents of these models progress across different grade levels. Secondly, the alternative conceptions of students about the greenhouse effect have been identified. Thirdly, the association between the participants' mental models of the greenhouse effect and their academic achievement was examined. The following research questions guided this study:

(i) What are students' mental models of greenhouse effect across different grade levels (G9, G11, PST)? What is the nature of their mental models?
(ii) What are students' alternative conceptions on the greenhouse effect across different grade levels (G9, G11, PST)?
(iii) Is there a significant relationship between students' academic achievement and the nature of their mental models on greenhouse effect?

3.1. Research Design

This research was designed as a cross-sectional study but adopted a qualitative approach in data collection and analysis phases, as it gathers data from different groups of students without any intervention as well as making sense of their verbal data in an interpretive manner. This cross-sectional qualitative study helped reveal the features (scientific or nonscientific) of the participants' mental models on the greenhouse effect. The employed methodology of this study provided the researcher with an optimal way that is congruent with the purpose of the research and enabled her to systematically describe and interpret the mental models of the participants about the greenhouse effect.

The research questions as stated above guided the design of this study. For the research question (1), there is a need for identifying the main features of mental models on the greenhouse effect generating overarching categories of mental models for individual participants. To elaborate, questions (1) and (2) focus on the conceptual understanding about how the greenhouse effect is happening, and what the participants' nonscientific conceptions are about the greenhouse effect. The research question (2) requires identifying the alternative conceptions on the greenhouse effect. The research question (3) examines the relationship between the participants' academic achievement and the types of mental models they held about the greenhouse effect at the same grade level. All research questions of the current study require making sense of the participants' knowledge on the greenhouse effect. Since the research design needs to interpret the data explicitly, the qualitative research approach was mainly chosen in order to answer and meet the requirements of the three research questions.

More specifically, this study used the constant comparative method (Glaser, 1965) and an inductive approach and categories emerging from the data, because there is a lack of knowledge regarding the main categories and their relationships that comprise students' mental models of greenhouse effect. This qualitative approach fundamentally relies on the participants' answers to the interview questions that explains a particular event. A purposeful theoretical selection of the participants is suitable to this study's design (Creswell, 2012). Understanding the nature of the transition of students' science ideas through time requires examining the patterns of consistency in students' responses to the questions asked. While novices can only express superficial characteristics of a certain phenomenon, experts can grasp the main ideas, connect them, and make logical reasoning to explain the particular concept or event (NRC, 2007). Accordingly, the cross-sectional method was selected to recruit participants and collect data from distinct age groups (grade levels) at a single time in this study.

The study's methodological approach is used to develop a framework of the process that explains how the students' mental models of greenhouse effect differ across grade levels. The qualitative data gathered through the semi-structured interviews and drawings requested during interviews. Such information was to identify individual participants' mental models of the greenhouse effect. As Jones et al. (2011) stated, each individual has a unique model representing what is going on in the world. The nature of qualitative research is based on looking at a phenomenon through the perspective of the participants. As a result, this study includes a sample of drawings as part of the interviews that reflect their comprehension of a natural event, qualitative analysis of the interviews by labeling and deriving codes, and eventually developing mental models based on the codes by utilizing the framework of Libarkin, Thomas, and Ording (2015). In the study of Libarkin et al. (2015), student drawings were compared to the scientific models to determine the sophistication level of the mental models and also they had identified the most salient features of each mental model to generate codes. Different from Libarkin et al. (2015)'s study, this study did not utilize computer-based analysis. Instead, this study used an expert-based inspection.

3.2. Participants

The study was announced to all the prospective participants in the first and second semester of the 2021-2022 academic year. The participants of this cross-age study were from different student groups. The first group was Grade 9 students with ages ranging from 14 to 16. The second group was Grade 11 students with ages ranging from 17 to 19. The third group of participants was the pre-service chemistry/physics teachers with ages ranging from 24 to 29. A total number of 42 high school students and 19 undergraduate chemistry and physics education students participated in this study. The distribution of the sample was illustrated in Table 3.1 below.

Table 3.1. Age and gender distribution of the participants.

*				Gender	
Group Name	Number of Participants (*N*=64)	Age Range	Age Mean	Female *f* (%)	Male *f* (%)
Grade 9 (G9)	18	14 to 16	15	7 (39)	11 (61)
Grade 11 (G11)	24	17 to 19	17	11 (46)	13 (54)
Preservice Teachers (PST)	19	22 to 29	24	16 (84)	3 (16)

The high school student participants were from the same private school and highly educated families with mutually high socio-economic backgrounds. The Grade 9 participants consisted of 7 females and 11 males. The Grade 11 participants consisted of 11 females and 13 males. The pre-service chemistry/physics teacher participants were from the same public university with diverse socio-economic and family backgrounds. The participants included 16 females and 3 males in the PST group. Furthermore, the higher education students in Turkey are taking the university entrance exam to be placed in the universities. By looking at which university they are placed in, the university student participants can be considered as high achievers compared to the students at the same departments of the other universities.

Before conducting the interviews, permissions were received from the school principal, Istanbul Provincial Directorate of National Education and Institutional Review Board, called Research into Science and Engineering Fields-Human Research Ethics Committee (FMINAREK) (see Appendix A). The participants were involved in the study on a voluntary basis. All participants were informed in detail about the research by their instructors through e-mail (see Appendix B). Since a group of high school students were between the ages of 14 and 18, parental consent was obtained from their families. Study details were also provided in the consent form and sent to the parents in a sealed envelope. It was emphasized that this study was not expected to pose any risk to the participants. They were informed that their participation in this study would not affect their grades in any way and that they would not be paid any fees. In addition, it was also stated that personal information would not be shared with third parties or institutions in any way and would not be used in scientific publications. A pseudonym was used for each participant. The participants were asked to share their school transcripts with the researchers, after obtaining permission, in order to reach their grade point averages from the Physics and Chemistry courses they had previously taken.

3.3. Context of the Study

According to Dierking et al. (2003), the construction of scientific knowledge is not restricted to the school environment but profoundly affected by the interactions people make with their surroundings, such as their friends, family, and the Internet. They considered learning as a holistic process to build personal meaning by making interaction with the surroundings. In this respect, the school environment is assumed to be the major source of information for students' scientific knowledge in this study, considering the intense coursework of mandatory science courses. The Grade 9 students have 2 hours of physics and 2 hours of chemistry lessons (35 minutes each) per week. The Grade 9 participants' English language course content also covers climate change and greenhouse effect as a whole unit. The Grade 11 students had 4 hours of elective chemistry and 4 hours of elective physics lessons in their programs. The senior undergraduate pre-service chemistry teachers had 11 chemistry courses and 3 physics mandatory courses in their departmental programs. The pre-service physics teachers had to take 11 physics and 3 chemistry compulsory courses until they graduate. In this study, 18 out of 20 of the undergraduate student participants have taken at least one environmental course as an elective course.

In order to acknowledge the prior knowledge of the student participants, the primary and secondary school curriculum and the science, chemistry, physics textbooks were examined in terms of the concepts related to the greenhouse effect. In Turkey, curricula have been renewed regularly to keep up with the requirements of the time and meet the needs of the citizens and society, and textbooks were renewed accordingly. The fundamental objectives of the science, chemistry and physics curriculum are presented iteratively at different grade levels. The spiral organization of curriculum provides an opportunity for going over the same fundamental subjects at different times to develop a deeper understanding and avoiding memorization (Bruner, 1977). Similar topics are addressed in different courses. For example, environmental issues such as water pollution, earth pollution, acid rains are examined in Grade 9 chemistry and Grade 10 biology curriculum, which gives the curricula complementary characteristics. That is why students may come across environment related topics a few times during their primary and secondary education. Based on the Ministry of National Education of the Republic of Turkey (MoNE)'s current curriculum, the Grade 5 level involves the objectives related to the propagation and reflection of the light (MoNE, 2017a). The course objectives of the Grade 6 level science lessons include the unit 'Heat and Matter'. The aligned unit in the textbook also mentions climate change, global warming, and its effects on Turkey (MoNE, 2017b). The only two units that mainly introduce the greenhouse effect in the complete middle school curriculum are the 'Climate and Air Movements' and the 'Environmental Issues' in the curriculum of

Grade 8 (MoNE, 2017d). The high school chemistry curriculum has been scanned as well, with a similar focus on the concepts related to the greenhouse effect. The 'Environmental Chemistry' unit was presented in the Grade 9 chemistry curriculum (MoNE, 2017e). The objectives of this unit are related to the greenhouse effect, ozone depletion, air pollution, global warming, and sustainable development (MoNE, 2017e). The Grade 10 chemistry curriculum also covers the environmental issues including the greenhouse effect (MoNE, 2017e).

All the previous curriculum objectives were assumed to be addressed in the classroom because teachers need to ensure consistency between the curriculum objectives and the course content, even though each teacher's teaching strategy is unique. Elmas et al. (2014) discussed that teachers are supposed to keep being loyal to the curriculum's subject-matter because of the university entrance examination.

Corcoran, Mosher, and Rogat (2009) described learning progression as how students use fundamental concepts and make scientific explanations more sophisticated over time. According to NRC (2007), students' learning progression increases cumulatively over the years. When students are exposed to instructional interventions about a specific subject for a long time, they are able to make more detailed connections and reason about the subject. In order to grasp students' learning progression about the greenhouse effect over the years, this study selected participants from different grade levels in secondary and tertiary education.

3.4. Data Collection

Interviewing is usually a primary source in qualitative social science inquiries to obtain first-hand personal data of targeted individuals, despite the fact that it is time-consuming. Interviews in a qualitative study elicits in-depth information about perspectives, intentions, stances of people about the events (Berg & Lune, 2007, p. 66). A semi-structured interview was conducted with each participant in order to provide an in-depth understanding of students' mental models of the greenhouse effect. Each interview lasted around 20 minutes. The participants were interviewed in an isolated room at the school, where only the participant and the researcher were present. All data were audio-taped and written explanations were documented. Besides, a demographic information form was given to be filled out by each participant immediately after the interview.

Interviews are suitable for understanding the experiences of the participants and the meaning they derive from these experiences (Seidman, 2006). The two critical points about the interview questions are that they should be purposefully selected, relevant, and shown to different individuals other than the researchers to prevent bias (Airasian et al., 1992). Wilson (2009) stated that for demonstrating the construct validity of a learning progression assessment, clear descriptions of what students are supposed to learn are required. Accordingly, the objectives about the greenhouse effect from the MoNE curriculum of different grade levels were considered during the preparation phase of the interview questions. The researcher prepared a questionnaire, and the questions were reviewed by the panel of experts. The panel of experts consisted of one chemistry education professor, one chemistry teacher, and one physics teacher.

Open-ended questions allow more questions to be asked depending on the flow of the interview. This study was inspired by an open-ended question utilized by several studies, which prompted drawings while explaining the greenhouse effect (see Harris & Gold, 2017; Libarkin et al., 2015; Shepardon et al., 2011). According to White and Gunstone (1992) and Shepardson et al. (2011), asking students to draw the subject matter may represent their mental models and indicate features of their models that cannot be uncovered through any other way. Moreover, in recent years, investigation of the visual representations of participants' mental models by utilizing student drawings are widely conducted in environmental education because of its efficacy in identifying alternative conceptions (Ainsworth, Prain, & Tytler, 2011; Bowker, 2007; Shepardson, Choi, Niyogi, & Charusombat, 2011). The interview questions about the greenhouse effect were designed as open-ended, including student-generated conceptual drawings to see whether participants are suggesting a mechanism to explain the greenhouse effect. The interview questions of this study were prepared by focusing on the mechanism, causes and consequences of the greenhouse effect. The interview protocol included the open-ended questions and student-generated drawings, which engaged the participants in describing the greenhouse effect in detail, so that the alternative conceptions were detected as well as the scientific ones.

3.5. Data Analysis

In the current study, the main data sources were interviews and student sketches. In order to answer the research questions, individual interviews were transformed into a written text. Then, constant comparative analysis was simultaneously performed for both the transcribed interviews and sketches (Glaser, 1965). According to Glaser (1965), the constant comparative method involves the following stages: (1) comparing data applicable to each category, (2) combining categories and their features, (3) defining the limits of the theory, and (4) stating the theory. The constant comparative method is mainly taking the gathered data from multiple sources and comparing it to the emerging categories (Conrad, 1978). Qualitative data analysis mainly relies on categorizing, organizing, interpreting data, and producing a rich descriptive synthesis (Creswell, 2018). In the current research, following the stages of the constant comparative method of analysis, the following types of coding were utilized in sequence: open coding, axial coding, and selective coding (Creswell, 2018, p.105).

For the initial stage of the constant comparative method, the researcher of this study generated as many categories (codes) as possible, describing the general features of student explanations concerning the greenhouse effect without any elimination. All the codes were iteratively compared to the other interview data generated from the same and different participants. With axial coding, the codes that were directly associated with the mechanism of the greenhouse effect were categorized around the overarching theme of the greenhouse effect (core phenomenon). In other words, axial coding helped building relationships between the codes constructed during the initial coding phase (Creswell, 2007, p.249). Then, selective coding was performed by focusing on the most frequently used concepts to describe greenhouse effect. In the selective coding phase, data were organized based on the relations between the emerged categories and their salience. The selective coding procedure continued until intensifying the data around specific categories (Berg & Lune, 2007, p. 193). Thereby, a visual representation with a narrative that explains its features was generated for each type of mental model that emerged from the data.

The codes derived during the open coding phase that encompasses the greenhouse effect included peripheral topics such as climate change or types of greenhouse gases, and so on. Since this study's focus was on the mechanism of greenhouse effect, the codes concerning these kinds of topics were eliminated at the axial coding stage. Similarly, the types of greenhouse gases mentioned during the interviews have also been eliminated but their frequency counts are reported in the findings chapter.

The first cycle of coding made it possible to describe the frequencies of features of the greenhouse effect that were observed in the participants' explanations. The broader categories at the final stage were used to describe the participants' mental models about the greenhouse effect. In total, eight mental models were identified. These models have mutual features and include some differences as well (Table 3.1). Based on the characteristics of mental models, the mechanism of the greenhouse effect was narrated for each model. During the discrimination of the eight mental models, certain criteria based on model's features were considered (see Table 3.1). Yet, some of the features stated in the explanations; for instance, the wavelength of incoming and outgoing radiation, were not considered as a criterion. Some of the student answers regarding these features were scientifically correct, some were not. The alternative conceptions that students hold about these categories are explained in the Chapter 4. The features of mental model categories emerged from the data are described both visually and verbally in Table 3.2 and Table 3.3.

Table 3.2. Fundamental features of mental models.

Features of Mental Models	**Codes**
Sun rays reach the Earth by passing through the atmosphere	SRE
Ozone layer is a barrier to some of the incoming radiation	OB
The Earth's surface absorbs solar radiation	EAR
The Earth's surface reflects solar radiation	ERR
Greenhouse gases absorb outgoing radiation	GAR
Greenhouse gases reflect outgoing radiation in various directions	GRR
Outgoing radiation is trapped in the layers of atmosphere and on the Earth's	RT

For addressing the research question (1), frequencies and percentages of each code were calculated for each group. The participant groups were compared according to their frequency counts of the types of mental models. For the research question (2), alternative conceptions were detected, frequencies, and percentages of each of them were determined. The groups were again compared in terms of the frequency of alternative conceptions. For answering the research question (3), the mental models emerged from the student explanations were ordered in terms of the extent of their alignment with the scientific greenhouse effect mechanism. The detected alternative concepts caused some mental models to be inferior models. Based on the order of the models from the most scientific one (*Micro Model A*) to the least scientific one (*Macro Model F*), the mental models can be sequenced as *Micro Model A, Micro Model B, Macro Model A, Micro Model C, Macro Model B, Macro Model C, Micro Model D, Macro Model D, Macro Model E, Macro Model F* (see Table 3.3 and Table 3.4).

Each student's academic achievement based on their grade point average (GPA) was correlated with their type of mental models by using the IBM Statistical Package for the Social Sciences (SPSS) (Pallant, 2010). This study was aware of the limitations of GPA, while choosing it as a measure of the academic achievement. GPA may not be an optimal predictor of the achievement since it reflects not just academic achievement but also some other factors such as teachers' grading procedures (Pui-Wa et al., 2001). However, GPA was the only available standard metric to predict academic achievement of the students in this research.

The non-parametric Kendall's tau-b test was utilized for the data analysis. Kendall's tau-b measure requires two variables to be ordinal or on a continuous scale. It measures the strength of a relationship between two variables. For this study, there was no violation for this non-parametric test since the two variables, GPA score and scientific level of mental models are ordinal. The correlation between these variables were searched for each group separately because the cognitive level of each grade level were not the same.

Table 3.3. The representations of macro mental models about the mechanism of greenhouse effect.

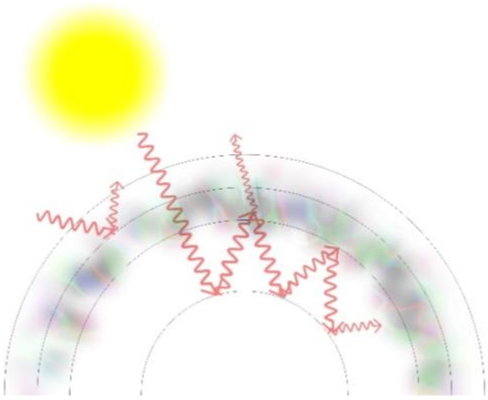
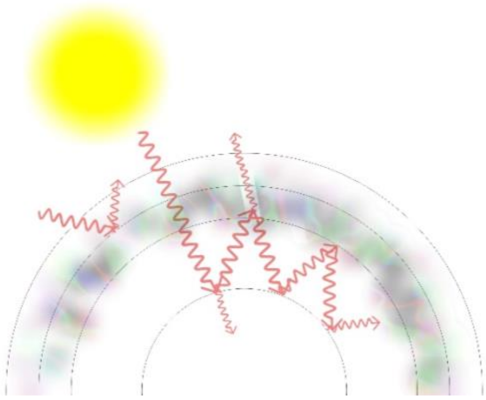
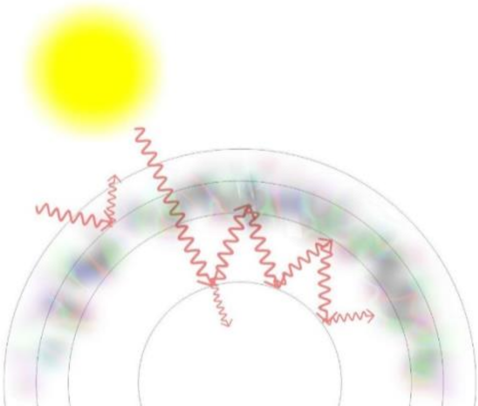
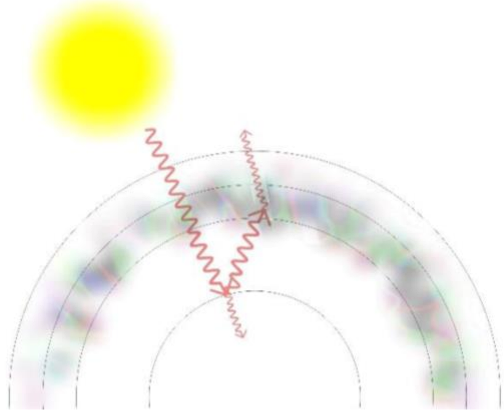
Macro Models	
Macro Model A	Macro Model B
	
The Macro Model A. There is a mixture of gases in the atmosphere. Some of the incoming radiation is reflected by the gas layer(s) in the atmosphere. There is no absorption of light at the Earth's surface. The reflection of incoming radiation from the Earth's surface and the reflection of outgoing radiation by the layer(s) of greenhouse gases were presented as a 'mirror effect'. Outgoing radiation is either totally trapped in the atmosphere or moves towards space. In this model, no features regarding the particulate nature of gases and their molecular behavior are present. The gases are merely introduced at macroscopic level.	*The Macro Model B*. The ozone layer as a gas layer blocks incoming radiation. Some of them are making their way through the atmosphere, arriving at the surface of the Earth, and being absorbed on the surface. The emitted radiation from the surface become trapped in between the atmosphere and the Earth's surface. Some of the outgoing radiation go back to space through the spaces between the gases.
Macro Model C	Macro Model D
	
The Macro Model C. The gas layer(s) in the atmosphere reflect some of the incoming solar radiation to space. Some are passing through the atmosphere and reaching the Earth's surface, and some are absorbed by the surface. The outgoing radiation from the surface cannot go beyond the atmosphere towards space and gets stuck in between the atmosphere and the Earth's surface.	*The Macro Model D*. There is no reflection of solar radiation happening from the atmosphere or clouds. The incoming radiation is either absorbed or reflected by the Earth's surface. The reflected radiation is mostly absorbed by the gases in the atmosphere. Outgoing radiation is absorbed by the gases and cause rise in temperature at the atmosphere.

Table 3.3. The representations of macro mental models about the mechanism of greenhouse effect (cont.).

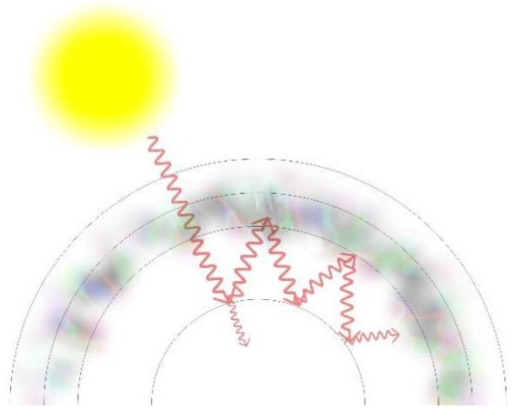
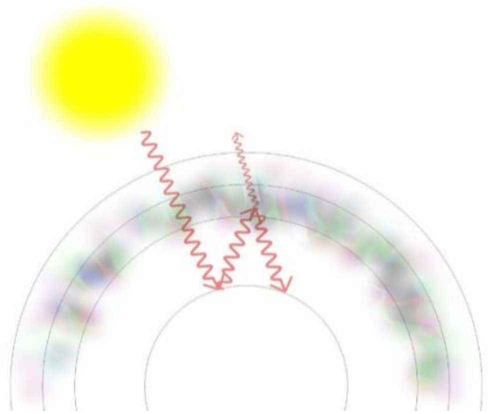
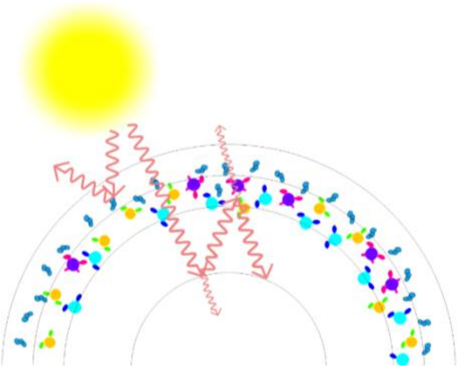
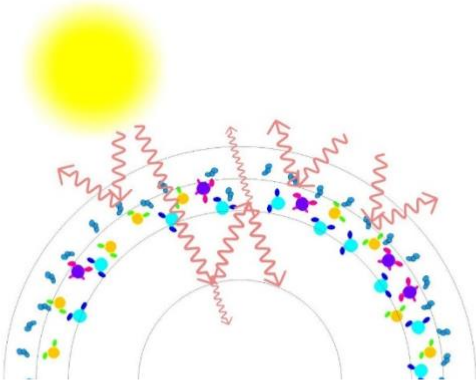
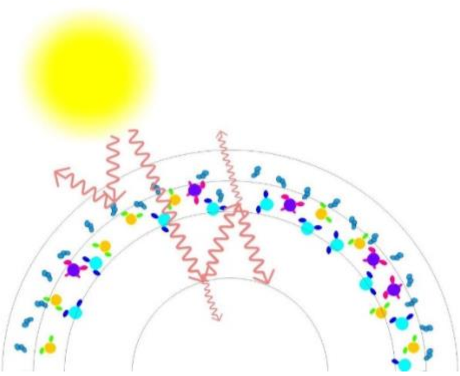
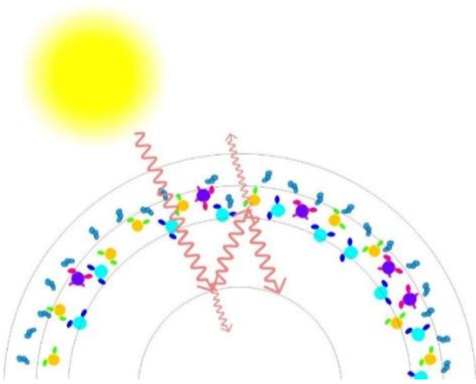
Macro Models	
Macro Model E	Macro Model F
	
The Macro Model E. There is no reflection of solar radiation happening from the atmosphere or clouds. Solar radiation directly goes through the atmosphere. The Earth's surface can absorb radiation. Longwave radiation is only trapped in between the atmosphere and the Earth's surface and do not go outside the atmosphere.	*The Macro Model F.* There is no reflection of solar radiation happening from the atmosphere or clouds. Solar radiation directly goes through the atmosphere. Such radiation is not absorbed by the Earth's surface. The reflected radiation from the surface of the Earth can either escape into space beyond the atmosphere or can be caught and trapped in between the atmosphere and the Earth's surface.

Table 3.4. The representations of micro mental models about the mechanism of greenhouse effect.

Micro Models	
Micro Model A	Micro Model B
	
The Micro Model A. Incoming solar radiation reaches the Earth's surface. Some are reflected by the gas particles in the atmosphere. Some others pass through the atmosphere and reaches the Earth's surface. Some of them is absorbed by the Earth's surface and increases the energy of the particles at the Earth's surface, while some others are reflected to the atmosphere. When they reach the atmosphere, the particles of greenhouse gases absorb some of the outgoing radiation. The particles of GHGs re-emit the radiation in various directions, including the Earth's surface and space. Some of the reflected radiation is trapped in the layers of atmosphere.	*The Micro Model B*. The ozone layer's gas molecules reflect some incoming radiation back to space. The Earth's surface absorbs some of the solar radiation that reaches to the surface. Some of the re-emitted radiation from the surface of the Earth is reflected by the gas particles in the atmosphere to the surface of the Earth and other directions, and some others reflected to space passing through the gaps between the gas molecules. Some are trapped in between the atmosphere and the Earth's surface.
Micro Model C	Micro Model D
	
The Micro Model C. As the particles existing in the atmosphere reflect some of the incoming solar radiation back to space. Some of the solar radiation reaches to the Earth's surface, and it is absorbed by the surface. Some of the radiation re-emitted by the surface goes back to space passing through the empty spaces in between the gas molecules, and some are reflected by the gas particles in the atmosphere, causing entrapment of heat on the Earth.	*The Micro Model D*. There is no reflection of solar radiation from the gas molecules or clouds. Solar radiation directly goes through the atmosphere. Some of the solar energy that reaches to the Earth's surface is absorbed. Heat is trapped in the atmosphere as some of the radiation is reflected by the gas particles to the surface of the Earth, and some others return to space by the spaces in between the gas molecules in the atmosphere.

3.5.1. The Scientific Model of Greenhouse Effect Mechanism

The scientific explanation about the mechanism of the greenhouse effect helped to examine the emerging mental models in certain steps while coding and analyzing the current data.

The steps of the greenhouse effect mechanism are explained in Chapter 1 respectively as; (1) The shortwave radiation (visible light) coming from the sun flows through the atmosphere or a few are reflected back to the space by the gases and clouds in the atmosphere, (2) the incoming radiation absorbed by the clouds flow towards the Earth's surface, (3) some of the shortwave radiation is absorbed by the Earth's surface, (4) and some are re-emitted from the surface as longer wavelengths towards the atmosphere, (5) the greenhouse gases and clouds in the atmosphere absorb the longwave radiation, (6) re-emission of the longwave radiation by the greenhouse gases occurs in various directions towards space and the Earth's surface, (7) the re-emitted radiation to the Earth's surface keeps the globe warm (see Figure 1.1).

3.6. Validity and Reliability

According to Creswell (2018) validity in a qualitative study is "an attempt to assess the accuracy of the findings, as best described by the researcher, the participants, and the readers (or reviewers)". Creswell and Miller (2000) underlines that the degree to which how well a qualitative study represents the truth of the examined problem indicates its validity. Nevertheless, as qualitative data are difficult to quickly summarize, qualitative researchers typically use defining examples to provide credibility. Reliability often refers to consistency of participant responses to different coders in qualitative methodology (Creswell, 2018).

Certain criteria have been developed for a good research study to fulfill. The quality of a qualitative research relates to: whether the research questions guide data collection and analysis; the degree of application of data collection methods; whether or not the assumptions researchers made were stated; whether ethical issues are taken into account

(Silverman, 2013). The researchers followed multiple methods to ensure validity and reliability. The methods used in this study are described in the following sections.

3.6.1. Triangulation

In qualitative research, the data can be gathered preferentially by using multiple data collection tools to grasp various aspects and infer different meanings, which is known as triangulation (Creswell, 2018). Another purpose of using triangulation is to combine different types of data and remove the threats to validity. Therefore, data interpretation part of a research can be improved in terms of carrying out the process in detail. Accordingly, this qualitative research utilized two sources of data (interview and sketches) to collect evidence for the codes constructed to avoid issues about validation. All the participants answered the questions verbally and they also had the opportunity to express themselves by drawings.

3.6.2. Generating Rich and Thick Descriptions

The effort to give detailed descriptions of the research setting and the group of interest is called “generating a rich, thick description” (Creswell, 2018, p.343). Qualitative research must be explained with all its details to convey the stance of the whole process to the readers. By describing the participants and the context of the research, this study tried to ensure the transferability of the findings to the other similar settings. Furthermore, in parallel to the statements of Glaser (1965), which was mentioned in the Section 3.5, the data were presented with illustrations and tables in order to explain how the researcher of this study deduced a conclusion.

3.6.3. Making Clear Researcher's Bias

In qualitative research, if the researcher is also the analyst of the data, then there is a potential for researcher bias (Miles & Huberman, 1994). The researcher's perspective, assumptions, stances, and theoretical framework of the study must be precisely and clearly stated in order to avoid disregarding participants' perspective in terms of the validity issues (Creswell, 2018, p.341). In this research, since the researcher is also conducting the data analysis, the position of the researcher was made explicit in the rationale, theoretical framework, method, and the findings chapters. Additionally, to lessen the impact of researcher's bias, interviews were conducted on neutral ground (Johnson & Gott, 1996) such that during the interviews with the participants, the questions were asked in a neutral tone of voice and without directing the participants.

Another technique to avoid overlooking participants' perspective is to actively include the participants into the analysis is *member checking*. Member checking is a method, also known as *participant validation*, used in qualitative research in order to increase the *trustworthiness* of the study (Birt et al., 2016). In this study, the participants were called for confirmation of their given response during the data analysis process if needed. For this purpose, the transcribed interviews were examined once again together with the participants. Through this way, accuracy of the data was increased. In order to avoid trustworthiness issues on member checking, this study critically evaluated the scope and limitations of this technique and decided to use it to provide exact findings.

3.6.4. Intercoder Agreement and Reliability

Determining codes by different coders and reaching an agreement by comparing them is called *intercoder agreement*, that is necessary to provide reliability (Kuckartz, 2014). The points that coders agree on and disagree must be precisely identified. Throughout this process, coders need to persuade each other of the differences in their categories. *Interrater reliability* evaluates the level of agreement between multiple coders in a research (Creswell, 2018, p.211). Miles and Huberman (1994) suggested a level of 80 percent agreement of coding between the coders of data. In this study, the codes were also generated separately by two of the researchers to ensure consistent coding.

The problem with inter-coder agreement is that it is often challenging for coders to reach an agreement. Words can have different meanings and need to be studied in the context in which they are used (Campbell et al., 2013). In depth semi-structured interviews may require multiple codes at the same time since the questions are eligible to be answered extendedly. In this kind of case, researchers need to be eligible, in other words have comprehensive knowledge of the subject matter, to drive meaning from the answers. Richards (2015) addressed the inconsistencies of the codes of different coders and suggested that a total agreement should not be anticipated. This notion was originally claimed by Glaser (1965) as "the constant comparative method is not designed (as methods of quantitative analysis are) to guarantee that two analysts working independently with the same data will achieve the same results; it is designed to allow, with discipline, for some of the vagueness and flexibility which aid the creative generation of theory" (p.438). In the current study, with constant comparative analysis, in other words, with constant comparisons within and across the groups, the meaning derived from the verbal explanations of participants and their labeling was aligned and established at the optimal level. The two coders independently coded the 15% of data, selecting sample data from each group of participants. The intercoder agreement was reached at 88.9% level for the types of mental models of participants.

3.7. Ethical Issues

This study was conducted after receiving permission from the Istanbul Provincial Directorate of National Education and the Research with Science and Engineering Fields Human Research Ethics Committee (FMINAREK), which can be found in Appendix D. All participants were given detailed information about the study and a consent form was given to be signed before data collection due to ethical concerns (Appendix B). Parental consent was obtained from the families of the high school students under the age of 18.

This study, which deals with a socio-scientific environmental problem, is not predicted to pose a psychological, physical, sociological, legal, or economic risk for participant students and pre-service teachers. The interviews conducted in the school where only the participant and the researcher were present to ensure the confidentiality of the data. The researcher of this study would never share the identity information of the persons to whom the data belongs with third parties.

Participants were informed that they would not be paid any fees if they participated in this study. They have been informed that their participation in this research will not affect their grade point averages of the courses they are taking in any way or that they will not earn credits.

4. FINDINGS

In this chapter, the findings of this study encompassing the students' mental models on the greenhouse effect were presented around research questions.

4.1. Students' Mental Models of Greenhouse Effect

Research Question 1: *How do students' mental models of greenhouse effect change across different grade levels (G9, G11, PST)? What is the nature of their mental models*?

With the analysis of the participant group's mental models of the greenhouse effect, the two types of mental models were mainly identified based on their explanations, namely micro model and macro model. Even though each type of the mental model showed the basic features of the scientific explanation regarding the mechanism of greenhouse effect in certain ways, various alternative conceptions were observed in some of their explanations, which are presented in the Section 4.2. These two categories of mental models ('Micro Model' and 'Macro Model') were mainly constructed around the references to the particulate and macroscopic level features of greenhouse effect in the participants' explanations. Overall, six 'Macro Models' (*Macro Model A, Macro Model B, Macro Model C, Macro Model D, Macro Model E, Macro Model F*) and four 'Micro Models' (*Micro Model A, Micro Model B, Micro Model C,* and *Micro Model D*) emerged from the data. The features of each type of mental model constructed from the data were provided in Chapter 3 (see Table 3.3 and Table 3.4).

Each type of mental model is unique, however, there are some similarities between such mental models emerged from the data. To start with the Macro Models, the *Macro Model A* is similar to the *Macro Model B* and *C* in terms of entrapment of rays and reflection of incoming rays from the atmosphere. However, there is no absorption of solar energy at the Earth's surface in the *Macro Model A* and *Macro Model D*. In contrast to the *Macro Model A* and *Macro Model D*, absorption of incoming radiation by the Earth's surface is present in the *Macro Model B*, *Macro Model C*, *Macro Model E* and *Macro Model F*. Entrapment of radiation is present in all types of Macro Models except for the *Macro Model*

D. In the *Macro Model E,* the outgoing radiation is mostly absorbed by the gases in the atmosphere, which causes the rise in temperature, then reemitted back to space. In the *Macro Model D*, *Macro Model E*, and *Macro Model F*, there is no reflection of incoming radiation in the atmosphere or clouds, in contrast to the other Macro Models. The *Macro Model B* and *Macro Model C* are similar to each other. They differ from each other with a nuance that ozone layer exists in *Macro Model B*, which enables more reflection of the incoming solar radiation compared to the *Macro Model A*. In *Macro Model C* and *Macro Model F*, reemission of outgoing radiation back to space is not happening.

The Micro Models also have some distinct and common fundamental features. To illustrate, all the Micro Models include the absorption of the incoming radiation and the entrapment of terrestrial radiation in common. The *Micro Model A* and *Micro Model B* are so close to each other. However, the main difference between them is that the outgoing radiation is returning back to space through the spaces between the gas particles in the *Macro Model B*, whereas in the *Micro Model A* outgoing radiation is first absorbed by the gas particles, then reemitted back to space in various directions. The outgoing radiation is also passing through the spaces between the gas particles in the *Micro Model C*. The key difference between the *Micro Model B* and *Micro Model C* is the presence of ozone layer in the *Micro Model C*. On the contrary to the other Micro Models, only the *Micro Model D* does not have the reflection of solar radiation in the atmosphere.

The exemplifying excerpts from the participants' statements concerning the specific features of mental models are presented in Table 4.1 below.

Table 4.1. Frequencies and percentages of different features of mental models.

Codes	G9 *f* (%) (*N*=18)	G11 *f* (%) (*N*=24)	PST *f* (%) (*N*=19)	Exemplifying excerpts
SRE	18 (100)	24 (100)	19 (100)	Student 9_PST: *"Sun rays pass through the atmosphere as photons and reach the earth's surface."*
OB	1 (5.6)	9 (32.5)	10 (52.6)	Student 13_G11: *"Photons come out of the sun and pass through the ozone layer. The ozone layer and the atmosphere reflect certain colors of light. It prevents harmful rays from reaching our world."*
				Student 2_PST: *"Not all rays from the sun reach the earth's surface. UV radiation is reflected from the ozone layer of the atmosphere, generally returning from places where greenhouse gases accumulate."*
EAR	12 (66.7)	15 (62.5)	15 (78.9)	Student 15_PST: "*Some of the incoming radiation is absorbed by the Earth's surface. We need energy. It increases the kinetic energy of the particles on the earth.*"
ERR	17 (94.4)	24 (100)	17 (89.5)	Student 9_G9: "*Sun rays are absorbed, while some is reflected as it meets the surface.*"
				Student 7_PST: "*Some of the radiation is absorbed but I can say that some of it is reflected when it hits the surface.*"
GAR	8 (44.4)	5 (20.8)	9 (47.4)	Student 15_PST: "*to what extent the greenhouse gases absorb the radiation is dependent on the gases' molecular structures.*"
GRR	17 (94.4)	19 (79.2)	14 (73.7)	Student 8_G11: "*Rays are reflected inwards towards the Earth by the greenhouse gases, while others are reflected outwards into space. The majority of the rays are reflected back inwards.*"
RT	17 (94.4)	16 (66.7)	19 (100)	Student 11_G9: "*The rays are trapped between the earth and the atmosphere, causing events such as temperature rise.*"
				Student 4_PST: "*Radiation will be reflected from the Earth back into space, but when greenhouse gases accumulate too much, such radiation cannot be reflected to space because gas particles will absorb them, and overheating occurs.*"

Table 4.2. shows the frequencies and the percentages of the types of mental models of greenhouse effect observed among the G9, G11, and PST groups.

Table 4.2. Frequencies and percentages of mental models of greenhouse effect.

Mental Models	Micro Model A	Micro Model B	Micro Model C	Micro Model D	Macro Model A	Macro Model B	Macro Model C	Macro Model D	Macro Model E	Macro Model F
G9 (N=18) f (%)	0	0	2 (11.1)	1 (5.6)	3 (16.7)	3 (16.7)	4 (22.2)	2 (11.1)	2 (11.1)	1 (5.6)
G11 (N=24) f (%)	1 (4.2)	0	1 (4.2)	0	2 (8.33)	6 (25.0)	4 (16.7)	1 (4.2)	5 (20.8)	4 (16.7)
PST (N=19) f (%)	3 (15.8)	3 (15.8)	2 (10.5)	1 (5.3)	4 (21.0)	3 (15.8)	2 (10.5)	0	1 (5.3)	0

Among the Grade 9 group, the total number of Macro Models (n=15; 83.3%) is more than the total number of Micro Models (n=3; 16.7%). The *Macro Model C* is the most seen mental model (n=4; 22.2 %). The *Macro Model A and Macro Model B* (n=3; 16.7 %) were the second most often seen mental models. Then, the *Micro Model C* (n=2; 11.1%)*, the Macro Model D* (n=2; 11.1 %), *Macro Model E* (n=2; 11.1 %), *Micro Model D* (n=1; 5.6%) and *Macro Model F* (n=1; 5.6%) follow. None of the Grade 9 students possessed *the Micro Model A* or *Micro Model B*.

For the G11 group, there were a higher number of Macro Models (n=22; 91.7%) than the Micro Models (n=2; 8.3%). The most frequently held mental model was the *Macro Model B* (n=6; 25.0 %). The second most frequently exhibited mental model was the *Macro Model E* (n=5; 20.8 %). The third most frequently detected mental models were the *Macro Model C and F* (n=4; 16.7 %). The fourth most frequently seen mental model was *Macro Model A* (n=2; 8.33 %). The least seen mental models were the *Macro Model D, Micro Model A, and Micro Model C* (n=1; 4.2 %). The *Micro Model B* and *Micro Model D* were not observed among Grade 11 students' mental models.

In the group of PST, the total number of Macro Models (n=10; 52.6%) are larger than Micro Models (n=9; 47.4%). The most frequently observed mental model was found to be the *Macro Model A* (n=4; 21.1%). It is important to note that 3 of the 19 PSTs (15.8%) held the *Micro Model A* and another 3 of the 19 PSTs exhibited the *Micro Model B* regarding the greenhouse effect. Only the 5.3% of the students had the *Micro Model D* or *Macro Model E*. None of the participants had the *Macro Model D* and *Macro Model F* in the PST group.

The *Micro Model A* (n=3)*, Micro Model B* (n=3)*, Macro Model A* (n=4) were the most widely observed mental models in the PST group. The *Micro Model C* was more often identified in the G9 group (n=2) and the PST group (n=2). The *Micro Model D* was seen in the G9 and PST groups in the highest number (n=1). The *Macro Model A* was the most abundant in the PST group (n=4). The *Macro Model C* had the highest percentage of presence in the G9 and G11 groups (n=4). The *Macro Model B* was more abundant in the G11 group (n=7) than the other groups. The *Macro Model D* was mostly held in the G9 group (n=2). The *Macro Model E* was comparably more detected in the G11 group (n=5). The *Macro Model F* was mostly abundant in the G11 group (n=3).

In conclusion, Macro Models are higher in number than the Micro Models in all groups of participants. Unlike the G9 and G11 students, the preservice teachers mostly held the *Macro Model A*, which was considered closer to the scientific greenhouse effect model, as discussed in Section 4.3. None of the participants in the groups G9 and G11 have the *Micro Model B*. The PST group participants did hold the *Macro Model D* and *Macro Model F*, which are least scientific model with several missing features of greenhouse effect (see Section 4.3).

4.1.1. Micro Models

The Micro Models vary based on codes emerged from the explanations participants have made during the interviews (see Table 4.3.). In Table 4.3., corresponding codes were indicated besides the exemplifying excerpts. The Micro Models mutually covers the shape, abundance, behavior, or particle level energy of gas molecules while explaining the greenhouse effect processes of reflection, absorption, and emission events. To illustrate, “the absorption and emission of radiation by the gases depends on the geometry of the gas molecules" statement was an example for the gas molecules' shape. Another example sentence about the gas molecules' abundance from the transcripts was "radiation will be reflected from the earth to space, but when greenhouse gases accumulate too much, they cannot be reflected back into space because gas particles will absorb them, and overheating occurs". Some of the different types of Micro Model explanations included that the nature of light is electromagnetic waves or that light is composed of photons. Nevertheless, none of the G9 participants made an explanation about the nature of light.

All the *Micro Models A, B, C* and *D* explained how greenhouse gas molecules interact with radiation from the sun and how the Earth reflects light. When the explanations of the participants of all groups were examined, this study found out that all the Micro Models had certain features close to the scientific model of the greenhouse effect. However, the mechanism of the *Micro Model A* was found to be closest to the mechanism of the scientific greenhouse effect model in terms of containing explanations at the particle level without missing any key features of the mechanism. In the mechanism of the *Micro Model A*, the absorption, emission and reflection of radiation were delineated with the gas molecules at the submicroscopic level. The *Micro Model D* was found to be the most unlike one to the scientific model because of lacking the fundamental features of the mechanism. All Micro Models, except for the *Micro Model D,* included the feature that describes how some of the incoming radiation is reflected from the atmosphere or clouds. Even though the *Micro Model D* is not so similar to the scientific model, it is still more scientific than the *Macro Model D, E* and *F.* Thereby, the Micro Models are not always more sophisticated than the Macro Models.

Besides the main characteristics of the Micro Models having explanations at the particulate level, some fundamental details of the context are missing in the mental models. For instance, participants with the Micro Models did not specify the layers of the atmosphere as the troposphere or stratosphere in none of the Micro Models. The participants, who have one of these Micro Models, assumed that greenhouse gases accumulate in all layers of the atmosphere without any particular order. Despite that ozone layer was mentioned in the *Micro Model B*. Furthermore, some explanations provide information about ozone layers' ability to reflect a particular wavelength range of radiation (11.1% of G9, 37.5 % of G11, and 52.6 % of PST).

The exemplifying excerpts of the features of the Micro Models from statements of participants, who have these models, were presented in Table 4.3. below.

Table 4. 3. Exemplifying excerpts of each micro mental model emerged.

Mental Models	**Exemplifying excerpts**
Micro Model A	Student 13_PST: "*After the sun's rays enter the atmosphere, they hit our earth here* (SRE). *Some are reflected back to space from the atmosphere* (ERR). *Some incoming radiation is absorbed by the Earth's surface and then, are reflected back to the atmosphere* (EAR). *Sunrays try to reach the Earth and come back again but it gets stuck in the atmosphere* (RT). *In this case, there is an increase in temperature in the world. [...] An increase in temperature means an increase in energy. Then when these rays come in, when they interact with the gas particles in this atmosphere, absorption of radiation is seen and the energy increases* (GAR). *In other words, because the energy of the particles around the world is increasing, our world is warming. Then, radiation is reemitted by the gases* (GRR)"
Micro Model B	Student 6_G9: *"When the sun's rays come to earth, some of them are first reflected in the ozone layer of the atmosphere [to the space]* (SRE, OB). *Some of them can enter directly to the atmosphere, some of the rays hit the ground. Heat is being absorbed by the Earth and causing the earth warm* (EAR). *That way, the world gets a little warmer, and some of the rays are reflected off the ground* (ERR). *[...] If the rays reflected back to the atmosphere hit a gas molecule or an atom, it returns to the Earth, but if it passes through the space between the gas particles, it can go into space* (GRR, RT). *[...] The greenhouse gases are able to absorb the outgoing radiation* (GAR)*".*
Micro Model C	Student 14_PST: *"Sun rays pass through space and reach the earth* (SRE). *In the outermost layer, the rays begin to reflect and refract. There are many layers in the globe and their densities are also different. Some rays are reflected from the atmosphere. The radiation reaches the earth is [again] reflected from the Earth* (ERR). *Some of it is absorbed [by the earth]* (EAR). *The reflected ones come back into the atmosphere. [...] There are too many atoms and molecules in the atmosphere. The rays are reflected many times around the atoms or absorbed by the gas atoms* (GAR, RT). *Then rays are reflected to space passing through the gaps between the gas molecules* (GRR)*".*
Micro Model D	Student 16_G9: *"The sun's rays hit the ground of the Earth, that is, the surface of the Earth* (SRE). *Some of this heat energy is absorbed by the Earth's surface, while another part is reflected off the Earth* (ERR, EAR). *While some of them return to space, some of them are reflected back to the world by gases and trapped* (RT). *The molecules of these gases can absorb the light* (GAR). *This causes a warming in the Earth [...]".*

Based on the Student_13_PST explanations on the greenhouse effect, it appeared that her understanding of the greenhouse effect matches with the scientific model because of its main characteristics' similarity with the scientific greenhouse effect model (see Table 4.3.).

All the codes derived in this study are present in her mental model. Student_13_PST's mental model was identified as *Micro Model A* because of the explanations regarding the radiation's interaction with the gas particles, energy difference, and temperature change.

The analysis of Student_6_G9's explanation of greenhouse effect was identified as *Micro Model B* since the mental model contains the main features of the scientific greenhouse effect model; however, it lacks the reemitted radiation by the gas particles. Nevertheless, this example of mental model contains micro-scale explanations of gas particles, interactions of radiations with those particles, and the ozone layer, reflecting some of the incoming sunlight. For example, the phrase '*rays striking a gas molecule or an atom*' is an atomic-level description confirming that the model is a Micro Model. The exemplifying excerpt for *Micro Model C* of Student 14_PST was categorized based on the explanations regarding the mechanism. In this model, there were statements about the reflections, refractions, densities of the layers of the atmosphere, abundance of atoms and molecules in the atmosphere, and absorption by the gas atoms. However, there is a statement regarding the outgoing infrared radiation that it passes through the spaces between the atoms without interaction, which is scientifically incorrect and makes the mental model less sophisticated than the *Micro Model A* and *Micro Model B*. The highlight of *Micro Model D* is having atomic-level explanations but not including the explanations of reflection of sunlight in the atmosphere or clouds. Since there were no phrases regarding the reflection and refraction of light in the atmosphere for Student 16_G9's mental model, it was identified as *Micro Model D*. Student_16_G9 had initially started to explain the mechanism of the greenhouse effect by stating that *'the sun's rays hit the ground of the Earth.'*

4.1.2. Macro Models

The Macro Models differ depending on codes derived from the explanations provided by participants during the interviews (see Table 4.3.). Along with the exemplifying excerpts, appropriate codes were mentioned in Table 4.3. The Macro Models explain the greenhouse effect processes without considering the events of reflection, absorption, and emission at the particle level. All Macro Model explanations mentioned the atmosphere without discussing gas particles and layers. The participants with the Macro Models depicted gas composition in the atmosphere like a wall. The particulate nature of gases and molecular dynamics were not represented by these participants in any way. Only a macroscopic level introduction of the gases was made. There were no explanations regarding the rotational and vibrational motions of gases as they absorb the radiation.

As Anderson (2007) stated, the sophistication level of understanding indicates being able to use central concepts of a particular domain. In that manner, due to the presence of some key features of the scientific model in the Macro Models (the *Macro Model A, B,* and *C*), some Macro Models are considered to have higher levels of sophistication compared to some Micro Models. There is a mixed order of sophistication between Macro and Micro models. For instance, the *Macro Model A* is the third most sophisticated mental model that comes after the *Micro Model A and Micro Model B.* The *Macro Model B* and *Macro Model C* have high levels of sophistication due to the lack of reflection of the solar radiation in the *Micro Model D*'s mechanism. The least sophisticated Macro Model is the *Macro Model F*, since there is no explanation regarding the solar radiation reflection from the atmosphere or clouds. In the mechanism of the *Macro Model F,* solar energy passes directly through the atmosphere. The Earth's surface does not absorb the incoming radiation, which is not in line with the scientific mechanism.

The exemplifying excerpts of participants' statements from the Macro Models were presented in Table 4.4 below. In Table 4.4, Student 19_G11's mental model was given as an example of *Macro Model A*. This mental model was named as *Macro Model A* because of the students' macro-level explanations about the radiation and gases such as, *'Greenhouse gases can absorb some of the rays'*. In this phrase, absorption of radiation was explained by mentioning only gases but not gas particles/atoms or molecules and these particles' behaviors, which makes this model a Macro Model. Student 10_G9's mental model was presented as an example of *Macro Model B* because it has macroscopic explanations regarding the greenhouse effect phenomenon and the ozone layer was present. In the script of Student 12_G9's mental model, the expression *'Greenhouse gases cover the atmosphere like a blanket and prevent the sun's rays from going back to space'* refers to see the gases in the atmosphere as a whole. Moreover, this sentence means that greenhouse gases are merely reflecting the outgoing radiation instead of absorbing or reemitting them. That is why Student 10_G9's mental model was presented as an example of *Macro Model C*.

Table 4.4. Exemplifying excerpts of each macro mental model emerged.

Mental Models	Exemplifying excerpts
Macro Model A	Student 19_G11: *"It enters the Earth's atmosphere. Some must be reaching the earth, reaching both the land and the sea, and some are reflected* (SRE). *These rays are then reflected back from the Earth's surface* (ERR). *Some go back into space, but some are trapped in the atmosphere* (GRR, RT). *[...] Greenhouse gases can absorb some of the rays after it comes to a place where greenhouse gases are more concentrated* (GAR). *The rest of the radiation exit the atmosphere and return to space".*
Macro Model B	Student 10_G9: *"As the sun's rays reach the Earth, some of them go directly to the Earth's surface, but some of them bounce off from the ozone layer and go into space* (SRE, OB). *Some of those who go to the ground reflected back to the atmosphere* (ERR). *Some of them are going to space again but there is a greenhouse effect due to greenhouse gases. [...]There are greenhouse gases emitted by both humans and nature itself. They absorb or reflect the sun's rays* (GAR). *Therefore, the sun's rays are trapped in the atmosphere* (RT). *It creates heat energy from there, and there is an unnecessary heating due to the constant contact of the rays and gases and the trapping of the rays".*
Macro Model C	Student 12_G9: *"After the rays reach the Earth, some of them are reflected and go back to space, but a certain part remains on the Earth* (SRE). *It's because of greenhouse gases. Also, some are absorbed by the Earth. [...] Greenhouse gases cover the atmosphere like a blanket and prevent the sun's rays from going back to space* (GAR). *By bouncing between the ground and the atmosphere like this, the remaining sun rays on the earth increase* (RT). *In this way, the temperature and the world are adversely affected".*
Macro Model D	Student 1_G9: *"At first the rays pass through the atmosphere* (SRE). *Then, it hits the surface and is reflected from the surface* (ERR). *The rays then hit the greenhouse gases, some of which are kept inside right now, it's all inside because it's too much. That's why the world is getting warmer. [...] Greenhouse gases form a layer in the atmosphere. That's why it prevents the rays going back to space* (GRR). *The rays are trapped and remain in the atmosphere* (RT)*."*
Macro Model E	Student 4_G11: *"The rays come from the sun, then they cross the atmosphere, and reach the Earth's surface* (SRE). *The rays reaching the earth are absorbed by the soil and used by plants* (EAR). *Some rays are reflected and return to the atmosphere* (ERR). *The rays trying to reach space are absorbed by greenhouse gases* (GAR). *Then they emitted to the Earth again* (GRR)*".*
Macro Model F	Student 5_G11: *"Rays enter our atmosphere* (SRE). *Then, it hits the ground and bounces back* (ERR). *When it bounces back, it reflects in various directions if it encounters a greenhouse gas* (GRR). *In that case, rays can escape from our atmosphere. But when the rays hit the gases due to the increase in the amount of gas, this time it remains inside the Earth* (RT). *[...] Since those rays also hold heat, our world is starting to heat up even more and cannot give out the heat. The rays and heat coming to us are starting to warm the world even more".*

For the *Macro Model D*, Student 4_G11 has mentioned '*[...] Greenhouse gases form a layer in the atmosphere. That's why it prevents the rays going back to space'*. This statement indicates that radiation is trapped in the layers of the atmosphere and cause heating which constitutes the mechanism of *Macro Model D*, different from all other Macro Models. The *Macro Model E* and *Macro Model F* stand out with their scientifically incorrect features, as can be seen in Student4_G11's and Student_5_G11's mental models. For example, these models contain expressions regarding the lack of incoming radiation's reflection from the atmosphere or lack of absorption at the Earth's surface. For this reason, these models were easily spotted and constituted as two different types of Macro Models.

Table 4.5. Frequencies and percentages of greenhouse gases mentioned during interviews.

The types of greenhouse gases	G9 *f* (%) (*N*=18)	G11 *f* (%) (*N*=24)	PST *f* (%) (*N*=19)
carbon dioxide	18 (100)	19 (79.2)	17 (89.5)
methane	11 (61.1)	8 (33.3)	7 (36.8)
water vapor	1 (5.6)	1 (4.2)	5 (26.3)
nitrous oxide	2 (11.1)	2 (8.3)	3 (15.8)
ozone	2 (11.1)	3 (12.5)	3 (15.8)
chlorofluorocarbons	0	4 (16.7)	4 (21.1)

In Table 4.5, the frequencies and percentages of greenhouse gases mentioned during the interviews were reported. Besides, further information on alternative conceptions of greenhouse gases were stated in section 4.2. Carbon dioxide, methane, water vapor, nitrous oxide, ozone, and chlorofluorocarbons were mentioned among greenhouse gases in both micro and macro models derived from student interviews and sketches. The G9 group's most frequently mentioned greenhouse gas was carbon dioxide (100 %). Grade 9 students did not mention chlorofluorocarbons in their answers. Grade 11 students mostly used carbon dioxide (79.2 %) in their answers. The least mentioned GHG was water vapor (4.2 %) in the G11 group. The most frequently mentioned greenhouse type was carbon dioxide among 89.5 percent of the pre-service teacher participants. The least mentioned greenhouse gases among the pre-service teachers were nitrous oxide (15.8 %) and ozone (15.8 %). Among the greenhouse gases mentioned by all participants of the groups, carbon dioxide was the most mentioned GHG.

4.2. Students' Alternative Conceptions about the Greenhouse Effect

Research Question 2: *What are students' alternative conceptions on the greenhouse effect across different grade levels (G9, G11, PST)?*

The frequencies and percentages of alternative conceptions observed in each group of participants can be seen in Table 4.6. Some of the students (G9 (5.56%), G11 (12.5%), PST (15.8%)) mistakenly think that carbon monoxide is a greenhouse gas. Even though carbon monoxide is not a greenhouse gas, since it is chemically active, it may contribute to the formation of ozone or may change the lifetime of methane gas. Since it can affect the abundance of the greenhouse gases, it is called 'indirect greenhouse gas' (Prather et al., 2001, p.241). Some students (G9 (16.8%); G11 (8.3%); PST (15.8%)) believed that because a molecule of a gas is made up of only 3 atoms like carbon dioxide, it is also a greenhouse gas. Students (G9 (5.6%); G11 (0%); PST (5.3%)) believed that oxygen is a greenhouse gas. Some students, mostly half of the Grade 9 participants, think that all the greenhouse gases are anthropogenic. Some greenhouse gases are emitted apart from human activities, such as water vapor and nitrous oxide. (Stocker, 2014).

The alternative conceptions regarding the incoming and outgoing radiation are explained in this paragraph. The first alternative conception is associated with the Earth's surface which cannot absorb but only reflect the incoming solar radiation (G9 (27.8%); G11 (25.0%); PST (10.5%)). However, normally absorption of solar radiation is happening in higher amounts than the reflection of light from the Earth's surface (Gray et al., 2010). A second alternative conception in association with the Earth's surface was that outcoming radiation has a shorter wavelength than the incoming radiation because its energy has decreased (G9 (22.2%); G11 (25.0%); PST (5.3%)). However, the reality is vice versa; solar radiation has a shorter wavelength than the outgoing radiation (NASA, 2010). A third alternative conception was that all the incoming radiation is absorbed by the greenhouse gases (G9 (16.8%); G11 (8.3%); PST (15.8%)). The vast majority (83.3 %) of Grade 11 participants stated that the gas layer is acting like a wall. Actually, it is the incoming radiation that is either absorbed and passes through or reflected from the greenhouse gases or clouds (NASA, 2010). Another alternative conception was about the absorption of light such that 'the Earth's temperature is increasing mostly because of the incoming solar radiation'. The rise in Earth' temperature is mostly due to the terrestrial radiation rather than solar radiation (NASA, 2010). Another related alternative conception was that 'the greenhouse gas layer is acting like a wall for the radiation and reflects all radiation back'. In reality, the greenhouse gases can absorb radiation. After all, some students believe that all atmospheric gases can absorb radiation. Nevertheless, only greenhouse gases are able to absorb the radiation. Greenhouse gases are responsible for heating the Earth's surface and the lower atmosphere by re-emitting the longwave radiation (Zhong & Haigh, 2013). Some students (G9 (0%); G11 (4.2%); PST (10.5%)) thought that the reflection of light and refraction of light are the same phenomena, so they used two of these terms interchangeably. Lastly, only a few students from PST (5.3%) alternatively thought that both the light and gas molecules are undergoing a chemical reaction and chemical bonds are physically structured.

Table 4.6. Frequencies and percentages of alternative conceptions related to the greenhouse effect.

Alternative conceptions related to the greenhouse effect	G9 *f* (%) (*N*=18)	G11 *f* (%) (*N*=24)	PST *f* (%) (*N*=19)
Carbon monoxide is a greenhouse gas	1 (5.6)	3 (13.0)	3 (15.8)
Heavy gas molecules may absorb the radiation much more than the light molecules	1 (5.6)	1 (4.2)	3 (15.8)
All outgoing radiation is trapped between the atmosphere and the Earth's surface	5 (27.8)	5 (20.8)	3 (15.8)
Gas layer is acting like a wall for the radiation	8 (44.4)	20 (83.3)	3 (15.8)
Reflection and refraction of light are the same	0	1 (4.2)	2 (10.5)
Greenhouse gases are accumulated at the ozone layer	1 (5.6)	0	2 (10.5)
Earth's surface cannot absorb energy	5 (27.8)	6 (25.0)	2 (10.5)
Nitrogen gas is a greenhouse gas	0	0	2 (10.5)
Atmospheric gases absorb outgoing radiation	2 (11.1)	0	2 (10.5)
Greenhouse effect causes ozone depletion	2 (11.1)	4 (16.7)	2 (10.5)

Table 4.6. Frequencies and percentages of alternative conceptions related to the greenhouse effect (cont.).

Alternative conceptions related to the greenhouse effect	G9 *f* (%) (*N*=18)	G11 *f* (%) (*N*=24)	PST *f* (%) (*N*=19)
The incoming and outgoing radiation have the same wavelength	0	0	1 (5.3)
All incoming radiation is absorbed by the greenhouse gases	4 (22.2)	6 (25.0)	1 (5.3)
Chemical bonds are physical structures	0	0	1 (5.3)
Outgoing radiation has shorter wavelengths than incoming radiation	0	0	1 (5.3)
All incoming radiation is reflected back at the Earth's surface	5 (27.8)	6 (25.0)	1 (5.3)
Since CO_2 and SO_2 have similar structures, they are both greenhouse gases	0	0	1 (5.3)
Light and molecules can react with a chemical reaction	0	0	1 (5.3)
All greenhouse gases are anthropogenic	9 (50.0)	5 (20.8)	1 (5.3)
Solar radiation heats the Earth mostly	7 (38.9)	1 (4.2)	1 (5.3)
Oxygen is a greenhouse gas	1 (5.6)	0	1 (5.3)

4.3. The Relation between Students’ Academic Achievement and their Types of Greenhouse Effect Mental Models

Research Question 3: *What is the relationship between students' academic achievement and the type of their mental models on greenhouse effect?*

The research question (3) examined the association between the participants' academic achievement and the sorts of mental models they had regarding the greenhouse effect while they were in the same grade level.

As stated in the data analysis section of Chapter 3, the mental models that evolved from the student explanations were ranked according to their degree of closeness to the scientific greenhouse effect process. The closest mental model to the scientific model, Micro Model A, had the most in-depth explanations regarding the particulate level behavior of gas molecules, absorption, emission, and radiation. The decreasing order of mental models is that *Micro Model A, Micro Model B, Macro Model A, Micro Model C, Macro Model B, Macro Model C, Micro Model D, Macro Model D, Macro Model E,* and *Macro Model F*. Using the IBM Statistical Package for the Social Sciences (SPSS), each student's academic accomplishment based on grade point average (GPA) was related to the type of their mental model (Pallant, 2010). Kendall's tau-b correlation was run to determine the relationship between student’s academic achievement and the type of their mental models. There was no correlation between Grade 9 students' academic achievement and the type of their mental models, which was statistically not significant ($\tau b = .070$, $p > .05$). There was a moderate statistically significant correlation between the academic achievement and the type of the greenhouse effect mental models of the Grade 11 students ($\tau b = .399$, $p < .05$). Similarly, a statistically moderate correlation had been found between the preservice teachers’ academic achievement and mental models ($\tau b = .345$, $p < .05$).

5. DISCUSSION

This chapter discusses the findings, implications, limitations, and suggestions for further studies. The findings of this study are examined, as well as their consistency with earlier findings of the relevant studies.

The purpose of this study was to determine the types of mental models of the greenhouse effect in Grade 9 (G9), Grade 11 (G11), and final year pre-service teachers (PST). As a result, the study investigated how the basic characteristics of these models change between grade levels. This study also sought to explore alternative conceptions on the greenhouse effect. The final goal of this study was to determine whether there was a relationship between students' academic progress and the types of mental models they held about the greenhouse effect.

As a consequence of data analysis, the following categories of the greenhouse effect mechanism formed.

- Sun rays reach the Earth by passing through the atmosphere
- Ozone layer is a barrier to some of the incoming radiation
- The Earth's surface absorbs solar radiation
- The Earth's surface reflects solar radiation
- Greenhouse gases absorb outgoing radiation
- Greenhouse gases reflect outgoing radiation in various directions
- Outgoing radiation is trapped in the layers of atmosphere and Earth's surface

Analysis of students' mental models of the greenhouse effect revealed that students from different grade levels have both similar and different mental models. To help with representing the complexity of the participants' mental models, those models were visually represented and categorized based on certain features. The features of mental models were generated based on considering the fundamental features of the scientific greenhouse effect model. As many mental models as possible were constituted to represent the data completely.

In many ways, student participants of this study's conceptions and mental models of the greenhouse effect are comparable to and distinct from prior findings. This section illustrates the similarities and differences between the findings of this research and the related literature.

This study revealed that the Grade 9 group was similar to the Grade 11 group in learning progression when considering their types and frequencies of mental models. The most frequently observed mental models in groups G9 and G11 were Macro Models (see Table 4.2). This finding may stem from the instruction students have experienced based on the objectives of the National Curriculum of Turkey. The lack of objectives concerning the particulate level explanations of the greenhouse effect, including the gas behavior, and radiation, may resulted in the number of Micro Models to be less than the Macro Models. Moreover, the total number of Micro Models in the PST group is higher than in the G9 and G11 groups (see Table 4.2). This finding suggests that the PST group members have exhibited a significant progression toward a scientific mental model of greenhouse effect compared to the groups of G9 and G11. The reason of why the PST group exhibited a greater learning progression may be due to the advanced science classes that they have taken at higher education, where particulate level explanations take place more than the high school level classes.

For the group G9, the most frequently held mental model was the *Macro Model C*, whereas the most scientific mental model that was observed was the *Micro Model C.* In fact, about 75% of the G9 students showed the mental models of *Micro Model C*, *Micro Model D*, *Macro Model A*, *Macro Model B* and *Macro Model C*. For the G11, the most frequently observed mental model was the *Macro Model B* (25%). However, the most scientific mental model observed within the group G11 was the *Micro Model A.* When we consider the sophistication sequence of the mental models, *Micro Model A*, *Micro Model B*, *Macro Model A*, *Micro Model C*, *Macro Model B*, *Macro Model C*, *Micro Model D*, *Macro Model D*, *Macro Model E*, *Macro Model F* (see Table 3.3 and Table 3.4), in the G9 group, the *Micro Model C* was the most sophisticated mental model reached, whereas the most sophisticated mental model observed in the G11 group was *Micro Model A* (see Table 4.2). In this respect, although there is a similarity between the number of Macro Models in the groups of G9 and G11, the group G11 showed certain progression toward a scientific understanding. This may be due to the higher number of objectives about the greenhouse effect-related topics studied by the Grade 11 participants in their classes throughout the years. The "Environmental Chemistry" unit was included in the Grade 9 chemistry curriculum (MoNE, 2017e). The unit's objectives are the greenhouse effect, ozone depletion, air pollution, global warming, and sustainable development (MoNE, 2017e). The greenhouse effect and other environmental problems are also included more extensively in the Grade 10 chemistry curriculum (MoNE, 2017e). For the group of PST, none of the mental models stood out as the most frequently observed one. In fact, the 45% of the PSTs held one of the Micro Models, and it is important to note that about the 80% of the PSTs mental models (*Micro Model B, Macro Model A, Micro Model C, Macro Model B, Macro Model C* and *Micro Model D*) were close to the most scientific mental model (*Micro Model A*). This finding indicated a great progression toward a scientific understanding of greenhouse effect within the PST group (see Table 4.2).

Although there was a learning progress from the G9 group to the PST group, there are still missing elements in the mental models of the groups of G11 and PST. The 83.3% of the group G11 participants held an alternative conception that the “gas layer is acting like a wall for the radiation.” The abundance of this alternative understanding for the G11 group may be due to the students forgetting the curriculum objectives at previous grade levels or the lack of immediate instruction for this group of students. In addition, the OB code, i.e. the ozone layer’s ability to reflect incoming radiation, is slightly visible in each of the groups, but it is still clear that such basic information is missing for each group; G9 (5.6%), G11 (32.5%), PST (52.6%). The 50.0% of the G9 group also falsely stated that all greenhouse gases are anthropogenic. These findings have been obtained because, in particular, the Grade 9 students did not learn about the properties of the ozone layer or sources of the greenhouse gases through instruction.

Varela et al. (2020) demonstrated that students’ mental models of the greenhouse effect and climate change became more sophisticated after instruction. However, students may still lack knowledge or have misconceptions about the mechanism of the greenhouse effect, and they maintained using simple and non-scientific definitions of the GHE and climate change. Moreover, students essentially mix up the causes and effects of climate change. Similar to Varela et al. (2020)’s study, this research has found that students from upper grade levels with more knowledge about environmental topics may continue to use lacking definitions or knowledge about the greenhouse effect. For example, this research, like other studies in related research field, also showed that secondary school students may have erroneous causal links between climate warming and the unrelated phenomenon of ozone depletion (Liarakou, Athanasiadis, and Gavrilakis, 2011; Punter, Ochando-Pardo, and Garcia, 2010). Not only secondary school students, but also students of all ages may demonstrate similar faulty causal links according to multiple research (Karpudewan et al., 2014; Lambert et al., 2011). In the context of this study, this finding of the related studies implies that the students from higher grade levels may have alternative or non-scientific conceptions.

The findings of this study regarding the mental models of the PST group students revealed that even the participants, who know more about the microscopic level and have an extent of scientific knowledge, may still have inert knowledge with fragmented information. This disorganized knowledge led them to have mental models that have non-scientific features. Similarly, Harris and Gold (2017) investigated undergraduate students' knowledge of the greenhouse effect using explanatory mental models. Following a 30-minute lecture about the behavior of gases at the particle level, data revealed that scientific representations were more visible in student drawings. Harris and Gold (2017) argued that learners' mental models are dynamic; however, a few transitions from a non-scientific model to another erroneous, novice model were observed.

Additionally, the third research question of the study revealed that there was no correlation observed between the participants' academic achievement and the greenhouse effect mental models of Grade 9 participants. There was, however, a moderately significant correlation between the mental models of the Grade 11 students and of the pre-service teachers. This finding suggests that as students proceed in their program of study, their higher GPA relates to their more scientific understanding of greenhouse effect; in other words, students who have high GPA develop more scientific (sophisticated) mental models about the mechanism of greenhouse effect. In line with this finding, Libarkin et al. (2003) implied that the sophistication of the learners' present understanding of a subject influences the formation of mental models.

Students from various educational backgrounds may have diverse perceptions and mental models. This study aimed to demonstrate distinct mental models that students have regarding the greenhouse effect and to broaden our understanding of how learners make sense of the natural world.

5.1. Implications

The findings of this study and the related research enlighten the ways to review curriculum planning on the greenhouse effect. The curriculum or lessons would be enriched with respect to the findings of research on the mental models of the greenhouse effect or the alternative conceptions about the GHE. In the following, the common findings of this study and other studies about the implications are stated.

By examining the greenhouse effect mental models of 164 college students, Harris and Gold (2017) revealed that the technique based on learning about molecular greenhouse gas behavior helps non-scientific models progress toward scientific models. In parallel to Harris and Gold (2017), this study deduced that mental models with microscopic features have more scientific features than the macro models. That is why covering more microscopic level characteristics should be considered during the curriculum planning or for lesson plans in the teaching phase of the greenhouse effect.

The findings of this study, which revealed that each student from Grade 9, Grade 11, and pre-service teachers have diverse alternative conceptions, can also be utilized to reconstruct students' disorganized ideas. According to McCaffrey and Buhr (2008), enlightening students' alternative concepts contributes to redesigning educational approaches. For students, alternative concepts are substantial barriers to conceptual understanding. The learners' pre-instructional beliefs must be widely recreated for allowing them to comprehend the desired scientific knowledge (Treagust & Duit, 2003). For instance, 44.4 % of the Grade 9 students and 83.3% of the Grade 11 students have exhibited the alternative conception 'gas layer is acting like a wall for the radiation' about the mechanism of the greenhouse effect, which is one of the major findings of this study. This important finding may be a consequence of an instructional strategy. That is why the sources of this alternative conceptions should be detected and necessary revisions on the instructional strategies or curriculum objectives should be made to eliminate possible alternative conceptions.

5.2. Limitations of the Study

As stated in the research design of this study, each individual has a unique mental model (Jones et al., 2011). Above that, mental models can be idiosyncratic, which means they may be different but high in accuracy (Buch, 2012). Mental models' idiosyncratic nature brings them a unique property: each individual's self-expression can vary but they may intend to say the same meaning. Driver et al. (1996, p.16) stated that students' ideas about science may not be properly expressed in scientific language but can still make sense.

The results of this research do not grant reflecting the more extensive picture of the same grade levels due to the limited number of students in each group. The similar studies should be conducted with the various participant groups from different communities. Thus, like other qualitative research, the basic premise of this qualitative research was that reaching an agreement semantically by gathering subjective experiences.

Moreover, despite the cross-age design of the study facilitating comparing groups of different ages, it is not providing evidence of how students develop understanding or reach a certain level of sophistication individually. The findings of this study presented not the individual situation of the students but represented the groups as a unit. Limited information was known about the participants' social and cultural experiences in informal contexts and how these could have influenced their answers to the questions or intellectual level.

5.3. Suggestions for Further Research

There is a need for continued research to further understand students' mental models at each grade level. This study can be expanded by collecting data from the grade levels other than the ones selected for this study. The data collection procedure of this study could be extended and questions on climate change could be raised. New protocols can be developed and tested with students from middle school or teachers. Conducting similar studies may be beneficial to understand more about the student conceptions of the greenhouse effect. For example, the vast majority of the G11 group falsely depicted the gas composition in the atmosphere like a wall. The particulate nature of gases and molecular dynamics were not represented by these participants in any way. Only a macroscopic-level introduction of the gases was made. In order to elaborate on such alternative conceptions, the questions may be reviewed. In addition, how to teach the greenhouse effect without giving rise to alternative concepts can be a research topic. Further considerations follows, such as 'How to teach students the greenhouse effect at the particle level' or 'How far can teachers go in teaching how to make connections between GHE, radiation and gas molecules'.

A significant majority of the high school student participants in this study did not point out their science classes as being beneficial in gaining them the fundamental instruction of the greenhouse effect. Some mentioned that they have learned the greenhouse effect from social media, news, TV programs or books. “In what ways do students’ environmental knowledge during the course of secondary education could be improved?” can be a research interest as well.

Moreover, since most of the pre-service teacher participants in this study had taken environmental electives in their departmental programs, it is possible to research the environmental knowledge of teacher candidates from different universities. Selecting pre-service teachers from more than one university enrolling students of different achievement levels could have provided a more pervasive depiction of the greenhouse effect on the learning progression. Also, pre-service teachers’ learning progression can be examined as they progress through more advanced stages of their careers. Further research on the relationship between students’ daily habits, behaviors, preferences, and the closeness of their mental models to scientific models can be conducted. Lastly, since this study does not provide cause and effect relationships, further studies may search for causal connections between the student knowledge level and mental models.

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APPENDIX A: PERMISSION LETTERS

In this section, the permission letter received from Istanbul Provincial Directorate of National Education and Institutional Review Board, Research with Science and Engineering Fields Human Research Ethics Committee (FMINAREK) were presented.

Evrak Tarih ve Sayısı: 05.11.2021-37259

T.C.
BOĞAZİÇİ ÜNİVERSİTESİ REKTÖRLÜĞÜ
Fen Bilimleri ve Mühendislik Alanları İnsan Araştırmaları Etik Kurulu
(FMİNAREK)

Sayı : E-84391427-050.01.04-37259 05.11.2021
Konu : 2021/21 Kayıt no'lu başvurunuz hakkında

Sayın Prof. Dr. Emine ADADAN
Matematik ve Fen Bilimleri Eğitimi Bölüm Başkanlığı - Öğretim Üyesi

"Lise Öğrencileri ve Öğretmen Adaylarının Sera Etkisine İlişkin Zihinsel Modellerinin İncelenmesi (Students' understanding of the greenhouse effect: A cross-age study)" başlıklı projeniz ile Boğaziçi Üniversitesi Fen Bilimleri ve Mühendislik Alanları İnsan Araştırmaları Etik Kurulu (FMİNAREK)'e yaptığınız 2021/21 kayıt numaralı başvuru 01.11.2021 tarihli ve 2021/09 No.lu kurul toplantısında incelenerek etik onay verilmesi uygun bulunmuştur.

Bu karar tüm üyelerin toplantıya on-line olarak katılımıyla ve oybirliği ile alınmıştır. COVID-19 önlemleri nedeniyle üyelerden ıslak imza alınamadığından bu onam mektubu tüm üyeler adına Komisyon Başkanı tarafından e-imzalanmıştır.

Saygılarımızla bilginize sunarız.

Prof. Dr. Tınaz EKİM AŞICI
Başkan

Bu belge, güvenli elektronik İmza ile imzalanmıştır.

Doğrulama Kodu :BSV3AEKTF3 Pin Kodu :69762 Belge Takip Adresi : https://turkiye.gov.tr/ebd?eK=4787&eD=BSV3AEKTF3&eS=37259
34342 Bebek-İstanbul
Telefon No:0212 287 17 53 Faks No:0212 265 70 06
İnternet Adresi:www.boun.edu.tr
Kep Adresi:bogaziciuniversitesi@hs01.kep.tr
Bilgi için: Nurşen MUNAR
Unvan: Mühendis

Bu belge, güvenli elektronik imza ile imzalanmıştır.

Figure A. 1. Permission letter received from the Research with Science and Engineering Fields Human Research Ethics Committee (FMINAREK).

T.C.
İSTANBUL VALİLİĞİ
İl Millî Eğitim Müdürlüğü

GÜNLÜDÜR

Sayı : E-59090411-44-48025224 19.04.2022
Konu : Anket ve Araştırma İzni (Ceren ÖZÇELİK)

BOĞAZİÇİ ÜNİVERSİTESİ REKTÖRLÜĞÜNE
(Yazı İşleri Şube Müdürlüğü)

İlgi : a) Yenilik ve Eğitim Teknolojileri Genel Müdürlüğünün 21.02.2020 tarihli ve 2020/2 sayılı genelgesi.
b) Valilik Makamının 18.04.2022 tarihli ve 47965263 sayılı oluru.

Valilik Makamının Anket ve Araştırma İzni konulu ilgi (b) oluru ve kullanılması uygun görülen ölçme araçlarının Müdürlüğümüzce mühürlenen örnekleri ekte gönderilmiştir.

İlgi (a) genelgenin 28. maddesinde; "Araştırma uygulama izni alan kamu kurum ve kuruluşları, uluslararası kuruluşlar, üniversiteler, sivil toplum kuruluşları ve araştırmacılar tamamladıkları bilimsel araştırma ile ilgili sonuç raporlarını, izni aldıkları ilgili birime çalışma bitiminden itibaren 30 gün içerisinde göndereceklerdir." ifadesi yer almaktadır.

Olur gereğince işlem yapılması ve araştırma sonuç raporunun ekte sunulan örneğe göre Müdürlüğümüz Strateji Geliştirme Şubesine gönderilmesi hususlarında gereğini arz ederim.

Abdurrahman ENSARİ
İl Millî Eğitim Müdürü a.
Şube Müdürü

Ek:
1- Valilik Oluru (1 Sayfa)
2- Rapor Örneği
3- Ölçekler

Bu belge güvenli elektronik imza ile imzalanmıştır.

Adres : Binbirdirek Mah. İmran Öktem Cad. No: 1 Sultanahmet Fatih İstanbul
Telefon : 0212 384 36 30
E-posta : stratejigelistirme34@meb.gov.tr
Kep Adresi : meb@hs01.kep.tr

Belge Doğrulama : https://www.turkiye.gov.tr/meb-ebys
Bilgi İçin : Aykut ÇELİK
Unvanı : Büro Hizmetleri
İnternet Adresi : http://istanbul.meb.gov.tr/

Figure A. 2. Permission letter received from Istanbul Provincial Directorate of National Education.

T.C.
İSTANBUL VALİLİĞİ
İl Milli Eğitim Müdürlüğü

Sayı : E-59090411-20-47965263 18/04/2022
Konu : Anket ve Araştırma İzni (Ceren ÖZÇELİK)

VALİLİK MAKAMINA

İlgi : a) Yenilik ve Eğitim Teknolojileri Genel Müdürlüğünün 21.01.2020 tarihli ve 2020/2 sayılı genelgesi.
b) Boğaziçi Üniversitesinin 25.03.2022 tarihli ve 59337 sayılı yazısı.
c) Müdürlüğümüz Araştırma ve Anket Komisyonunun 15.04.2022 tarihli tutanağı.

Araştırma Konusu	: Lise Öğrencileri ve Öğretmen Adaylarının Sera Etkisine İlişkin Zihinsel Modellerinin İncelenmesi
Araştırma Türü	: Anket
Araştırma Yeri	: E
Araştırma Yapılacak Kişiler	: Lise Öğrencileri
Araştırmanın Süresi	: 2021 - 2022 Eğitim ve Öğretim Yılı

Yukarıda bilgileri verilen araştırmanın; 6698 sayılı Kişisel Verilerin Korunması Kanununa aykırı olarak kişisel veri istenmemesi, öğrenci velilerinden açık rıza onayı alınması, yüz yüze eğitime geçmiş olan kurumlarımızda, Covid-19 tedbirlerinin araştırmacı ve ilgili kurum idarelerince alınması, bilimsel amaç dışında kullanılmaması, bir örneği Müdürlüğümüzde muhafaza edilen mühürlü ve imzalı veri toplama araçlarının kurumlarımıza araştırmacı tarafından ulaştırılarak uygulanması, katılımcıların gönüllülük esasına göre seçilmesi, araştırma sonuç raporunun kamuoyuyla paylaşılmaması ve araştırma bittikten sonra 2 (iki) hafta içerisinde Müdürlüğümüze gönderilmesi, okul idarelerinin denetim, gözetim ve sorumluluğunda, eğitim ve öğretimi aksatmayacak şekilde, ilgi (a) genelge esasları dâhilinde uygulanması kaydıyla Müdürlüğümüzce uygun görülmektedir.

Makamınızca da uygun görüldüğü takdirde olurlarınıza arz ederim.

Levent YAZICI
İl Milli Eğitim Müdürü

OLUR
18/04/2022
Dr. Hasan Hüseyin CAN
Vali a.
Vali Yardımcısı

Ek:
1- İlgi (b) Yazı ve Ekleri (5 Sayfa)
2- İlgi (c) Tutanak (1 Sayfa)

Bu belge güvenli elektronik imza ile imzalanmıştır.

Adres : Binbirdirek Mah. İmran Öktem Cad. No: 1 Sultanahmet Fatih İstanbul
Telefon : 0212 384 36 30
E-posta : stratejigelistirme34@meb.gov.tr
Kep Adresi : meb@hs01.kep.tr

Belge Doğrulama : https://www.turkiye.gov.tr/meb-ebys
Bilgi İçin : Aykut ÇELİK
Unvanı : Büro Hizmetleri
İnternet Adresi : http://istanbul.meb.gov.tr/

1b24-6f99-3ae4-a42d-e0b2

Figure A. 2. Permission letter received from Istanbul Provincial Directorate of National Education – Continued

APPENDIX B: CONSENT FORMS

EK 3: Lise Öğrencisi Katılımcılar İçin Bilgi ve Onam Formu

KATILIMCI BİLGİ ve ONAM FORMU

Araştırmanın adı:

Students' understanding of the greenhouse effect: A cross-age study

(Farklı yaş gruplarından öğrencilerin sera etkisine yönelik zihinsel modellerinin incelenmesi)

Proje yürütücüsü: Prof. Dr. Emine Adadan

Adres: Boğaziçi Üniversitesi, Eğitim Fakültesi, Matematik ve Fen Bilimleri Eğitimi Bölümü, Bebek, İstanbul, 34342

Telefon: +90-212-3597371

E-posta: emine.adadan@boun.edu.tr, ceren.ozcelik@boun.edu.tr

Sayın Veli,

Bu araştırma çalışması Boğaziçi Üniversitesi, Eğitim Fakültesi, Matematik ve Fen Bilimleri Eğitimi bölümünden Prof. Dr. Emine Adadan yürütücülüğünde yine aynı bölümde yüksek lisans öğrencisi olan Ceren Özçelik ile birlikte yürütülmektedir. Aşağıda yer alan, araştırma ile ilgili bilgileri okuduktan sonra velisi olduğunuz öğrencinin araştırmaya katılmasını uygun görürseniz lütfen bu formu imzalayıp kapalı bir zarf içinde bize ulaştırınız.

Bu çalışma bilimsel bir amaçla gerçekleştirilecektir. Çalışmanın amacı; farklı yaş gruplarındaki öğrencilerin sera etkisi ile ilgili zihinsel modellerini değerlendirmektir. Velisi olduğunuz öğrencinin araştırmaya katılmasını kabul ettiğiniz takdirde, sera etkisinin nasıl meydana geldiği ile ilgili düşüncelerini anlamak amacıyla öğrenciyle bireysel bir görüşme yapılacaktır. Katılımcı öğrenciden, bu görüşme sırasında sorulacak sorulara olabildiğince detaylı açıklamalar getirmesi beklenmektedir. Bireysel görüşme süresince, onay verdiğiniz takdirde, ses kaydı alınacaktır. Bireysel görüşmenin ortalama 30 dakika sürmesi beklenmektedir.

Bu çalışmanın katılımcıya herhangi bir risk getirmesi öngörülmemektedir. Öğrencinin bu çalışmaya gönüllü katılımıyla vereceği cevaplar sadece araştırmacılar tarafından değerlendirilecek olup, almakta olduğu derslere ilişkin notlarını hiçbir şekilde etkilemeyecektir. Sizden ücret talep edilmeyecek ve tarafınıza herhangi bir ödeme yapılmayacaktır. Ayrıca, katılımcının kişisel bilgileri (isim vb.) hiçbir şekilde üçüncü kişi veya kurumlar ile paylaşılmayacak ve bilimsel yayınlarda kullanılmayacaktır. Her katılımcı için bir rumuz kullanılacaktır.

İzin vermeniz durumunda, öğrencinin önceki yıllara ait ortaokul Fen Bilimleri veya lise Fizik ve Kimya derslerine ilişkin not ortalamalarına okul sisteminden erişim sağlanacaktır.

Çalışmaya ilişkin başka sorularınız olursa Prof. Dr. Emine Adadan'a ve Ceren Özçelik'e e-mail veya telefon yolu ile ulaşabilirsiniz. Proje ile ilgili olası şikayetlerinizi Boğaziçi Üniversitesi Etik Kurulu'na ait fminarek@boun.edu.tr e-mail adresine iletebilirsiniz.

Figure B. 1. Consent form for high school student participants.

Ben, (velinin adı) .... yukarıdaki metni okudum ve velisi olduğum (katılımcının adı) .... 'ın katılması istenen çalışmanın kapsamını ve amacını, gönüllü olarak üzerine düşen sorumlulukları tümüyle anladım. Velisi olduğum katılımcının çalışmayı istediği zaman ve herhangi bir neden belirtmek zorunda kalmadan bırakabileceğini ve bıraktığı takdirde herhangi bir olumsuzluk ile karşılaşmayacağını biliyorum.

Bu koşullarda söz konusu araştırmaya kendi isteğimle, hiçbir baskı ve zorlama olmaksızın velisi olduğum öğrencinin katılmasını kabul ediyorum. Bu formun bir kopyasını aldım.

Velisi olduğum öğrencinin bu çalışmaya katılmasını onaylıyorum.	
☐ **EVET**	☐ **HAYIR**

Araştırma için yapılacak bireysel görüşmeler sırasında ses kaydı alınmasını onaylıyorum.	
☐ **EVET**	☐ **HAYIR**

Katılımcı Adı-Soyadı:	İmzası:	Tarih:
....	....	....../..../.........
Katılımcının Velisinin Adı-Soyadı:	İmzası:	Tarih:
....	....	....../..../.........
Araştırmacı Adı-Soyadı:	İmzası:	Tarih:
Prof. Dr. Emine Adadan	....	....../..../.........
Yüksek Lisans öğrencisi	İmzası:	Tarih:
Ceren Özçelik	....	....../..../.........

Figure B. 1. Consent form for high school student participants (cont.).

KATILIMCI BİLGİ ve ONAM FORMU

Araştırmanın adı:
Students' understanding of the greenhouse effect: A cross-age study
(Farklı yaş gruplarından öğrencilerin sera etkisine yönelik zihinsel modellerinin incelenmesi)
Proje yürütücüsü: Prof. Dr. Emine Adadan
Adres: Boğaziçi Üniversitesi, Eğitim Fakültesi, Matematik ve Fen Bilimleri Eğitimi Bölümü, Bebek, İstanbul, 34342
Telefon: +90-212-3597371
E-posta: emine.adadan@boun.edu.tr, ceren.ozcelik@boun.edu.tr

Sayın Öğretmen Adayı,

Bu araştırma çalışması Boğaziçi Üniversitesi, Eğitim Fakültesi, Matematik ve Fen Bilimleri Eğitimi bölümünden Prof. Dr. Emine Adadan yürütücülüğünde yine aynı bölümde yüksek lisans öğrencisi olan Ceren Özçelik ile birlikte yürütülmektedir. Aşağıda yer alan, araştırma ile ilgili bilgileri okuduktan sonra araştırmaya katılmayı uygun görürseniz lütfen bu formu imzalayıp bize teslim ediniz.

Bu çalışma bilimsel bir amaçla gerçekleştirilecektir. Çalışmanın amacı; farklı yaş gruplarındaki öğrencilerin sera etkisi ile ilgili zihinsel modellerini değerlendirmektir. Araştırmaya katılmayı kabul ettiğiniz takdirde, sera etkisinin nasıl meydana geldiği ile ilgili düşüncelerinizi anlamak amacıyla sizinle bireysel bir görüşme yapılacaktır. Katılımcılardan bu görüşme sırasında sorulacak sorulara olabildiğince detaylı açıklamalar getirmesi beklenmektedir. Bireysel görüşme süresince, onay verdiğiniz takdirde, ses kaydı alınacaktır. Bireysel görüşmenin ortalama 30 dakika sürmesi beklenmektedir.

Bu çalışmanın katılımcıya herhangi bir risk getirmesi öngörülmemektedir. Bu çalışmaya gönüllü katılımınız ile vereceğiniz cevaplar sadece araştırmacılar tarafından değerlendirilecek olup, almakta olduğunuz derslere ilişkin notlarınızı hiçbir şekilde etkilemeyecektir. Sizden ücret talep edilmeyecek ve tarafınıza herhangi bir ödeme yapılmayacaktır. Ayrıca, kişisel bilgileriniz (isim vb.) hiçbir şekilde üçüncü kişi veya kurumlar ile paylaşılmayacak ve bilimsel yayınlarda kullanılmayacaktır. Her katılımcı için bir rumuz kullanılacaktır.

İzin vermeniz durumunda, önceden almış olduğunuz Fizik ve Kimya derslerine ilişkin not ortalamalarınıza erişim sağlanabilmesi için transkriptlerinizi araştırmacılar ile paylaşmanız beklenecektir.

Figure B. 2. Consent form for pre-service teacher participants.

Çalışmaya ilişkin başka sorularınız olursa Prof. Dr. Emine Adadan'a ve Ceren Özçelik'e e-mail veya telefon yolu ile ulaşabilirsiniz. Proje ile ilgili olası şikayetlerinizi Boğaziçi Üniversitesi Etik Kurulu'na ait fminarek@boun.edu.tr e-mail adresine iletebilirsiniz.

Ben, (katılımcının adı) .... yukarıdaki metni okudum ve katılmam istenen çalışmanın kapsamını ve amacını, gönüllü olarak üzerime düşen sorumlulukları tümüyle anladım. Bu çalışmayı istediğim zaman ve herhangi bir neden belirtmek zorunda kalmadan bırakabileceğimi ve bıraktığım takdirde herhangi bir olumsuzluk ile karşılaşmayacağımı biliyorum.

Bu koşullarda söz konusu araştırmaya kendi isteğimle, hiçbir baskı ve zorlama olmaksızın katılmayı kabul ediyorum. Bu formun bir kopyasını aldım.

Bu çalışmaya katılmayı onaylıyorum.	
☐ **EVET**	☐ **HAYIR**

Araştırma için yapılacak bireysel görüşmeler sırasında ses kaydı alınmasını onaylıyorum.	
☐ **EVET**	☐ **HAYIR**

Katılımcı Adı-Soyadı:	İmzası:	Tarih:
....	....	...../..../.........
Araştırmacı Adı-Soyadı:	İmzası:	Tarih:
Prof. Dr. Emine Adadan	....	...../..../.........
Yüksek Lisans öğrencisi	İmzası:	Tarih:
Ceren Özçelik	....	...../..../.........

Figure B. 2. Consent form for pre-service teacher participants (cont.).

APPENDIX C: DEMOGRAPHIC FORMS

EK 2: Lise Öğrencisi Katılımcılar için Demografik Form

Demografik Form

Ad Soyad: ____

Cinsiyet: Erkek ☐ Kadın ☐

Doğum Yılı: ______________________

Okul: ____

Sınıf: _________________________

Genel Not Ortalaması: __________________

- **Ortaokul 8.sınıfta Fen Bilgisi dersinden aldığınız notlarınızı birinci ve ikinci dönem olmak üzere aşağıda verilen tabloya yazınız.**

Sınıf Seviyesi	Birinci Dönem	İkinci Dönem
8. Sınıf		

- **Kimya dersi notlarınızı dokuzuncu sınıftan itibaren birinci ve ikinci dönem olmak üzere aşağıda verilen tabloya yazınız.**

Sınıf Seviyesi	Birinci Dönem	İkinci Dönem
9. Sınıf		
10. Sınıf		
11. Sınıf		

- **Fizik dersi notlarınızı dokuzuncu sınıftan itibaren birinci ve ikinci dönem olmak üzere aşağıda verilen tabloya yazınız.**

Sınıf Seviyesi	Birinci Dönem	İkinci Dönem
9. Sınıf		
10. Sınıf		
11. Sınıf		

Figure C. 1. Demographic form for high school student participants.

EK 3: Öğretmen Adayı Katılımcılar için Demografik Form

Demografik Form

Ad Soyad: ____

Cinsiyet: Erkek ☐ Kadın ☐

Doğum Yılı: ________________________

Okul: ____

Sınıf: ___________________________

Bölüm: ____

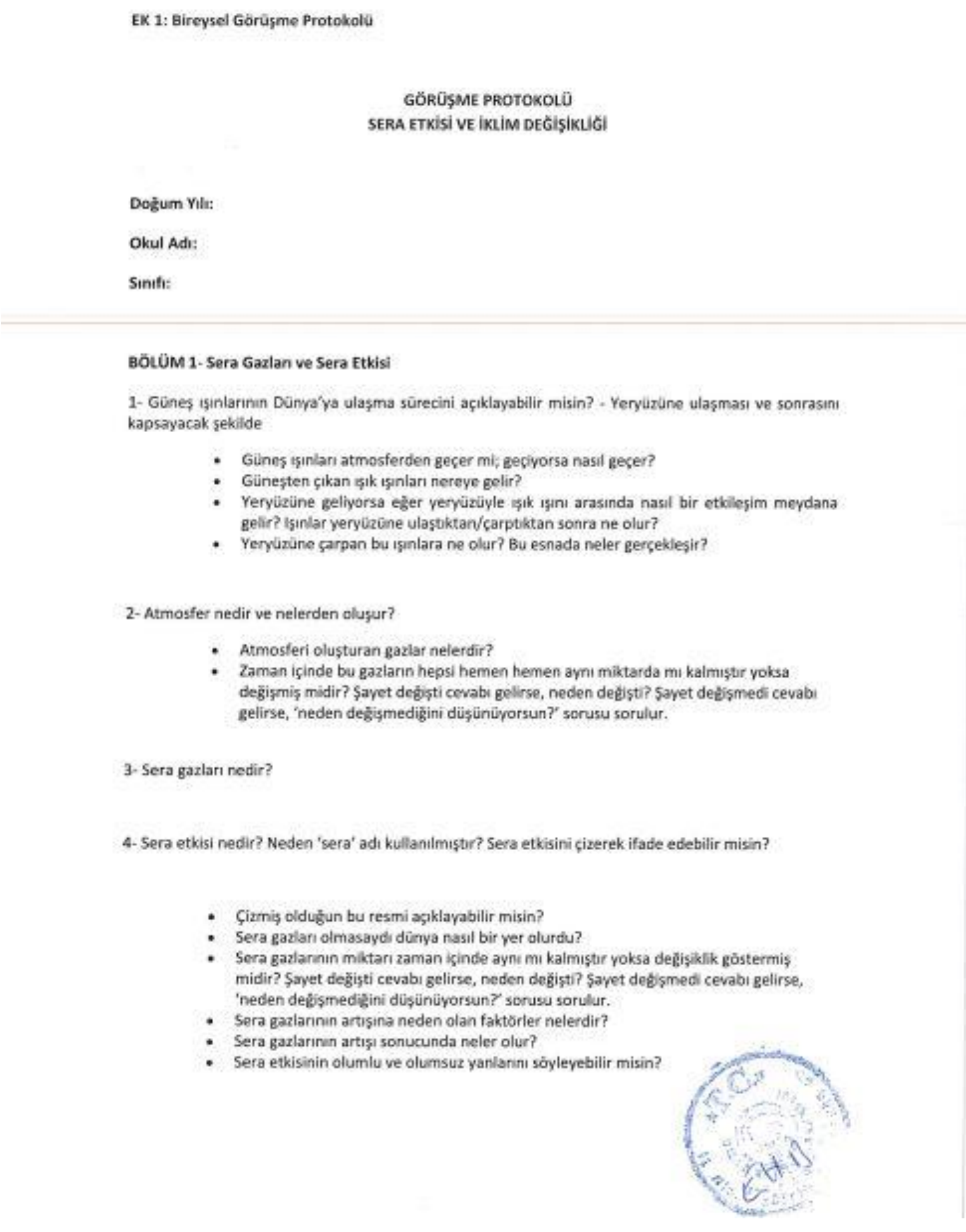
Genel Not Ortalaması: ___________________

Birinci sınıftan itibaren aldığınız Fizik ve Kimya dersi harf notlarınızı ve dersi aldığınız yılı aşağıda verilen tabloya yazınız.

Ders Kodu	Ders Adı	Harf Notu	Yıl

Figure C. 2. Demographic form for university student participants.

APPENDIX D: INTERVIEW PROTOCOL



EK 1: Bireysel Görüşme Protokolü

GÖRÜŞME PROTOKOLÜ
SERA ETKİSİ VE İKLİM DEĞİŞİKLİĞİ

Doğum Yılı:

Okul Adı:

Sınıfı:

BÖLÜM 1- Sera Gazları ve Sera Etkisi

1- Güneş ışınlarının Dünya'ya ulaşma sürecini açıklayabilir misin? - Yeryüzüne ulaşması ve sonrasını kapsayacak şekilde

- Güneş ışınları atmosferden geçer mi; geçiyorsa nasıl geçer?
- Güneşten çıkan ışık ışınları nereye gelir?
- Yeryüzüne geliyorsa eğer yeryüzüyle ışık ışını arasında nasıl bir etkileşim meydana gelir? Işınlar yeryüzüne ulaştıktan/çarptıktan sonra ne olur?
- Yeryüzüne çarpan bu ışınlara ne olur? Bu esnada neler gerçekleşir?

2- Atmosfer nedir ve nelerden oluşur?

- Atmosferi oluşturan gazlar nelerdir?
- Zaman içinde bu gazların hepsi hemen hemen aynı miktarda mı kalmıştır yoksa değişmiş midir? Şayet değişti cevabı gelirse, neden değişti? Şayet değişmedi cevabı gelirse, 'neden değişmediğini düşünüyorsun?' sorusu sorulur.

3- Sera gazları nedir?

4- Sera etkisi nedir? Neden 'sera' adı kullanılmıştır? Sera etkisini çizerek ifade edebilir misin?

- Çizmiş olduğun bu resmi açıklayabilir misin?
- Sera gazları olmasaydı dünya nasıl bir yer olurdu?
- Sera gazlarının miktarı zaman içinde aynı mı kalmıştır yoksa değişiklik göstermiş midir? Şayet değişti cevabı gelirse, neden değişti? Şayet değişmedi cevabı gelirse, 'neden değişmediğini düşünüyorsun?' sorusu sorulur.
- Sera gazlarının artışına neden olan faktörler nelerdir?
- Sera gazlarının artışı sonucunda neler olur?
- Sera etkisinin olumlu ve olumsuz yanlarını söyleyebilir misin?

Figure D. 1. Interview protocol.

BÖLÜM 2- İklim Değişikliği

1. İklim değişikliği nedir? / İklim değişikliği hakkında neler biliyorsun? Bu bilgileri nereden edindin?
    - İklim değişikliğine yol açan en önemli nedenler nelerdir?
    - İklim değişikliğinden sorumlu başlıca gazlar nelerdir? (Cevap gelmediği durumda 'bu gazlardan hangileri iklim değişikliğinden başlıca sorumlu üç gazı temsil eder? Oksijen, karbondioksit, metan, su buharı, kloroflorokarbonlar, ozon.)
    - Güneş ışığı, enerjileri farklı dalga boylarındaki ışınım türlerinden oluşur. İklim değişikliğinden sorumlu olan güneş ışınım/(lar)ı ne/(ler)dir?

2. Bireyler/toplumlar/devletler iklim değişikliğinden ne derece sorumludur?

3. İklim değişikliği nasıl önlenebilir?

- Bireysel olarak yapabileceklerimiz nelerdir?
  - İklim değişikliği konusunda günlük hayatımızda ne gibi pratiklere yer verebiliriz?
- Toplumun yapması gerekenler nelerdir?
- Ülkenin yapması gerekenler nelerdir?

Figure D. 1. Interview protocol (cont.).