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Meta-Synthesis Study on Socioscientific Issues in Science Education

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Abstract

The aim of this study is to examine the importance of socioscientific issues in science education at the graduate level. For this purpose, the data obtained as a result of the searches on the National Thesis Centre (YOKTEZ) database were analysed. The literature review was conducted with the keywords 'socioscientific', 'socioscientific issues' and 'socioscientific issues. In line with the inclusion criteria, 58 postgraduate studies (48 master's theses and 10 doctoral theses) were found. Although these three different keywords were searched by the researcher, it was noticed that there were common postgraduate thesis authors. The theses of these authors were included in the study only once. Following this situation, postgraduate theses whose field of study was not science education (science education, biology education, chemistry education, physics education) were not included in the study. After the inclusion and exclusion criteria, a total of 58 studies were reached. As a result of the examination in this field, a total of 48 master's and 10 doctoral theses were reached. Content analysis method was used in this meta-synthesis study which analysed the theses published in YOKTEZ database on socioscientific issues in science education. As a result of the analyses, a general framework was drawn about the theses published on socioscientific issues in Turkey and the findings were interpreted. At the end of the study, it is recommended that future SSI research contribute to the holistic development of the field by diversifying study groups and topic contexts, adopting longitudinal and in-depth methodological approaches, and focusing on effective pedagogical strategies and teachers' professional development.

INTRODUCTION

Science has affected and continues to affect society from the past to the present (Topçu, 2017). As scientific advancements began to rapidly impact social life, they gave rise to dilemmas, disagreements, and a desire among people to defend their own thoughts while rejecting others. For example, the recent pandemic (Covid-19) that affected the entire world led people to debate the issue of vaccines, experience disagreements, and sometimes fanatically defend the ideas they believed to be correct. With the increase in scientific research in this area, socioscientific issues (SSI) have taken their place on the agenda, partly due to media influence. Another example is villagers protesting against the felling of trees to shorten roads, or local people trying to prevent the construction of hydroelectric power plants due to concerns about ecological damage. Many such events are presented to the public through the media, which naturally leads everyone to view the situation from their own perspective, and these topics become the focus of debates (Aydın & Mocan, 2019). The media provides the easiest way for more people to learn about socioscientific issues and for people to mobilize collectively (Topçu, 2017). While a limited number of media channels, such as radio, newspapers, and magazines, might present biased news from a narrow perspective; today, news is reported from multiple perspectives and approached from various angles. With the proliferation of social media tools, even minority opinions can make their voices heard by the public (Kılıç, 2023). All these and similar events exemplify the reflections of science on society. Such examples are identified in the literature as socioscientific issues. According to Topçu (2008), socioscientific issues are topics related to problems people encounter in their daily lives, which they defend by presenting evidence. Socioscientific issues are intentionally designed to enable students to communicate with each other, engage in discussions, and develop arguments (Zeidler & Nichols, 2009). According to Topçu (2008), this engagement is necessary for students to become scientifically literate individuals.

Evren and Kaptan (2014) stated that teachers or prospective teachers aiming to cultivate scientifically literate individuals need to answer five questions to determine whether any encountered topic is a socioscientific issue. These are:

- Is the topic under examination scientific?
- Does the topic under examination create a dilemma in the mind?
- Does the topic under examination involve science-society-technology interactions?
- Is the topic under examination open-ended and does it accommodate more than one correct answer/perspective?
- Can the answers given within the scope of the topic vary depending on ethical, moral, or emotional values?

Socioscientific issues focus on listening to students' claims, developing arguments related to these claims (Zeidler et al., 2009), and acquiring skills on controversial topics. A correct understanding of socioscientific issues is important for individuals to acquire discussion skills and make sound decisions (Handan Hacıoğlu, 2022). In this context, Sadler and Zeidler (2005), similar to Evren and Kaptan (2014), divided the characteristics of SSI into five points. These are:

- SSI are open to discussion and bring together different perspectives.
- They lead to dilemmas within society.
- They are problematic and await understanding.
- They cannot be easily resolved.
- They generally involve ethical and moral issues.

When the five points above are examined, it is seen that there is no difference among field researchers regarding the fact that socioscientific issues are directly related to the problems we encounter in our daily lives and the characteristics they entail.

The role of socioscientific issues has been a significant driving force in promoting scientific literacy in the science education community over the last two decades (Zeidler et al., 2019). The National Science Education Standards (NSES), put forth by the NRC (1996), aimed to create a scientifically literate society. These standards were addressed under six main headings: Science Teaching, Professional Development, Assessment in Science, Science Content, Science Education Programs, and Standards for Science Education Systems. The standards generally propose an educational approach where students develop scientific thinking and reasoning skills, take an active role in their learning processes, and learn through experience. While teachers play a guiding and decision-making role in this process, it is emphasized that educational programs should be supportive of learning and encourage success (Kardas, 2024).

Every day, the number of closely related issues at the intersection of science and social life (e.g., artificial intelligence, pandemic vaccines, euthanasia, nuclear power plants) is increasing (Kardas, 2024). Therefore, such issues need to be evaluated based on science and research (Topcu, 2017).

When the literature is reviewed, it is observed that studies related to socioscientific issues generally aim to measure skills such as argumentation, decision-making, higher-order reasoning, and scientific literacy. This situation is closely related to the nature of socioscientific issues. Studies show that socioscientific issues enhance students' skills such as higher-order reasoning (Kolstø, 2001), argumentation (Ozturna & Atasoy, 2024; Topcu & Atabey, 2017), and scientific literacy (Lomas & Ritchie, 2014; Yapıcıoglu & Kaptan, 2017).

The Purpose of Study

Since the study deals with postgraduate theses on socioscientific issues within the scope of science education, it plays a critical role in accessing accumulated knowledge in this field and guiding future studies. Therefore, the study is important in terms of its contribution to the literature. In light of all this information, the aim of this study is to conduct a meta-synthesis by examining postgraduate theses published in the YÖK National Thesis Center (YÖKTEZ) database on socioscientific issues in science education within the context of the formulated research questions. In line with this aim, the study sought to answer seven questions within the scope of the main problem: "What is the distribution of postgraduate theses written on SSI in Science Education in the context of the determined research questions?" The research questions of the study are as follows:

1. Which research designs were used in published theses on socioscientific issues in science education?
2. What is the distribution by year of published theses on socioscientific issues in science education?
3. What are the aims of published theses on socioscientific issues in science education?
4. On which study groups were studies conducted in published theses on socioscientific issues in science education?
5. In which science subject areas were studies conducted in published theses related to socioscientific issues in science education?
6. Which data collection tools were utilized in published theses on socioscientific issues in science education?
7. What were the research durations in published theses on socioscientific issues in science education?

Limitations

This study:

- Is limited to postgraduate theses published between 2020 and 2024.
- Is limited to postgraduate theses published in the YÖKTEZ database.
- Is limited to postgraduate theses published within the Science Education subject area.

METHOD

Study Design

In this study, a meta-synthesis, which is one of the qualitative research methods, was conducted to synthesize research written with qualitative, quantitative, and mixed research designs on socioscientific issues within the scope of science education, sourced from the YÖK TEZ database. Meta-synthesis is the re-combination, evaluation, comparison, and interpretation of similar studies conducted on a topic, phenomenon, or theme identified by researchers, "under specific criteria" (Dincer, 2018). While quantitative data can be included in a meta-synthesis, meta-synthesis does not aim to reach a definitive conclusion; it aims to reveal what exists (Dincer, 2018).

Data Collection

In this study, data were obtained from the YOKTEZ database. First, a preliminary scan was conducted to access studies in the field of socioscientific issues. In the preliminary scan, searching with the keyword “sosyobilimsel konular” yielded 104 studies. Subsequently, searching with the keyword “sosyobilimsel” yielded 139 studies. Then, the English equivalent of this keyword, “socioscientific issues,” was searched, and 77 studies were found. Although these three different keywords were searched by the researcher, it was noticed that there were common postgraduate thesis authors. The theses of these authors were included in the study only once. Following this, postgraduate theses whose study area was not science education (Science teaching, biology education, chemistry education, physics education) were not included in the study. After applying the aforementioned inclusion and exclusion criteria, a total of 58 studies were identified. As a result of the review in this field, a total of 48 master's theses and 10 doctoral theses were identified.

Inclusion and Exclusion Criteria for the Study

The inclusion criteria for the master's and doctoral theses considered in this study are as follows:

- Theses written on Socioscientific Issues in Science Education being published in the YÖK National Thesis Center database.
- Theses being published in the YÖK National Thesis Center between 2020 and 2024.
- Theses being written in the subject areas of science teaching, physics education, chemistry education, and biology education.

Data Anaysis

Descriptive content analysis was used in this meta-synthesis study, which examined theses published in the YOKTEZ database on socioscientific issues in science education. Descriptive content analysis is a research method that aims to define the presence and frequency of elements by systematically coding a specific content, usually according to predetermined categories or themes (Berelson, 1952; Creswell & Poth, 2018; Krippendorff, 2018). The primary purpose of this method is to describe the directly observable and countable elements of the examined material (Neuendorf, 2017). In this context, descriptive content analysis relies on analyzing data by segmenting it into meaningful units, coding them, and then forming broader patterns or themes from these codes (Creswell & Poth, 2018). The codes and themes were also developed with input from a field expert who has studies in the area of socioscientific issues. The master's theses examined in this study were coded as MT1, MT2...MT48, and the doctoral theses as DT1...DT10, and are presented in Table 1. In study, a Microsoft Word file (Table 2) was created for the postgraduate theses based on their year of study, aims, methods, sample groups, data collection tools, research durations, and obtained results; these were then analyzed through the determination and application of codes and themes.

Table 1. Codes of study according to thesis type

Level of Postgraduate Thesis	Codes of the Study According to Postgraduate Thesis Type	f
Master's	MT1, MT2, ……MT48	48
Doctoral	DT1, DT2 ……DT10	10

Table 2. Form used as a data collection tool

Thesis Details
Thesis title: Type of Thesis: Year: Author: University: Department:
Topic: Methodology: Qualitative: .... Quantitative: .... Mixed: .... Sample: Student: .... Pre-service Teacher: .... Teacher: .... Parent: .... Sample Size :………………………………………………………………………………. Data Collection Tool(s):………………………………………………………………… Data Analysis Technique(s):
Conclusion(s): Recommendation(s):

Ethics, Validity, and Reliability

To ensure the validity and reliability of the study, during the process of generating codes and themes, tentative codes and potential themes were developed from the raw data obtained from a total of 58 postgraduate theses (10 doctoral, 48 master's), aligned with the research objectives. To assess the conceptual clarity, appropriateness, and comprehensiveness of this initially developed coding framework, expert opinion was sought from an academic with 11 years of experience in the field of socioscientific issues and qualitative research methods. Based on the expert's feedback, necessary revisions were made to the code list and theme definitions, thereby strengthening the content validity of the coding scheme (Creswell & Poth, 2018).

Furthermore, to ensure the reliability of the coding process and to minimize coder bias, an inter-coder reliability procedure was implemented. In this regard, following the initial coding by one of the researchers (the first coder), a randomly selected subset of the examined theses, representing approximately 20% of the total sample (12 theses), was recoded by a second, independent coder using the same coding scheme. The codings of the two coders were compared, points of disagreement were resolved through discussion, and consensus was reached. Inter-coder agreement was calculated using the formula proposed by Miles and Huberman (1994), [(Number of Agreements / (Number of Agreements + Number of Disagreements) x 100], and an agreement level of 86% was determined. A reliability percentage of 70 and above indicates that there is reliability between coders (Miles& Huberman,1994).

FINDINGS

This section presents and categorizes the tables and figures related to the data obtained to answer the research questions addressed in this study.

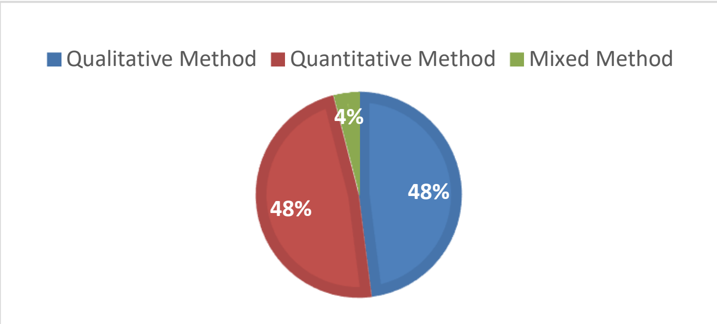

Figure 1. Methodological distributions of theses examined within the scope of the research

As seen in Figure 1, of the 58 studies obtained from the YÖK database, 48% were written using a mixed research design, 48% used a qualitative research design, and 4% used a quantitative research design. This indicates that qualitative and mixed methods are prominent in postgraduate theses. The higher prevalence of qualitative and mixed research designs may suggest that they were preferred due to the need for multi-dimensional data and in-depth analysis of the chosen topic.

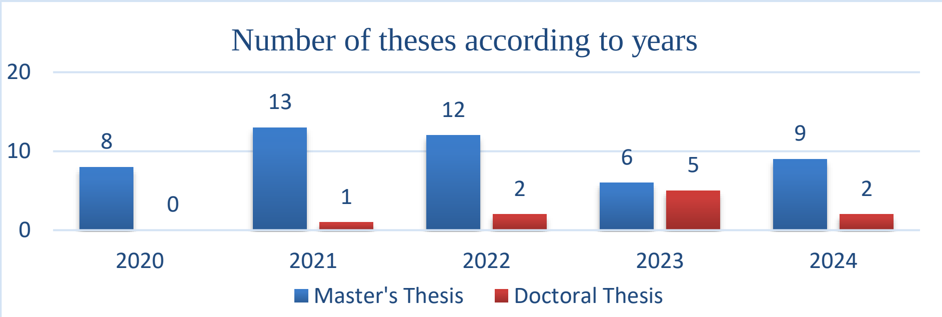

Figure 2. Distribution of theses examined within the scope of the research by year

This graph shows the number of master's and doctoral theses by year. Master's theses were written in greater numbers each year compared to doctoral theses. The trend, which began with 8 Master's (MT) theses in 2020, peaked in 2021 with 13 theses, then decreased to 12 in 2022 and 6 in 2023. In 2024, it rose again to 9.

These fluctuations may be influenced by factors such as an increase or decrease in the popularity of certain topics. The decrease in 2023 is particularly noteworthy.

Doctoral theses, on the other hand, gradually increased from 2021 onwards and peaked in 2023. In 2023, it is observed that the number of doctoral and master's theses was close to each other. This situation, while indicating a slowdown in master's theses, suggests that doctoral theses gained momentum in this subject context. While there were no doctoral theses in 2020, they made a slow start with 1 thesis in 2021 and 2 in 2022, showed a significant increase with 5 theses in 2023. In 2024, this number dropped to 2.

This increasing trend in the number of doctoral theses (especially until 2023) may indicate that the field of SSI (Socioscientific Issues) is beginning to be the subject of more in-depth and comprehensive academic research, and that the number of researchers specializing in the field has increased or has the potential to increase. The 5 doctoral theses in 2023 could be a positive sign in terms of the maturation of the field and the addressing of more sophisticated research questions. The decrease in 2024 can be interpreted as such fluctuations being normal on an annual basis due to the long duration of doctoral programs, or it may reflect a decrease in the number of theses completed that year.

Another point to note is that doctoral theses require a long preparation time. Despite there being no doctoral theses published in this subject context in 2020, the gradual increase in 2021, 2022, and 2023 indicates that studies at this level are slowly beginning to be completed.

Table 3. Distribution of theses examined within the scope of the research according to aims

Aim of Study	Study Codes	f
Argumentation	MT3, MT10, MT24, MT44, MT46, MT47, DT1, DT5, DT8, DT10	10
Decision-Making Skill	MT1, MT18, MT23, MT28, MT33, DT1, DT4, DT8, DT9	9
Attitude	MT3, MT8, MT17, MT19, MT34, MT42, MT48, DT9	8
Opinion	MT9, MT13, MT22, MT27, MT35, MT38, DT5, DT7	8
Judgment	MT10, MT14, MT23, MT25, MT31, MT32, MT37, MT45	8
Critical Thinking	MT1, MT29, DT4, DT9	4
Academic Achievement	MT1, MT47, DT8	3
Understanding of the Nature of Science (NOS)	MT36, MT44, DT5	3
Pedagogical Content Knowledge (PCK)	MT15, DT3	2
Communicative approach / discourse patterns	MT26, MT39	2
Problem-Solving Skill	MT29, MT36	2
Metacognition	MT41, DT1	2
Epistemological Beliefs	MT47, DT5	2
Reasoning	MT34, DT10	2
SSI (Socioscientific Issues) Awareness	DT4	1
Misconceptions	DT5	1
Scientific Process Skills	DT5	1
Relating to Daily Life	DT2	1
Entrepreneurial Skills	DT2	1
Gender	MT47	1
Content Knowledge	MT44	1
Teaching of SSI	MT43	1
Thinking Skills	MT38	1
Design Development and Evaluation (STEM)	MT40	1
Learning StMTes	MT41	1
Teaching Method Preferences	MT41	1
Impact on the Nature of Scientific Inquiry/Research	MT30	1
Critical Thinking Skills	MT36	1
Examination of Mental Structures	MT19	1
Examination of Textbooks	MT20	1
Scale Development	MT21	1
Effect on Discussion Tendencies	MT8	1
Science Learning Motivations	MT7	1
Moral Reasoning	MT8	1
Awareness Levels	MT11	1
Metaphorical Perception	MT12	1
Mental Modeling	MT12	1
Perception Levels	MT11	1
Effect on its Use as a Pedagogical Tool	MT2	1

Table 3 shows the aims addressed in the postgraduate theses and the frequency with which these aims appear in the studies. Since the postgraduate theses included in the study often had multiple aims, a single thesis could be coded under several aims. Among the examined studies, the research aim with the highest frequency is the examination and development of argumentation (f=10) skills. This finding is directly related to the nature of SSIs (Socioscientific Issues), which are inherently controversial, multidimensional, and involve diverse perspectives.

The development of evidence-based claims about SSIs by individuals, their evaluation of counter-arguments, and their effective participation in discussions are considered fundamental goals of education in this field. Following argumentation, decision-making skills (f=9), examination of attitude (f=8), opinion/view (f=8), and reasoning (f=8) abilities are also topics frequently addressed by researchers. This situation indicates that SSIs have not only cognitive but also affective and ethical dimensions, and that research tends to reflect this holistic structure. How individuals' attitudes towards SSIs and their opinions on these topics are shaped and changed, and how they interact with reasoning processes, are among the important research questions in the field. Decision-making skills (f=9) processes and skills can also be included in this dominant group, as interaction with SSIs ultimately directs individuals to take a stance and make decisions on a subject. Other frequently addressed topics include critical thinking (f=4), impact on academic achievement (f=3), decision-making skill (f=3), and especially understanding of the nature of science (NOS) (f=3). Addressing the understanding of the nature of science in conjunction with SSI studies emphasizes the critical importance of understanding the characteristics, validity, limitations, and societal context of the scientific knowledge that forms the basis of these issues. This frequency suggests that while the nature of science is accepted as an intertwined structure with SSIs, it is not as central a research focus as argumentation or attitude. Aims appearing at lower frequencies (f=1 or f=2), while demonstrating the breadth and diversity of the SSI field, also indicate that more research is needed in some areas. For example, pedagogical content knowledge (PCK) (f=2), despite being vitally important for teachers to effectively teach SSIs, has been relatively less studied. Similarly, structures such as metacognition (f=2), epistemological beliefs (f=2), and problem-solving skills (f=2), which profoundly affect an individual's learning and thinking processes, also deserve more attention.

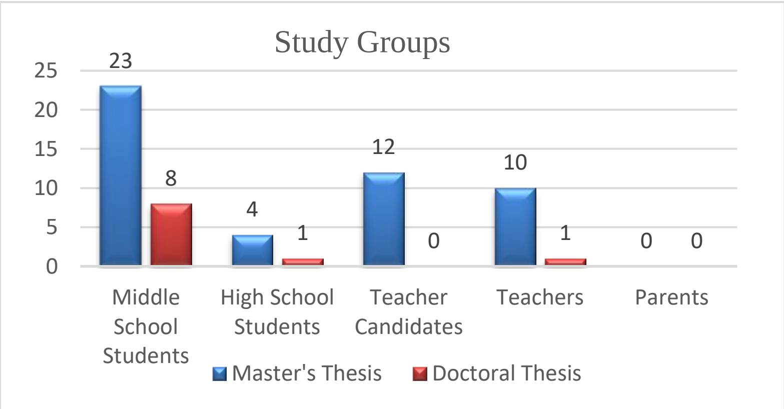

Figure 3. Distribution of theses examined within the scope of the research according to study groups

This figure compares the number of participants used in master's and doctoral theses according to study groups. Consequently, it is observed that studies were most frequently conducted with middle school students in both master's and doctoral theses. This can be explained by SSIs (Socioscientific Issues) generally being more prominent in science curricula for this age group, students being in a period where their abstract thinking skills are developing yet they are still receptive to guidance, and the relative ease of access to this age group. It is understood that there is an educational expectation and research interest towards fostering skills such as argumentation, critical thinking, and decision-making, which form the basis of SSIs, during this critical developmental period. Preservice teachers and teacher groups were also seen as important sample groups for master's theses. The graph shows that postgraduate thesis researchers generally prefer to work with middle school students and preservice teachers, who are easily accessible and observable groups in the educational environment. The fact that no studies were conducted with parents indicates the difficulty of accessing this group. Another noteworthy situation is that doctoral thesis authors have worked with less diverse groups. The lack of research on topics such as parents' perspectives on SSIs and how these issues are discussed or supported at home can be considered a significant deficiency in addressing SSI education with a holistic approach.

Table 4. Implementation durations of socioscientific issues in theses within the scope of the research

Duration of Implementation	**Code**	**f**
1 class hour (40 min)	MT6, MT7, MT11, MT13, MT16, MT19, MT24, MT31	8
10 weeks	MT1, MT40, DT3, DT4, DT5, DT6	6
8 weeks	MT5, MT23, MT29, MT38, MT44	5
6 weeks	MT2, MT17, MT30, DT9, DT10	5
5 weeks	MT8, MT39, DT1, DT2	4
2 terms	MT37, MT46, MT47	3
9 weeks	MT4, MT10	2
1 terms	MT48	2
24 weeks	DT7	1
15 weeks	MT14	1
12 weeks	DT8	1
7 weeks	MT18	1
3 weeks	MT12,	1
30-minute interview	MT15	1

When the table is examined, there are differences in terms of implementation durations. The most striking finding is that implementations lasting "1 lesson period (40 min)" have the highest frequency with 8 studies. This situation suggests that many studies in the SSI (Socioscientific Issues) field focus on measuring immediate states (e.g., opinions on a topic, argumentation level after a specific activity) through cross-sectional or short-term interventions within existing course curricula. Such studies may be advantageous in terms of practical applicability but may be insufficient for monitoring long-term changes or skill development.

Implementation durations of several weeks, such as "10 weeks" (f=6), "8 weeks" (f=5), and "6 weeks" (f=5), also hold a significant place. These durations may generally indicate research examining SSI integration throughout a unit or theme, more comprehensive interventions aimed at supporting the development of specific skills (e.g., argumentation, decision-making), and the effects of these interventions. These durations offer a more suitable time frame for students to process topics more deeply and reinforce their skills.

The low frequency (generally f=1 or f=3) of longer-term implementations such as "24 weeks," "15 weeks," and "2 semesters" is noteworthy. Although such longitudinal or long-term studies are ideal for observing lasting changes over time in attitudes, understanding, and skills related to SSIs, they might be less preferred due to challenges in their implementation (time, resources, participant tracking, etc.).

The table shows a wide range, from very short durations for specific data collection purposes, such as "30 min interview," to periods covering an academic year, such as "2 semesters." This diversity demonstrates that SSI research can serve various purposes (e.g., obtaining immediate

opinions, skill development, tracking attitude changes) and accommodate different methodologies (e.g., experimental, case study, action research).
Consequently, the inclusion of longer-term studies (e.g., DT7 - 24 weeks, DT8 - 12 weeks) in doctoral theses is consistent with the fact that doctoral research allows for more in-depth and extended investigations.

Table 5. Distribution of socioscientific issues covered in theses examined within the scope of the research

Socioscientific Issues	Code	f
Genetically Modified Organisms (GMOs)	MT4, MT8, MT10, MT12, MT13, MT17, MT19, MT24, MT31, MT38, MT39, MT42, MT44, DT1	14
Global Warming	MT6, MT7, MT19, MT29, MT38, MT39, MT40, MT42, MT44, DT5, DT10	11
Nuclear Energy	MT4, MT10, MT12, MT24, MT39, MT42, MT44, MT45, MT48, DT2	10
Organ Donation/Transplantation	MT4, MT12, MT13, MT19, MT46, DT9, DT10	7
Pandemic Vaccine/Vaccination	MT4, MT13, MT29, MT45, MT46, MT47	6
Space Pollution	MT4, MT10, DT9, DT10	4
Cloning	MT4, MT13, MT44, DT5	4
Recycling	MT6, MT30, DT9, DT10	4
CurrentEnvironmental Issues/Environmental Pollution	MT2, MT48, DT9	3
Global Climate Change	MT4, MT31, DT3	3
Transplantation	MT4, MT13, MT44	3
Plastic Use	MT5, MT16, MT23	3
Blood Donation	MT6, MT11, MT13	3
Biotechnology	MT13, MT19, DT4	3
Hydroelectric Power Plants	MT19, MT28, DT2	3
Genetic Engineering	MT48, DT4, DT5	3
Energy Sources	MT1, DT5	2
Pesticides / Agricultural Pesticides	MT11, MT38	2
Organic Farming	MT14, DT10	2
Hydraulic Fracturing	MT25, MT45	2
Animal Testing	MT29, MT47	2
Endangered Species	MT38, MT39	2
ArtificialIntelligence Technologies	MT47, DT1	2
Solar Energy	DT9, DT10	2
Ecosystem Ecology	MT2	1
Euthanasia	MT4	1
Medicine and Alternative Medicine	MT4	1
Consanguineous Marriage	MT6	1
Substance Addiction / Substance Abuse	MT6	1
Thermal Power Plant	MT11	1
Chemical Industry	MT11	1
Antibiotic Use	MT13	1
Water Wells	MT14	1
Fishing Activities in Protected Areas (SIT Areas)	MT14	1
Dam Activities / Dam Projects	MT14	1
Tourism Activities	MT14	1
Delta UNESCO World Heritage	MT14	1
Genetic Improvement / Genetic Breeding	MT15	1
Artificial Organs	MT15	1
Fishing in the Black Sea	MT23	1

Cryobiology	MT23	1
Nanotechnology	MT28	1
Processed Foods	MT29	1
/Domestic Waste	MT30	1
Acid Rain	MT31	1
Care of Stray Animals / Street Animal Care	MT32	1
Genetically Designed Babies / Designer Babies	MT34	1
Causes of Forest Fires	MT37	1
Diet Pills / Weight Loss Drugs	MT38	1
Geothermal Energy	MT38	1
Base Station	MT38	1
Air Pollution	MT40	1
Plastic Bag Usage	MT41	1
Inappropriate Medication Use	MT41	1
Excessive Salt Consumption	MT41	1
Boiling Point	MT41	1
Colligative Properties	MT41	1
Nanoparticles	MT41	1
Human Genome Project	DT1	1
Biodiversity	DT2	1
Noise Pollution	DT6	1
Healthy Nutrition and Diet	MT46	1
Light Pollution	DT9	1

This table presents a frequency distribution of socioscientific issues and their coverage in postgraduate theses. The most frequently addressed topic is "Genetically Modified Organisms (GMOs)" with a frequency of 14, while the second most common topic is global warming with a frequency of 11, and the third is nuclear energy with a frequency of 10. Some of the less studied topics in postgraduate theses, with a frequency of 1, include consanguineous marriage, euthanasia, antibiotic use, and thermal power plants.

Looking at the distribution of topics in the studies, it is seen that they span a wide spectrum, covering multifaceted areas such as environmental pollution, genetics, energy sources, plastic use, and endangered species.

The fact that topics such as GMOs, nuclear energy, and global warming are addressed and examined in many studies suggests that these issues create dilemmas in people's minds from both scientific and societal perspectives and lead to debate. Additionally, the topic of Vaccines/Pandemic vaccines, a current issue studied with a frequency of 6 in postgraduate theses, shows that this subject is not confined to health sciences or medicine but is also related to fields such as education and ethics.

Table 6. Data collection tools used in theses examined within the scope of the research

Data Collection Tools	Code	f
Interview	MT1, MT2, MT3, MT5, MT6, MT9, MT10, MT11, MT15, MT17, MT18, MT26, MT28, MT29, MT30, MT33, MT35, MT38, MT42, MT43 DT2, DT3, DT9, DT10	27
Attitude Scale	MT7, MT8, MT9, MT10, MT12, MT17 MT19 MT34, MT35, MT38, MT42, MT48, DT7, DT9	15

Scenario	MT5, MT10, MT11, MT13, MT15 MT23, MT34, MT37, MT44, MT46, MT47, DT10	12
Argument Texts/Forms	MT4, MT5, MT10, MT16, MT24, MT28, DT1, DT2 DT5	8
Observation Records	MT2, MT4, MT10, MT23, MT39 MT40, DT1	7
Critical Thinking Scale	MT1, MT29, Y38, DT4, DT4, DT9	6
Decision-Making Scale	MT1, MT18, MT23, DT1, DT7, DT8	6
Classroom Observation	MT2, MT38, MT43, DT2, DT3, DT9	6
Academic Achievement Test	MT1, MT18, MT37, DT7, DT8	5
Moral Thoughts/Reasoning Scale	MT8, MT14, MT25, MT32, MT45	5
Epistemological Belief Scale	MT46, MT47, MT48, DT10	4
Dilemma Cards	MT4, MT10, MT27	3
Diary	MT29, MT40, DT7	3
Conceptual Understanding Questionnaire	MT1, DT6	2
Motivation Scale	MT7, MT10	2
Word Association Test	MT11, MT19	2
Textbooks	MT20, MT33	2
Nature of Science Questionnaire	MT31, DT5	2
Student Written Documents	MT38, MT40	2
Awareness Scale	DT2, DT4	2
Audio Recordings	MT39, DT1	2
Developed Material(s)	MT2	1
Critical Thinking Disposition Scale	MT5	1
Reasoning Scale	MT7	1
Discussion Skills Scale	MT8	1
Metaphor Forms	MT12	1
Drawing Analyses	MT12	1
Self-Efficacy Belief Scale	MT15	1
Affective Disposition Scale	MT21	1
Informal Reasoning Scale	MT25	1
Problem-Solving Skills Questionnaire	MT29	1
Open Reflective Classroom Discussions	MT30	1
Reflective Thinking Scale	MT38	1
Discourse Pattern Models	MT39	1
STEM Attitude Scale	MT40	1
Parent Opinion Form	MT40	1
Rubric	MT40	1
Learning Skilles Scale	MT41	1
Teaching Method and Preferences Questionnaire	MT41	1
Metacognition Scale	MT41	1
Logical Thinking Ability Test	MT47	1
Science Learning Skill Scale	MT48	1
Character and Values Scale	MT48	1
Inquiry Skills Scale	MT48	1
Metacognitive Ability Scale	DT1	1
Science Literacy Test	DT9	1

When the table is examined, it is observed that interviews (f=27) were the most frequently used data collection method in theses conducted within this subject context. This situation clearly shows that it is one of the primary methods preferred by researchers for understanding the complex, multidimensional, and often intertwined nature of SSIs (Socioscientific Issues) with individuals' personal values and beliefs. Interviews offer the opportunity to explore in depth participants' thoughts, reasoning processes, attitudes, experiences, and arguments regarding

SSIs. Their intensive use in both Master's (MT) and Doctoral (DT) theses emphasizes the importance placed on the richness of qualitative data. This contributes to obtaining in-depth information and allows for the detailed analysis of personal opinions.
After interviews, attitude scales are the second most frequently used tool. They offer a quantitative approach to measuring affective dispositions towards SSIs, science, or related topics. Since one of the important goals of SSI education is attitude change, the widespread use of these scales is understandable.

Data collection tools such as the Critical Thinking Scale (f=6) and the Decision-Making Scale (f=6) are preferred for measuring core higher-order thinking skills associated with SSIs in a standardized way. They are important for monitoring the development of these skills and evaluating the effectiveness of interventions.

The Academic Achievement Test (f=5) was used to measure the impact of SSI-based teaching on students' academic achievement in related subjects.
The Moral Thoughts/Reasoning Scale (f=5) and the Epistemological Belief Scale (f=4): These scales are specific measurement tools used to assess the ethical dimension of SSIs and individuals' beliefs about knowledge and knowing.

CONCLUSION, DISCUSSION AND SUGGESTIONS

This meta-synthesis study was conducted to determine the general trends, focal points, and potential research gaps in the field by examining postgraduate theses (N=58) on socioscientific issues (SSI) completed in Turkey between 2020 and 2024 through content analysis. The obtained findings are discussed in detail below in light of the research questions and relevant literature, and significant conclusions for the field have been drawn.

The distribution of the examined studies by year indicates that academic interest in the SSI field has remained active, especially in the last five years. The fact that master's theses peaked in 2021-2022 and doctoral theses in 2023 suggests a concentration in the field during certain periods. The shorter completion time for master's theses compared to doctoral theses (Cohen, Manion, & Morrison, 2018) and the more comprehensive, long-term nature of doctoral studies can be considered as primary reasons for this temporal differentiation. These trends are consistent with the general postgraduate education dynamics observed in similar literature reviews by Aydın and Mocan (2019), confirming that SSI has become an established topic in Turkey's educational research agenda.

Methodologically, qualitative and mixed research methods were found to be more dominant in the examined postgraduate theses compared to quantitative methods. This finding may contrast with general observations in the literature indicating that quantitative methods could be more dominant in certain periods; however, in the period covered by this study, qualitative and mixed methods were observed to be prominent. In this context, the prominence of qualitative and mixed methods can be considered a reflection of researchers' efforts to understand and interpret in-depth individuals' experiences, personal opinions, value judgments, ethical reasoning, and argumentation processes regarding SSIs (Creswell & Plano Clark, 2017). Such methods offer a more suitable ground for grasping the multidimensional nature of SSIs.

Regarding the aims of the postgraduate theses examined, it was determined that the vast majority aimed to develop or assess students' argumentation skills, attitudes towards SSIs, opinions, and reasoning abilities. This situation reflects a widespread acceptance of imparting high-level cognitive skills such as critical thinking, evidence-based decision-making, and scientific literacy, which are fundamental objectives of SSI education (Driver, Newton, & Osborne, 2000; Jiménez-Aleixandre & Erduran, 2008).

When examining the study groups, middle school students were found to be the most frequently studied group in both master's and doctoral theses. This finding aligns with the results of Takaoğlu (2023) and other literature reviews (e.g., Aydın & Mocan, 2019; Değirmenci & Doğru, 2017). The middle school years, a period when students' abstract thinking skills begin to develop, yet their critical perspectives and argumentation abilities are still forming (Zeidler & Nichols, 2009), and when learning outcomes related to SSIs are prominently featured in the Science Curriculum (MEB, 2018), may have influenced researchers' preference for this group. Pre-service teachers and teachers were also frequently studied groups, especially at the master's level, reflecting the central role of current and future teachers' preparedness in the effective teaching of SSIs (Sadler, 2011). However, the complete absence of studies involving parents indicates that a significant stakeholder in SSI education has been overlooked, highlighting a serious research gap in this area. Considering the influence of families on children's value judgments and worldviews (Epstein, 2011), this omission is noteworthy. The fact that doctoral thesis authors worked with less diverse groups can be explained by the tendency for doctoral research to be more in-depth and specifically focused.

Among the SSI contexts addressed, "Genetically Modified Organisms (GMOs)," "global warming," and "nuclear energy" were prominent, stemming from their scientific complexities as well as their societal, ethical, and economic dimensions, which are continuously debated in public and create dilemmas for individuals (Oulton, Dillon, & Grace, 2004). These topics are also frequently presented as examples of SSIs in the literature (e.g., Topçu, Sadler, & Yılmaz-Tüzün, 2010). Less studied topics such as consanguineous marriage, euthanasia, and antibiotic use, while demonstrating the broad spectrum SSIs can cover, also indicate a need for more research in these areas. The inclusion of a current topic like "Vaccines/Pandemic vaccines" in theses underscores that SSIs are not limited to science or medicine but are also related to fields like education and ethics.

Regarding the implementation durations in postgraduate theses, it is noteworthy that short-term applications, such as "1 class hour (40 min)," were the most frequently preferred. Such brief interventions might focus on understanding a specific concept or an instantaneous attitude change; however, it can be argued that they may not be sufficient for the in-depth understanding, development of complex skills, and lasting attitude changes required by SSIs (Dawson & Venville, 2010). The prevalence of medium-term implementation periods, such as 6, 8, and 10 weeks, indicates that researchers tend to examine the effects of SSI education through more structured and process-oriented interventions.

The overwhelming predominance of interviews among data collection tools is consistent with researchers' quest to understand in-depth individuals' experiences, thought processes, and arguments regarding SSIs (Kvale & Brinkmann, 2009). The use of argumentation, attitude, decision-making, and critical thinking scales, as well as various scenarios and observation forms, reflects an effort to evaluate the multidimensional nature of SSIs from different perspectives. This diversity of tools also entails a methodological richness aimed at developing high-level thinking skills (Kolstø, 2001), argumentation (Özturna & Atasoy, 2024; Topçu & Atabey, 2017), and scientific literacy (Lomas & Ritchie, 2014; Yapıcıoğlu & Kaptan, 2017), which are fundamental objectives of SSI education.

In conclusion, this meta-synthesis study has comprehensively revealed the current state of SSI research in Turkey, identifying its strengths and areas for development. The findings and suggestions presented are expected to guide future researchers, educators, and policymakers in enhancing the quality of SSI education. Considering the key role of SSIs in fostering individuals as scientifically literate, critical thinking, ethically sensitive, and socially responsible citizens (Sadler, Chambers, & Zeidler, 2004), the continuity and deepening of research in this field are of great importance.

Recommendations

While the focus of current research on middle school students is understandable, it is important to include different age and experience groups to evaluate the effectiveness of SSI education from a broader perspective. In particular, the potential of high school and university students to cope with more complex SSIs and their different cognitive-affective responses (King & Kitchener, 1994; Perry, 1970) would make studies with these groups valuable. Furthermore, including the perspectives of families, and especially parents (Epstein, 2011), who play a significant role in shaping students' attitudes and opinions towards SSIs, in the scope of research will contribute to addressing SSI education with a holistic approach.

The development of high-level abilities such as critical thinking, decision-making skills, and scientific literacy, which are among the fundamental objectives of SSI education, requires time and continuous exposure (Dawson & Venville, 2010; Zeidler, Sadler, Simmons, & Howes, 2005). Therefore, in addition to short and medium-term cross-sectional studies, there is a clear need for longitudinal research designs that examine the long-term effects of SSI education, the retention of learning, and the transfer of skills to different contexts.

There is a need for studies that comparatively examine the effectiveness of different SSI teaching strategies (e.g., inquiry-based approaches, argumentation-focused activities) on various learning outcomes (Sadler, 2011). In this process, research centered on teachers' pedagogical content knowledge (Shulman, 1987) necessary for effectively teaching SSIs, and their skills in translating this knowledge into classroom practices (Lee, Abd-El-Khalick, & Choi, 2006), will play a key role in improving the quality of SSI education.

SSIs often involve complex and uncertain problems that do not have a single, definitive answer. To effectively cope with such problems, it is critically important for individuals to use metacognitive strategies (Flavell, 1979; Schraw & Dennison, 1994), which are their abilities to monitor, evaluate, and regulate their own thinking processes. Similarly, individuals' epistemological beliefs regarding the nature of knowledge and knowing processes (Hofer & Pintrich, 1997; Schommer, 1990) also influence how they address SSIs and the quality of their arguments (Zeidler et al., 2002). Consequently, more research is needed on how these constructs can be developed in the context of SSIs and how they affect learning processes.

In addition to popular and global SSIs, addressing issues directly related to students' daily lives, local environments, and cultural experiences as SSIs can increase motivation for and engagement in learning (Aikenhead, 2006; Levinson, 2006). Such contextualized SSIs can enable students to integrate scientific knowledge with their own life experiences and to produce more meaningful solutions to problems.

For teachers to effectively bring SSIs into the classroom environment, they need to possess adequate knowledge and skills regarding the nature of these issues, relevant pedagogical approaches, and assessment strategies (Sadler, Foulk, & Friedrichsen, 2017). Therefore, it is of great importance to design comprehensive, practice-oriented, and sustainable training programs for SSI education in both pre-service teacher education programs and in-service professional development activities, and to research the effects of these trainings on teacher competencies and student outcomes.

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The Effect of Technology Supported Education on the Academic Achievement of Middle School Students in Science Lessons and Their Interest in Science Topics[1]

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Abstract

The aim of this study is to examine the effects of technology-supported science education on the academic achievement and interest in science subjects of 6th grade students. A pre-test-post-test matched control group model, one of the quasi-experimental designs, was used in the study. The sample of the study consisted of 52 students studying in the 6th grade of a middle school in Karaman in the 2022-2023 academic year. Data were collected through the Academic Achievement Test for the Solar System Unit and the Interest Scale for Science Subjects. The application was carried out for 5 weeks. While the lessons were taught according to the current program in the control group, the lessons were taught with technology-supported science education in the experimental group. As a result of the research, it was found that technology-supported science education had a significant effect on academic achievement and this effect was in favor of the experimental group. However, despite the increase in the scores of the experimental group in terms of interest in science subjects, no significant difference was found between the two groups. According to the results of the research, suggestions were made such as increasing the use of technology in science classes, using technology not only in the Solar System and Eclipses unit but also in other units, and providing schools with the necessary technology infrastructure and materials.

INTRODUCTION

Education is a phenomenon that is given importance throughout human life and constantly thought about how it can be done better. It constantly develops by being affected by the developments that shape human life. Rapid technological changes that continue for years cause the emergence of new technological tools every day. These technological developments inevitably affect educational activities, as in every area of life (Meriçelli and Uluyol, 2016). The use of technology in education is also important in terms of students' adaptation to rapid changes in science and technology, getting used to using technology effectively, and creating the basic infrastructure of the education-teaching process (Kenar and Balcı, 2013). For this reason, individuals who try to learn only by reading books or only with methods where the

[1] This study was produced from Emrah Öztürk's master's thesis under the supervision of Büşra Bakioğlu. It was also presented as an oral presentation at the ASES IV. International Educational Sciences Conference.

teacher is at the center cannot usually be effective in technology-supported education. On the other hand, education through both audio and visual media channels affects students' attitudes and success more positively in science lessons (Asan and Haliloğlu, 2005; Demirci Güler and Irmak, 2018; Ortaakarsu and Sülün, 2025; Özmen and Kolomuç, 2004).

Science lessons include abstract concepts, but they gain more meaning when connections are made between concrete experiences and daily life. In cases where abstract concepts are dominant in explaining nature and natural events, science lessons need to be strengthened with technological support. Activating technology in the learning process increases students' interest and motivation in the lessons at school and the subjects they are trying to learn, while also helping them remember their previous knowledge. The information presented with technology is simplified and students can grasp the subject with original learning methods (İşman et al., 2002). Activating technology during science lessons helps to increase the quality of science lessons, develop students' reasoning skills, access information, advance their problem-solving skills, and convey situations that are rare or dangerous to observe in our lives (Karamustafaoğlu et al., 2012). Using technology in effective and efficient science teaching is very important, and this shows us that technology-supported science teaching is important (Şahin, 2016).

The Purpose of Study

This study aimed to measure the effect of the technology-supported lesson plans prepared for the “Solar System” subject of the Science course “Solar System and Eclipses” on the academic success of 6th grade students and their interest in science subjects. The reason for including this unit in the study was that there were abstract events and situations regarding space and the universe and that technology would be better utilized in this unit and subject.

The problem statement of this study was determined as; ‘‘Does the technology-supported teaching used in the Science course affect the academic success and interest in science subjects of 6th grade students?’’

The sub-problems are listed as follows;

1. The experimental group in which the Science course was conducted with technology support and the control group in which the 2018 Science Course Curriculum was used in the subject of “6th Grade Solar System and Eclipses Section, Solar System”;
    - Is there a statistically significant difference between the academic success pre-test scores?
    - Is there a statistically significant difference between the academic success post-test scores?
2. The students in the experimental group and the control group;
    - Is there a statistically significant difference between the pre-test scores of interest in science subjects?
    - Is there a statistically significant difference between the post-test scores of interest in science subjects?

METHOD

Study Design

In this study, the pre-test-post-test matched control group model, one of the experimental methods, was used to determine the cause-effect relationship. In this model, there are two groups assigned impartially. Measurements are made in these two groups both before and after the application (Karasar, 2015). Before the application phase, students at the relevant grade level were divided into two groups as experimental and control groups with an unbiased assignment. In the first phase, previously prepared scales were applied to both groups as pre-tests. The Academic Achievement Test developed by Yeşiltepe (2019) and the Science Interest Scale developed by Şimşek and Nuhoğlu (2009) were applied to all students as pre-tests.

Table 1. Research design

Group	Pre-Test	Teaching according to the current program	Technology-Assisted Teaching	Post-Test
Experimental group	X		X	X
Control group	X	X		X

During the implementation, the "Current Program" was applied to the control group, and the "Technology-Supported Instruction", the effectiveness of which was investigated, was applied to the experimental group. When the implementation was completed, the scales applied as pre-tests were repeated as post-tests, and the effectiveness of the methods applied to both groups on their academic success and interest in science subjects was examined. The implementation took five weeks in total.

Study Group/Partipicants

The study group consisted of 52 students studying in the 6th grade of a secondary school in Karaman province in the 2022-2023 academic year. The experimental and control groups were determined by the convenience sampling method, which is a non-random sampling method. The reason for determining the experimental and control groups by the convenience sampling method is that this method provides the opportunity to prevent loss of money, labor and time (Büyüköztürk et al., 2014). The two branches closest in terms of academic success according to their 5th grade grade point averages were randomly selected as the experimental and control groups, and the study groups were determined in this way.

Data Collection

First, the students were informed about the research. After obtaining permission from the parents, the Academic Achievement Test for the Solar System Unit (Yeşiltepe, 2019) and the Interest Scale for Science Subjects (Şimşek and Nuhoğlu, 2009) were applied to the students as a pre-test. The lessons were taught to the control group without any changes in the current curriculum. In the experimental group, lesson plans for technology-supported science education were prepared and lessons were taught according to these lesson plans. Technologies such as augmented reality, virtual reality, QR codes, educational computer games, holograms and interactive concept maps were used in the experimental group. The application lasted 5 weeks and at the end of the lesson process, an achievement test and an interest scale for science subjects were applied to each group regarding the determined outcomes.

Data Anaysis

The data were analyzed with the SPSS 21 program. Before the analysis, a normality test was applied and skewness and kurtosis values were reviewed. The results of the normality test are given in Table 2.

Table 2. Normality test results

Scales	N	x̄	ss	Skewness	Kurtosis
Academic achievement test (pre)	52	13.42	3.72	-.694	.189
Academic achievement test (post)	52	17.23	4.84	-.807	.330
Interest scale for science subjects (pre)	52	62.13	14.58	.307	-.739
interest scale for science subjects (post)	52	63.23	15.00	.262	.029

As indicated in Table 2, the Skewness value was found to be between -.807 and .307, and the Kurtosis value was found to be between .330 and -.739. According to Tabachnick and Fidell (2013), Kurtosis and Skewness values between -1.5 and +1.5 indicate normal distribution. When the results of the normality test were examined, it was determined that parametric tests were appropriate for this study.

FINDINGS

In this section, the data collected with the scales specified in the method section were analyzed using appropriate statistical methods and the results obtained were presented.

Is There a Statistically Significant Difference Between Academic Achievement Pre-Test Scores? Findings Regarding the Research Question

Independent t-test was conducted to compare the academic achievement pre-test scores of the application and comparison groups. The data obtained as a result of the analysis are given in Table 3.

Table 3. Independent t-test results of academic achievement pre-test scores of the experimental and control groups.

	Groups	N	x̄	ss	Min.	Maks.	t test		
							t	sd	p
Academic achievement test (pre)	Experimental group	26	13.03	4.33	22	44	-.742	50	.462
	Control group	26	13.80	3.03					

When Table 3 is examined, it is understood that there is no statistically significant difference between the academic achievement pre-test scores of the experimental and control groups ($t[50]= -0.742$; $p>0.05$).

Is There a Statistically Significant Difference Between the Academic Achievement Post-Test Scores? Findings Regarding the Research Question

Independent t-test was performed on the experimental and control groups to examine the academic achievement post-test scores. The results obtained from this test are shown in Table 4.

Table 4. Independent t-test results of the academic achievement post-test scores of the experimental and control groups.

	Groups	N	x̄	ss	t test			
					t	sd	p	Cohen'd
Academic achievement test (post)	Experimental group	26	18.80	4.56	2.463	50	.017*	0.68
	Control group	26	15.65	4.67				

According to Table 4, it was determined that there was a significant difference between the academic performance post-tests of the application and comparison groups ($t[50]= 2.463$; $p<0.05$). It was found that the academic success average of the experimental group (X=18.80) was significantly higher than the control group (X=15.65). When the effect size was examined, Cohen's d value was calculated as 0.68 and according to Cohen's (1988) classification, this value indicates a medium-level effect.

Is There a Statistically Significant Difference Between the Pre-Test Scores of Interest in Science Subjects? Findings Regarding the Research Question

Independent t-test was applied to the experimental and control groups to examine the pre-test scores of the interest scale for science subjects. The analysis results are presented in Table 5.

Table 5. Independent t-test results of the pre-test scores of the interest scale for science subjects of the experimental and control groups.

	Groups	N	x̄	ss	Min.	Maks.	t test		
							t	sd	p
The interest scale for science subjects (pre)	Experimental group	26	59.46	13.21	27	135	-1.332	50	.189
	Control group	26	64.80	15.62					

When Table 5 was examined, it was seen that there was no statistically significant difference between the pre-test scores of the experimental and control groups regarding science subjects ($t[50]= -1.332$; $p>0.05$).

Is There a Statistically Significant Difference Between the Post-Test Scores of Interest in Science Subjects? Findings Regarding the Research Question

An independent t-test was performed on the experimental and control groups to examine the post-test scores of the Interest Scale for Science Subjects. The findings obtained from this test are given in Table 6.

Table 6. Independent t-test results of the post-test scores of the Interest Scale for Science Subjects of the groups participating in the study.

	Groups	N	$\bar{x}$	ss	t test			
					t	sd	p	Cohen'd
The interest scale for science subjects (pre)	Experimental group	26	61.34	17.49	- .904	50	.370	0.25
	Control group	26	65.11	12.06				

When Table 6 is examined, there is no statistically significant difference between the post-test scores of the experimental and control groups regarding science subjects ($t[50]=-0.904$; $p>0.05$). However, when the pre-test and post-test means of the interest in science subjects of the application group are compared, it is seen that the mean increased more in the application group compared to the comparison group. The effect size was determined to be low at $d=0.25$ (Cohen, 1988).

CONCLUSION, DISCUSSION AND SUGGESTIONS

In light of the research findings, no significant difference was found between the academic achievement pre-test score averages of both groups. This finding showed that the academic achievement levels of the groups were equal before the application. At the end of the study, the academic achievement test was applied to both groups as a post-test. When the academic achievement post-test scores of the experimental and control group students were examined, the academic achievement test scores of the experimental group students were found to be significantly higher than the academic achievement test scores of the control group students. These data show that technology-supported science education has a positive effect on academic performance. There are similar studies in literature. In the studies conducted, it was found that there were significant differences in favor of the experimental groups between the experimental groups applied computer, simulation and technology-supported learning and the control groups receiving education with existing programs (Akçay et al., 2007; Bell and Trundle, 2008; Carlsen and Andre, 1992; Doğan, 2025; Emrahoğlu and Bülbül, 2010; Güvercin, 2010; Jimoyiannis and Komis, 2001; Karamustafaoğlu et al., 2005; Kıyıcı and Yumuşak, 2005; Ortaakarsu and Sülün, 2025; Saka and Yılmaz, 2005; Tokur, 2011). Studies in which approaches that confirm traditional knowledge are used in technology-supported education show that technology has positive effects on academic achievement by Azar and Şengüleç (2011), Bozkurt and Sarıkoç (2008), Çinici et al. (2013), Kıyıcı and Yumuşak (2005). The study conducted by Güven and Sülün (2012) and the study conducted by Çetin and Günay (2010) reached similar results in terms of academic success and student attitudes. Both studies reveal that computer-aided and web-based teaching methods have positive effects on students' academic performance and interest in lessons. The study by Güven and Sülün (2012) showed that computer-aided education increased students' success in science and technology lessons and that they had a more positive attitude towards lessons. Similarly, the study by Çetin and Günay (2010) showed that students achieved success in science lessons and gained a positive approach towards the lesson thanks to web-based education. These compatible results show that computer and web-aided education methods are important tools in innovative teaching and contribute to students' learning processes. In line with the findings obtained, it was concluded that the role of technology in modern education is increasing, supporting students' natural motivation and has the potential to increase academic success. Kerdvibulvech (2022) developed some virtual reality and digital game applications in his research and applied them as distance education during the pandemic period and looked at the results. He saw that it was as effective as face-to-face education and predicted that it could be used in normal education periods and that interest and success in lessons could increase. Hwang and Chien (2022) made an application by integrating virtual reality glasses and augmented reality situations into education with existing applications in their research and achieved successful results in permanent learning in students. It even concluded that virtual reality applications are better in terms of permanence and success. They revealed that virtual reality-based education will contribute to future generations becoming scientifically literate individuals by developing artificial intelligence technology. Kramarski and Feldman (2000) concluded in their research that although the technology-supported education environment increased students' motivation and interest in the lesson, there was no difference in metacognitive awareness levels in the technology-supported environment compared to the control group. Regardless of the learning approach, students can develop the skills necessary to manage their own cognitive processes. Alexander et al. (2006) stated that with the effect of the education students receive throughout their school years and the equipping of this education with technology, metacognitive skills also develop in parallel with the development of mental abilities, and academic success in lessons also increases. In their research, Lockee (2021) supported each other with the positive effect on students' academic success and attitudes as a result of the permanent and traceable interaction between students and teachers who teach technology-supported lessons. Virtual reality glasses, in other words, head-mounted displays, allow users to experience a high degree of immersion (Kim et al., 2020; Radianti et al., 2020). High-quality graphics and immersive content presented using head-mounted displays allow students to explore complex subjects in ways that traditional teaching methods cannot (Hamilton et al., 2021). Similarly, in a trend study conducted by Jensen and Konradsen (2018) on the effects of the use of head-mounted virtual reality devices on immersion and presence, they found that the use of virtual reality glasses in designed virtual reality environments had a more positive effect on students. At the beginning of the study, no statistically significant difference was found between the pre-test scores obtained from the interest scale for science subjects applied to both groups. This showed that the initial levels of the experimental and control groups were equal. At the end of the study, the Interest Scale for Science Subjects was applied to both groups as a post-test. Although there was no statistically significant difference between the post-test scores of the experimental and control groups, the experimental group showed a greater increase in average scores compared to the control group. Contrary to other studies investigating the level of interest in science subjects, it was concluded that there was no significant difference in students' interest in science subjects in this study (Gibson and Chase, 2002; Yaman and Öner, 2006). It is thought that the short period of time that the study was conducted may be effective in the findings obtained in the study. A longer period is needed for affective characteristics such as interest and attitude to change significantly. (Güven and Sülün, 2012). Moreover, since the pre-test scores of the experimental group students were already high, although their interest scores for science courses increased, it did not create a significant difference. It was concluded that a longer period of application should be carried out to increase students' interest in science subjects.

According to the results of the research, the following suggestions are presented;

- Since technology-supported science teaching increases students' academic success, it is recommended that science courses be taught with technological support.
- Based on the results of the study, it is recommended that teachers implement Technology-Supported Science Teaching at different levels and in various subjects.
- It is recommended that technology support be used in science classes for a long time to meaningfully increase students' interest in science subjects.
- Technology-supported teaching is recommended to be used especially in units where abstract concepts are intense, such as the "Solar System" unit.

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Digital Educational Tools for Student-Centered Physics Instruction: Applications of the Türkiye Century Education Model

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Abstract

This study examined the effectiveness of using digital educational tools in student-centered physics instruction within the scope of the Türkiye Yüzyılı Maarif Modeli (Türkiye Century Education Model, TCEM). The research was conducted with 61 ninth-grade students from two classrooms at a public Anatolian high school in Türkiye. Based on an action research design, qualitative data were collected through observations and focus group interviews, while quantitative data were obtained using a performance-based rubric. Students carried out digitally supported activities in groups of four. Augmented reality applications, simulations, and interactive digital platforms were utilized during the research process. The findings indicate that these tools enhanced student engagement, improved conceptual understanding, and supported collaborative learning. However, a lack of prior experience with digital technologies among some students posed challenges during the learning process, and technical infrastructure and internet connectivity issues limited the efficiency of implementation. Additionally, behavioral tendencies toward digital addiction is observed in some students following the intensive use of digital tools, raising concerns about potential future dependency. These findings highlight the need for mindful and balanced use of digital tools, alongside their pedagogical benefits.

INTRODUCTION

Physics education aims to enable students to explain natural phenomena through scientific principles, enhance their critical thinking skills, and foster awareness of scientific processes, thereby necessitating instructional approaches aligned with contemporary educational demands (Bao & Koenig, 2019). In this context, traditional teaching methods based solely on knowledge transmission are found to be insufficient; instead, learning environments that allow students to construct knowledge, learn through experience, and engage cognitively and affectively in the process prove to be more effective (Darmaji, Kurniawan, & Irdianti, 2019). Particularly, topics involving dynamic and abstract relationships tend to be challenging for students to comprehend, which adversely affects their conceptual understanding (Hung & Jonassen, 2006).

In recent years, with the increasing impact of digitalization in education, there has been a marked rise in the use of digital instructional tools such as augmented reality, simulations, and gamification in physics education (Lampropoulos & Kinshuk 2024). These tools encourage students' active participation in learning, facilitate the connection between acquired knowledge and real-life contexts, and enable the visualization of abstract principles (Ateş & Polat, 2025). By integrating digital information into the physical environment, augmented reality technology provides students with multisensory and interactive learning experiences (Buesing & Cook, 2013). Similarly, the gamification approach enhances students' engagement and fosters positive attitudes toward lessons by incorporating elements such as competition, rewards, and tasks into the learning process, thereby supporting more sustainable learning outcomes (Lampropoulos & Kinshuk, 2024).

In light of these developments, the Türkiye Century Education Model (TCEM), developed by the Ministry of National Education (MoNE), adopts a student-centered instructional approach that prioritizes cognitive, affective, and social development and aligns with the demands of the digital age. The model aims to equip students with essential 21st-century skills such as problem-solving, critical thinking, research, and collaboration, while encouraging the integration of digital learning environments into this process. When used consciously, in a balanced manner, and aligned with pedagogical goals, digital educational tools not only enhance learning outcomes but also foster students' ability to establish healthy relationships with technology (MoNE, 2024). However, the successful implementation of this process depends on several factors, including the level of digital literacy, accessibility to digital tools, and the pedagogical design skills of educators (Lewin, Cranmer, & McNicol, 2018). In this context, the use of digital tools in physics education should be carefully examined in terms of both instructional effectiveness and its impact on student behaviors.

The Türkiye Century Education Model and the Transformation in Physics Education

TCEM, developed by the Ministry of National Education, is a structural transformation initiative grounded in a student-centered and value-oriented approach that aims to establish a holistic educational system responsive to the needs of the 21st century. The model is based on the principles of epistemological diversity, a virtue-centered human conception, and developmental integrity, aiming to foster students' intellectual, emotional, social, and moral growth. Within this framework, the student is not merely a passive recipient of knowledge but is positioned as an active agent who questions, constructs, and relates knowledge to real-life experiences. A key component of the model is digitalization, which seeks to enhance students' digital literacy, enable meaningful and collaborative use of digital tools, and promote effective communication in digital learning environments (MoNE, 2024). Diversifying learning environments, integrating digital content into instructional processes, and expanding student-centered technological practices reflect the model's vision of integration with contemporary education (Banaz, 2024; Kurnaz & Eksi, 2015).

In the context of physics education, the TCEM aims to support students in explaining natural phenomena through scientific methods, developing reasoning and problem-solving skills, and maintaining scientific curiosity. The new physics curriculum prioritizes interactive and concrete learning experiences that facilitate understanding of abstract principles and aims to create learning environments responsive to individual differences through constructivist activities that promote active student engagement (MoNE, 2024). In this regard, digital learning tools such as augmented reality, simulations, and gamification are considered key components in enabling students to experience and internalize physical phenomena (Vidak, Šapić, Mešić & Gomzi, 2024). The physics education vision of the model seeks to shape students' understanding of scientific knowledge through both theoretical and practical dimensions, supported by multi-interactive and technology-driven pedagogical approaches.

The Role of Digital Tools in Physics Education within the Scope of the TCEM

Physics education is inherently composed of abstract content that requires explaining natural phenomena through scientific cause-and-effect reasoning (Li, Suzuki, & Nakagaki, 2023). The physics curriculum developed under the TCEM promotes interactive and student-centered learning environments supported by digital tools to facilitate the understanding of such complex concepts (MoNE, 2024). Augmented reality (AR), simulations, and interactive digital platforms enable experiential learning and activate multiple cognitive processes that enhance conceptual understanding (Laine, Nygren, Dirin, & Suk, 2016).

AR applications, by overlaying digital layers on the physical environment, support students in modeling, analyzing, and interpreting dynamic flow processes such as the Bernoulli principle in various contexts—thereby fostering a deeper understanding of the underlying physical mechanisms (Jiao, Zhang, Cheng, & Xu, 2010). Similarly, virtual laboratories and simulation environments offer repeatable, safe, and time- and space-independent opportunities for experimentation, which enhance learning retention (De Jong, Linn, & Zacharia, 2013). Interactive platforms further promote active student engagement while developing 21st-century skills such as collaboration, critical thinking, and problem-solving (Verawati & Purwoko, 2024). In line with the vision of TCEM, the pedagogically intentional and balanced use of these tools offers an effective learning process that deepens physics education.

The Educational Role of Gamification within the Scope of TCEM

Gamification is a learning approach that incorporates game design elements into non-game contexts to enhance individuals' motivation, engagement, and performance (Kalogiannakis, Papadakis, & Zourmpakis, 2021). In alignment with the objectives of the TCEM, the physics curriculum emphasizes active student participation, responsibility in learning processes, and the development of collaboration-based skills (MoNE, 2024). Within this framework, gamification emerges as an effective method for capturing students’ attention, maintaining their motivation, and transforming the learning experience into an enjoyable process (Richter & Kickmeier-Rust, 2025).

The gamification approach reinforces a sense of competition and achievement through elements such as point collection, badge earning, level progression, task completion, and leaderboards. These features also contribute to the development of learning strategies such as goal setting, receiving feedback, and monitoring one’s own learning progress. In group-based activities, gamification enhances peer interaction, thereby supporting collaboration and social learning (Lee & Hammer, 2011).

Bernoulli’s principle was purposefully chosen as the focus of this study due to its conceptual complexity and documented learning challenges among high school students. Research in physics education has consistently shown that students struggle to understand the relationship between pressure and velocity in fluid dynamics, often holding persistent misconceptions (Ivanov, Nikolov & Petrova, 2014). This difficulty is compounded by the abstract nature of the principle and the lack of direct, observable phenomena in traditional classroom settings. Furthermore, there is a significant shortage of interactive and engaging instructional materials specifically designed to teach Bernoulli’s principle effectively (Brown & Friedrichsen, 2011). Given the increasing emphasis on integrating digital technologies into science education, this study aims to fill a gap by developing and testing innovative, technology-enhanced learning environments tailored to this challenging yet foundational physics topic.

When systematically and pedagogically integrated into the physics curriculum, gamification provides a holistic learning environment that supports both cognitive and affective development. Physics instruction aims to enable students to analyze natural phenomena from a scientific perspective and to understand foundational principles through meaningful connections. TCEM supports this vision by promoting student-centered, interactive, and technology-enhanced learning environments (MoNE, 2024). The curriculum prioritizes active student engagement, scientific process skills, and collaborative learning experiences (MoNE, 2024). In this context, group activities supported by digital tools offer strong potential for reinforcing students' scientific understanding and increasing their interest in physics topics. Gamification elements contribute to this by fostering a fun and positive attitude toward learning. However, the intensive use of digital environments may also pose risks, such as decreased attention spans and tendencies toward digital addiction. This study aims to examine the practical implications of these factors in educational settings. The research seeks to address the following questions:

1. How do group activities supported by augmented reality and digital learning tools affect students’ conceptual understanding of the Bernoulli principle?
2. How do gamified activities influence students’ participation and motivation levels regarding the Bernoulli principle?
3. What are the effects of teaching the Bernoulli principle through digital tools on students’ collaboration, attention levels, and tendencies toward digital addiction?

METHOD

Study Design

This study adopted a qualitative research methodology within a collaborative and practice-oriented action research model. The primary aim of this model is to enhance instructional practices through the interactive, critical, and constructive engagement of teachers and students, under the guidance of a researcher actively involved in the learning process (Yıldırım & Şimşek, 2018). Throughout the study, the researcher was able to observe both the strengths and the areas needing improvement within the instructional process, thereby developing context-specific solutions and pedagogical enhancement strategies.

The instructional activities implemented in this research were planned with consideration for students’ readiness levels and individual interests (McNiff, Lomax, & Whitehead, 2004). The researcher's professional experience in physics education and close engagement with the structure and goals of the recently introduced TCEM Physics Curriculum supported a pedagogically informed and systematic design of the learning activities, even as the full implementation across all grade levels remains in progress. Furthermore, the integration of digital learning tools, such as augmented reality, simulations, and interactive platforms, supported the development of students’ academic and social competencies through group-based learning approaches.

The instructional process was structured around the topic of the Bernoulli principle, employing gamified digital activities carried out in student groups of four. Group size was intentionally limited to four members to promote active participation, facilitate peer interaction, and ensure that each student could meaningfully engage in collaborative tasks. Each stage of the intervention was guided by a student-centered and interaction-focused instructional approach. Following the principles of action research, data were collected through classroom observations, focus group interviews, and analytic rubrics. Both instructional content and student engagement were systematically monitored and iteratively refined through reflective cycles consistent with the action research model.

The school in which the study was conducted provided a conducive environment for digital, collaborative, and group-based learning due to its robust physical and technological infrastructure. The availability of a computer lab allowed students to actively utilize digital tools, while the interactive whiteboard in the physics laboratory facilitated the visual presentation of digital content and enriched conceptual understanding through interactive learning experiences. Additionally, as a boarding school, the institution offered extended opportunities for academic and social interactions beyond regular class hours, thus enabling continuous support for group-based learning processes. In this context, the school's infrastructural and organizational features strongly justified implementing the student-centered, technology-enhanced, and collaborative instructional design envisioned in this study.

The instructional practices implemented in this study were grounded in the design framework developed in our previous work titled "Digital Educational Tools for Student-Centered Physics Instruction: Applications of the Türkiye Century Education Model." These practices emphasize the integration of interactive digital technologies and student-centered strategies to enhance conceptual understanding in physics. A comprehensive description of the instructional sequence, tools, and classroom activities based on this model is provided in Appendix 1.

Participants

This study was conducted during the spring semester of the 2024–2025 academic year at an Anatolian high school affiliated with the Turkish Ministry of National Education. The implementation involved a total of 61 ninth-grade students enrolled at the school. The instructional activities were conducted over three weeks, comprising a total of six class hours.

The school admits students through a centralized placement system and accepts those within the top 29th percentile, indicating an above-average academic profile among public high schools in its province. Of the participating students, 39 (64%) were female and 22 (36%) were male. An analysis of their first-semester academic grade point averages showed that 12 students had averages between 50 and 70, 33 students between 70 and 85, and 16 students between 85 and 100. Additionally, 16 students were boarders, while 45 were day students. The participant profile was deemed suitable for the digital, group-based, and collaborative instructional practices planned for this study.

Data Collection Tools

Three primary instruments were utilized to collect data in this study: an observation form, a focus group interview form, and an analytic rubric. The observation form was designed to observe students' participation in the lesson and their interactions within the group. The development of the form was based on the thematic observation framework proposed by Yıldırım and Şimşek (2018). It was structured around three main themes aligned with the specific objectives of the study: level of participation, collaborative behaviors, and digital tool proficiency. This approach aimed to ensure systematicity and reliability in the qualitative data collection process. Observations under each category were systematically recorded by the researcher during class sessions and were evaluated from a developmental perspective.

The focus group interview form was used to gain an in-depth understanding of students' perspectives following the implementation. The form was developed according to the qualitative data collection principles outlined by Yıldırım and Şimşek (2018). The questions were designed in line with the student-centered learning philosophy of TCEM and the sub-objectives of the study. Expert opinions were obtained during the development process. Initially consisting of five open-ended questions, the form was revised based on feedback from two subject-matter experts and finalized with four questions. The questions were intended to explore students' experiences with group work supported by digital tools, their perceptions of the learning process, and their overall attitudes. The interviews were conducted face-to-face in small student groups, and audio recordings were transcribed for analysis.

The analytic rubric was developed to evaluate the digital products prepared by students during group activities. It was based on performance-based assessment approaches proposed by Brookhart (2013). The rubric consisted of six criteria, each rated on a four-level scale. The criteria included content accuracy, conceptual coherence, visual and design layout, collaborative contribution, digital tool proficiency, and originality. Each criterion was scored from 1 to 4, and total scores were used for further analysis.

Validity and Reliability Studies

Validity and reliability studies were conducted separately for each of the three primary data collection instruments used in this research: the observation form, the focus group interview form, and the analytic rubric. Each tool was reviewed for content and construct validity, and its reliability was enhanced through triangulation with multiple data sources.

The Observation Form was evaluated by two academic experts in the fields of physics education and instructional methods for content validity. Expert feedback confirmed that the form was comprehensive in covering dimensions such as group interaction, digital tool proficiency, and task responsibility. Observations were conducted simultaneously by the researcher and a subject teacher. The evaluations made independently by the two observers were compared, and the inter-rater agreement was calculated to be 90%, indicating that the observations were consistent and reliable.

The initial Interview Form, consisting of five open-ended questions, was reviewed for content validity by two subject-matter experts in physics education. The experts provided feedback indicating that two of the questions overlapped conceptually and could be merged to avoid redundancy. They also suggested rewording certain items to improve clarity, eliminate ambiguity, and ensure alignment with the research objectives. As a result, the total number of questions was reduced to four, and minor linguistic revisions were made to enhance comprehensibility for high school students. The final interview questions were as follows: "How can augmented reality applications support your learning of physics topics?", "How did gamification elements affect your participation in the lesson?", "What aspects of group work contributed to your learning experience?", and "Was using digital tools easy for you? Why or why not?". Inter-coder reliability was calculated using the formula proposed by Miles and Huberman (1994): Reliability = Agreement / (Agreement + Disagreement) × 100. Coding was conducted independently by two researchers for each interview question. The reliability scores obtained were as follows: Question 1: 88%, Question 2: 85%, Question 3: 84%, Question 4: 87%, with an overall average of 86%. These values exceed the commonly accepted threshold of 80% in qualitative research, indicating strong coding reliability.

The Analytic Rubric, comprising six criteria and four performance levels, was specifically developed by the researcher to assess student products related to the topic of Bernoulli's principle. The development process was informed by both relevant literature on performance assessment in science education and the pedagogical goals of the study. The criteria included:

conceptual understanding, adherence to task distribution, effective use of digital tools, group communication, originality of ideas, and presentation skills. Clear and distinctive descriptors were provided for each performance level. To establish content validity, the rubric was reviewed by two experts in physics education, and minor revisions were made based on their suggestions. Each group's product was scored independently by two evaluators using the finalized rubric. Scoring consistency between evaluators was examined using the Spearman-Brown reliability coefficient, with a calculated agreement rate of 91%. Furthermore, the close alignment between score averages and variances indicated strong internal consistency of the assessment tool. The data are presented in Table 1.

Table 1. Validity indicator table for the analytic rubric

Reliability Type	Method / Analysis	Observation / Result
Agreement between Raters	Spearman-Brown Reliability Coefficient	0.91 (High level of agreement)
Average Agreement Based on Criterion	Agreement percentage (examining the criteria one by one)	91%
Score Average	Average score of all students	3.12 / 4 (high level of success)
Score Variance	Variance of all scores	0.42 (concentration around the mean, consistency indicator)

Data Anaysis

The data collected in this study were analyzed using both qualitative and quantitative techniques. Qualitative data were obtained through student observations and focus group interviews. Observation data were thematically analyzed based on structured observation forms. Students' interactions within groups, proficiency in using digital tools, and task distribution performance were categorized under three main themes and interpreted accordingly.

Data from focus group interviews were analyzed using the content analysis method. In this process, audio recordings were transcribed into written texts, and two independent researchers carried out the coding to ensure reliability.

Quantitative data were gathered through the analytic rubric used to evaluate the products created by the student groups. Each group was scored based on six criteria across four performance levels. The resulting scores were analyzed using descriptive statistical methods. The findings were presented in tables and interpreted accordingly.

FINDINGS

This section presents the findings regarding the effects of instructional practices supported by augmented reality, gamification, and digital tools on students' conceptual understanding of the Bernoulli principle, motivation, engagement, and digital behavior tendencies.

Findings on the Impact of Augmented Reality and Digital Educational Tools on Conceptual Learning in the Context of the TCEM

Within the scope of the study, the performance of a total of 61 students working in collaborative groups was evaluated using a rubric structured around six criteria, each with four performance levels. These criteria included content accuracy, conceptual coherence, visual and design organization, intra-group task distribution, digital tool usage skills, and originality. Each criterion was scored on a scale from 1 (beginning level) to 4 (advanced level). The arithmetic mean, minimum, maximum, and standard deviation values of the obtained scores are presented in Table 2.

Table 2. Descriptive statistics of student performance based on the rubric criteria

Criterion	Mean ($\bar{X}$)	Min.	Max	Standard Deviation (SD)
Content Accuracy	3.42	2	4	0.57
Conceptual Coherence	3.28	2	4	0.61
Visual and Design Organization	3.14	1	4	0.73
Intra-group Task Distribution	3.36	2	4	0.51
Originality	3.05	1	4	0.78

According to the data presented in Table 2, there are notable differences in the mean scores of students across various rubric criteria during the collaborative learning process. When the scores are examined based on the evaluation criteria, the highest mean score was observed in the "Content Accuracy" criterion (M = 3.42), while the lowest mean was found in the "Originality" criterion (M = 2.89). The high performance in "Content Accuracy" indicates that students demonstrated strong abilities in producing scientifically accurate content related to the topic. Conversely, the relatively lower score in "Originality" suggests that students may require further support in generating creative ideas and proposing unique solutions. Overall, the average score across all criteria was approximately 3.19, which indicates a desirable level of performance. The relatively low standard deviation values across all criteria imply a homogeneous distribution of student performance, meaning that the majority of the students performed at similar levels. These findings support the conclusion that digitally supported collaborative learning environments positively contribute to students' physics learning processes.

Table 3. Frequency and Percentage Distributions of Student Performance Levels Based on Rubric Criteria

Score	Content Accuracy		Conceptual Integrity		Visual-Design Order		Intra-Group Division of Labor		Digital Tool Usage Skills		Originality	
	N	%	N	%	N	%	N	%	N	%	N	%
1	4	6.5	6	9.8	10	16.4	7	11.5	9	14.8	11	18.0
2	12	19.7	14	23.0	15	24.6	10	16.4	16	26.2	20	32.8
3	27	44.3	25	41.0	22	36.1	24	39.3	21	34.4	18	29.5
4	18	29.5	16	26.2	14	23.0	20	32.8	15	24.6	12	19.7
Total	61	100	61	100	61	100	61	100	61	100	61	100

As shown in Table 3, students demonstrated varying performance levels across different assessment criteria. For the Content Accuracy criterion, 44.3% of students performed at level 3, while 29.5% reached level 4. This suggests that a substantial portion of students had grasped the essential principles of scientific accuracy. Similarly, in the Conceptual Coherence criterion, 41.0% of students achieved level 3, and 26.2% achieved level 4 performance, indicating that many students attained a satisfactory level of conceptual understanding. Regarding Visual-Design Organization, 36.1% of students performed at level 3 and 23.0% at level 4. However, the combined percentage of students at levels 1 and 2 (41.0%) indicates room for improvement in this skill area. For the Teamwork and Task Distribution criterion, 39.3% of students scored at level 3 and 32.8% at level 4, reflecting active participation in collaborative processes by most students. In terms of Digital Tool Proficiency, a majority of students (34.4% at level 3 and 24.6% at level 4) demonstrated adequate or higher-level competence in using digital tools. Lastly, for the Originality criterion, 18.0% of students were rated at level 1, and 32.8% at level

2, highlighting a need for further support in developing creativity and producing engaging content.

The findings suggest that most students exhibited moderate to high performance across the assessment criteria. However, areas such as originality and visual-design organization, which require more creative thinking, appear to need further instructional support.

The following section presents the observation data obtained from 14 student groups participating in the Student-centered physics instruction supported by augmented reality and digital educational tools, conducted within the scope of the TCEM. Observations were structured around three thematic categories: Level of participation, collaborative behaviors, and technology use proficiency. Each theme was scored on a three-point scale—low (1), moderate (2), and high (3)—based on structured observation forms. In addition to statistical summaries, qualitative excerpts from observation notes are also provided to support the thematic analysis (see Table 4).

Table 4. Observation data of 14 student groups in the TCEM-based instructional practice (with thematic and qualitative descriptions)

Group	Participation level	Collaboration	Use of technology	Observation notes
G1	3	3	2	Group members remained active throughout the implementation process, with frequent verbal interaction and exchange of ideas. However, some students required guidance in using digital tools.
G2	2	2	1	Participation was not equally distributed; group leadership was primarily assumed by two students. Members appeared hesitant toward digital tools.
G3	3	3	3	The group maintained an active role throughout the entire process. Digital materials were used creatively during the conceptual design phase.
G4	2	2	2	Task distribution among group members was limited. Student participation was sustained primarily through teacher guidance.
G5	3	3	3	A high level of interaction was observed. Within the augmented reality application, rotation of tasks and shared responsibilities were evident.
G6	2	3	2	Although participation was not balanced, collaboration among group members was strong. Technical difficulties occurred with the use of digital tools.
G7	1	2	1	Student motivation was low. Most tasks were undertaken by only two group members.
G8	3	2	3	Participation was high, yet the division of labor within the group was imbalanced. The AR application was used effectively.
G9	2	2	2	Group roles were clearly defined. Digital interaction proved effective in supporting conceptual explanations.
G10	3	3	3	Group roles were clearly defined. Digital interaction proved effective in supporting conceptual explanations.
G11	2	2	1	Fluctuations in participation were noted. Technical support was needed during the use of digital applications.
G12	3	3	3	Group members acted per the predefined division of tasks. Digital presentations demonstrated conceptual accuracy.
G13	2	1	2	Group interaction was weak. Difficulties were encountered in accessing digital resources.
G14	3	2	2	Despite high levels of participation, a lack of coordination among group members was noticeable.

As shown in Table 4, the findings obtained from the observation of 14 student groups during the implementation of augmented reality and digital tool-supported activities within the scope of the TCEM indicate that students were largely engaged in the learning process. The average participation score of 2.43 suggests a generally positive attitude toward active learning. Similarly, the average score for collaboration behaviors was 2.36, indicating a substantial level of cooperation and task sharing among group members. However, the relatively lower average score of 2.14 for technological proficiency suggests that some students experienced difficulties in using digital tools effectively and independently. Notably, groups G3, G5, G10, and G12 demonstrated high performance across all three dimensions, reflecting strong alignment with the student-centered, digital, and collaborative learning approach advocated by TCEM. In contrast, the lower scores for technology use observed in some groups (e.g., G7 and G11) highlight a continued need for support and guidance in accessing and utilizing digital tools during the implementation process.

Findings on the Impact of Gamification-Based Activities on Student Engagement and Motivation within the Context of TCEM

Below, the observation data related to the subheading "Findings on the impact of gamification-based activities on student engagement and motivation within the context of the TCEM" are presented through thematic analysis. Observations were categorized under four main themes: level of participation, indicators of motivation, interaction behaviors, and attention span, and were evaluated across 14 collaborative student groups.

Table 5. Observed student behaviors during gamification-based activities

Group	Participation level	Motivation Indicators	Interaction Behaviors	Attention Level
G1	High – All members are active	Continuous participation, interest in scoring	Active exchange of ideas, sharing of tasks	High – Task orientation
G2	Medium – 1 member passive	Interest moderate, externally motivated	Occasional disagreements	Variable – Off-task conversations
G3	High – Clear role distribution	Badge and reward motivation is evident	High cooperation, supportive communication	High – Focus on task process
G4	Low – Involvement is unbalanced	Task meaning is low, attention is easily distracted	Little interaction, off-task conversations	Low – Continuous loss of attention
G5	High – Full participation	Sense of fun and competition	Orientation to common goal, exchange of ideas	High – Focus on the game
G6	Medium: 1-2 members are shy	Motivation increases with guidance	Interaction is medium, some members are shy	Medium – Loss of focus at times
G7	High – Everyone is involved in the process	Game rules are interesting	Task sharing within the group is effective	High – Careful follow-up
G8	Medium – Low at first, increasing later	Time limit is a trigger	Scattered at first, then cooperation develops	Variable – Low at first, increasing later
G9	High – Most active group in the class	Highest motivation observed	Coordination is strong, continuous exchange of ideas	High – Least external stimulus effect
G10	Low – Participation is weak	Alienation from the task	Weak cooperation, tension within the group	Low – Constant outward orientation

G11	High – Rotational assignment	Desire to score is evident	Cooperation is dynamic, democratic role distribution	High – Continuous activity monitoring
G12	Medium – Participation is lacking from time to time	Motivation is stimulating but short-term	Interaction is low, individual solutions are dominant	Medium – Concentration is up and down
G13	High – Active participation	High interest in the game process	Task distribution is fair, constant communication	High – Eye contact and focus on the work process
G14	Medium – One member is distant from the process	Visual materials increased interest	Limited interaction within the group, leadership is dominant	Medium – Limited attention span

As shown in Table 5, gamification-based activities generally had a positive impact on students' levels of engagement and motivation. In 8 out of 14 groups (G1, G3, G5, G7, G9, G11, G13), high levels of participation, strong motivation, and focused task orientation were observed. In these groups, student involvement was consistent and purposeful, with clear signs of collaboration and task sharing. However, in 3 groups (G4, G6, G10), low to moderate levels of engagement and motivation were recorded. These outcomes may be attributed to individual differences, lack of intrinsic motivation, or communication challenges within the group. Observational data suggest that the effectiveness of such activities depends not only on instructional design but also on the management of group dynamics.

In some groups (G8, G12, G14), an initial lack of attention and low engagement levels were observed to improve over time. This finding highlights the "habit-forming" nature of gamification and underlines the importance of the teacher's facilitative role throughout the process. Below, based on the four interview questions provided, three main themes, six categories, and 18 codes were developed from student responses. The frequency of these codes was analyzed and presented in table format, followed by interpretive commentary. These data, structured through thematic analysis, are intended to add depth to the qualitative findings of the study.

Table 6. Thematic coding analysis of interview data

Theme	Category	Code	f
Conceptual Understanding and Learning	Augmented Reality	Provided Concretization	12
		Visual support facilitated the concept	10
		Contributed to experiential learning	9
	Digital Tool Usage Proficiency	Interfaces were user-friendly	6
		I used the applications without difficulty	5
		I experienced technical problems	4
Participation and Motivation	Gamification Elements	Point and reward system motivated	13
		Competition was fun	10
		A sense of achievement increased	8
	Group Dynamics and Participation	Interaction with group mates motivated	11
		Taking a role in the group gave responsibility	7
		Increased desire to participate	9
Collaboration and Process Management	Intra-Group Interaction	Task sharing provided convenience	10

Learning Process Experience	We learned from each other	8
	Harmonious group work was productive	7
	I learned better as I actively participated	9
	I completed the process without getting bored	6
	Time passed quickly	4

Table 6 shows that students' reflections on their experiences with augmented reality, digital tools, gamification, and group work were categorized under three main themes. Under the conceptual understanding and learning theme, students emphasized that augmented reality applications significantly supported their comprehension of abstract physics concepts through visualization and concretization (f=12 and f=10). The impact of experiential learning was also frequently noted (f=9). Although a smaller number of students reported technical difficulties with digital tools (f=4), this highlights the importance of ensuring accessibility and usability of technological components.

In the theme of engagement and motivation, gamification elements, particularly the point system (f=13) and competitive aspects (f=10), substantially enhanced students' motivation. Many students also noted that interacting with their group members (f=11) increased their commitment to the learning process. These findings suggest that learner-centered approaches aligned with the TCEM can foster strong motivational outcomes. Within the theme of collaboration and process management, students expressed that distributing tasks, learning from peers, and maintaining a harmonious working environment contributed to a productive learning experience. Comments indicating that the learning process was not boring and that time passed quickly further support the idea that well-structured gamified learning environments enrich the student experience.

Findings on the Effects of Digital Tools on Collaboration, Attention, and Digital Addiction Tendencies within the TCEM Framework

In line with the sub-objective "Findings on the effects of digital tools on collaboration, attention, and digital addiction tendencies within the tcem framework" the data obtained from structured observation forms were analyzed thematically. Student behaviors were categorized under specific themes based on this analysis. The observational results developed within this scope are presented thematically in Table 7.

Table 7. Observed student behaviors in digital tool-based activities

Theme	Category	Observed Student Behaviors	Number of Groups Observed (n=14)	Description
Collaboration	Interactive Task Sharing	Natural sharing of tasks among students and helping each other	11	In most groups, roles were determined spontaneously, and cooperation was observed consciously.
	Shared Decision Making	Exchange of ideas and joint decision making within the group	10	Group members decided together which tools they would use in digital applications.
Attention Level	Process-Oriented Tracking	High focus time on digital applications	9	In 64% of the activities, students maintained their attention span throughout the activity.

Theme	Category	Observed Student Behaviors	Number of Groups Observed (n=14)	Description
Digital Addiction	Asking Task-Related Questions	Students asking questions to the teacher or group mates to understand the process	8	Students demonstrated active questioning behavior.
	Digital Tool Request Outside of Break	Wanting to use digital applications outside of class time	5	5 group members stated that they wanted to use the application even during recess.
	Application Timeout Trend	Behavior of staying connected to digital applications for longer than the given time	6	In 6 groups, students wanted to stay in the digital content for longer than the given time.

As shown in Table 7, students demonstrated a high level of collaboration and attention. In particular, interactive task-sharing and joint decision-making behaviors were prominently observed in more than 10 groups. However, another notable finding was the tendency of some groups to engage in excessive or off-task use of digital tools. This indicates both an improvement in digital competence and a need to be cautious about the potential risk of digital addiction.

Within the scope of the research, descriptive statistics related to rubric-based evaluation data obtained to determine the effects of digital tool-supported instructional practices, conducted in alignment with the TCEM framework, on students' collaboration, attention level, and digital tool use awareness are presented in Table 8.

Table 8. Descriptive statistics regarding measures of collaboration, attention and awareness of digital tool use

Criterion	Mean ($\bar{x}$)	Standard Deviation (SD)	Minimum	Maximum
Collaboration	2,90	0,78	1	4
Attention Level	2,76	0,84	1	4
Digital Tool Usage Awareness	2,59	0,88	1	4

As shown in Table 8, the mean score for students' level of collaboration was ($\bar{x}$ = 2.90), indicating a moderate-to-high range on the scale. This finding suggests that physics lessons supported by augmented reality and digital content provided a collaborative learning environment that effectively promoted teamwork. The average score for attention level was ($\bar{x}$ = 2.76), revealing that digital materials were generally effective in maintaining students' focus during the learning process. However, the mean score for digital tool use awareness was relatively lower, at ($\bar{x}$ = 2.59), indicating a need for students to further develop their ability to use technology consciously and responsibly. The fact that all average scores are above the moderate level supports the conclusion that the digital practices structured within the TCEM framework have made a positive contribution to students' learning processes. Nevertheless, it is recommended that pedagogical support be increased, particularly in the area of digital literacy and awareness.

CONCLUSION, DISCUSSION AND SUGGESTIONS

The findings of the study revealed that collaborative activities supported by augmented reality and digital educational tools significantly enhanced students' conceptual understanding of the Bernoulli principle, which can be attributed to the interactive, visual, and inquiry-based structure of the learning environment. Such an environment enabled students to connect theoretical concepts to real-life phenomena through experimentation and group dialogue, thereby fostering a deeper cognitive engagement with the topic. High scores in "content accuracy" and "conceptual coherence" suggest that digital tools facilitated the construction of scientifically accurate mental models within collaborative settings. These results are in line with Doğru (2023), who emphasized the role of next-generation technologies in transforming conceptual learning experiences, and with Kumaş (2022), who showed that context-based activities in hybrid learning settings improve both understanding and assessment practices. Similarly, the study by Bozdemir Yüzbaşıoğlu, Candan Helvacı, Ezberci Çevik, and Kurnaz (2020) highlighted the positive impact of digital peer interaction, even in informal environments like WhatsApp groups, in enhancing conceptual dialogue and reflection. However, the relatively lower scores in the "originality" criterion reveal a gap in fostering students' creative thinking skills. This limitation may arise from the predominance of structured tasks over open-ended challenges and is consistent with the findings of Öksüz and Taşçı (2023), who observed that group work alone does not significantly improve creativity without deliberate instructional strategies. These insights indicate that while technology-supported and student-centered methods aligned with the Türkiye Century Education Model (TCEM) effectively promote conceptual understanding, their full potential can be realized only when enriched with creativity-oriented approaches such as scenario writing, project-based learning, and open-ended inquiry tasks.

This study, within the scope of "Digital Educational Tools for Student-Centered Physics Instruction: Applications of the TCEM," examined the impact of digitally supported collaborative activities on students' performance in learning the Bernoulli principle. The students' high-level achievement in content accuracy, conceptual coherence, and digital tool usage aligns with the TCEM's objectives of fostering digital competence, active engagement, and collaborative learning. However, the relatively lower scores in creativity-oriented criteria, such as originality and visual-design organization, indicate the need for more pedagogical support in these areas during instructional design. For abstract and conceptually challenging physics topics like the Bernoulli principle, which students often struggle to relate to daily life, the motivating and concretizing effects of digital tools such as augmented reality and gamification have once again been confirmed through this study. Similar findings in the literature (Kumaş & Kan, 2021; Ormancı, 2019) also highlight the positive contribution of digital technologies to students' conceptual understanding and motivation. In this context, it is recommended that digital tools in physics instruction be regarded not merely as supplementary aids but as essential components for structuring the learning environment. Moreover, the development of teachers' pedagogical and digital competencies is critical. This approach would more effectively realize the Türkiye Yüzyılı's vision of a student-centered, technology-integrated, and creativity-oriented educational model.

The data collected through structured observations and student interviews indicate that learning environments integrating augmented reality and gamification within the TCEM framework fostered enhanced student engagement, motivation, and conceptual understanding. Observations revealed that most students actively participated, collaborated effectively, and demonstrated proficiency with digital tools. Furthermore, thematic analysis of interviews highlighted that augmented reality applications helped students visualize and concretize complex physical concepts, while gamification elements notably increased their motivation and involvement in classroom activities. These findings align with previous research by Gürsoy (2021) and Zourmpakis, Papadakis, and Kalogiannakis (2022), which underscore the role of digital content in promoting active learning and improving cognitive outcomes.

One of the core approaches of the TCEM framework, student-centered digital learning proved effective in multiple dimensions throughout this study. Specifically, students took an active role in their learning processes by interacting with augmented reality applications and participating in gamified tasks requiring problem-solving, collaboration, and critical thinking. Observation data indicated increased engagement and initiative among students, while interview responses revealed that learners felt more autonomous, motivated, and capable of understanding abstract physics concepts when digital tools were integrated into the learning environment. These outcomes suggest that student-centered digital learning within the TCEM enhanced participation and contributed to deeper conceptual comprehension and sustained interest in the subject matter. Students' ability to learn from one another, share responsibilities efficiently, and use technology functionally during group work reflects the foundational principles of Vygotsky's theory of learning through social interaction. Additionally, gamification practices that enhance student motivation align with Ryan and Deci's self-determination theory, particularly the concept of intrinsic motivation. The high levels of motivation and participation observed among students underscore the need for pedagogically robust and interactive digital content design within the TCEM framework. In this regard, it is recommended to: systematically expand the use of augmented reality applications for teaching abstract concepts such as the Bernoulli principle, structure gamified elements in alignment with students' developmental levels, and increase in-service training opportunities for teachers to improve their effective use of digital tools.

The findings of this study reveal that augmented reality and digitally supported activities effectively enhance students' levels of collaboration and attention. Observational data provide strong evidence that students often shared tasks, made joint decisions within groups, and maintained high levels of focus on digital content. These results are consistent with findings from digital tool–based physics education studies conducted by Pokhrel (2024) and Kan & Kumaş (2024), which also highlight the role of digital environments in enhancing student attention and collaboration. However, in some groups, tendencies toward digital overuse, such as extended screen time and off-task usage beyond lesson hours, were also observed, suggesting potential signs of digital dependency. This concern echoes the arguments of Wood (2021), who emphasized that, alongside pedagogical benefits, the risks of digital addiction should also be considered. Accordingly, it is recommended that instructional designs be developed to support the active yet controlled integration of digital tools in physics education under the TCEM framework. Specifically, for abstract topics such as the Bernoulli principle, it is important to design digital content that supports attention, collaboration, and conceptual coherence while also enhancing teacher guidance to prevent digital dependency.

The findings also indicate that students generally demonstrated moderate to high levels of collaboration and sustained attention within digitally supported learning environments. Most students actively engaged in group tasks, used digital tools purposefully, and remained focused on the course content throughout the sessions. These behaviors suggest that the integration of interactive and visually enriched digital materials, such as augmented reality and gamified elements, can create a stimulating learning atmosphere that naturally fosters cooperative learning and attentional focus. Such environments likely reduce cognitive overload by making abstract concepts more accessible and by breaking down complex tasks into manageable, engaging components. Moreover, the structured nature of digital tools may support clearer role distribution and goal-setting within groups, promoting more meaningful collaboration. These results align with the conclusions of Haleem, Javaid, Qadri, and Suman (2022) and Singh (2021), who emphasize the capacity of digital content to enhance students' attention spans and collaborative efforts. Taken together, the findings suggest that well-designed digital learning environments do more than enhance academic performance; they also play a pivotal role in fostering key 21st-century competencies such as collaboration, digital literacy, and sustained attention. This outcome can be attributed to several interrelated factors. First, the interactive and multimodal nature of digital tools, such as augmented reality and gamified tasks, encourages students to engage actively with content, rather than passively receive information. This active engagement often requires students to collaborate, solve problems, and make decisions together, thereby naturally enhancing teamwork skills. Second, navigating these digital platforms helps students build technological fluency, an essential component of digital literacy. Third, the immersive and goal-oriented structure of gamified environments can sustain students' attention by offering instant feedback and clear progress indicators, reducing distractions commonly found in traditional settings.

These findings point to a broader implication: when thoughtfully implemented, technology-enhanced learning environments can simultaneously support cognitive development and socio-emotional skills. This suggests a shift in educational design, from merely delivering content to creating ecosystems that support holistic student growth. Therefore, educators and curriculum designers should not view digital tools as supplementary but as integral elements that shape both the process and outcomes of learning in meaningful ways. On the other hand, the relatively low performance in the "digital awareness" criterion observed among some students draws attention to a potential trend toward digital dependency. In this context, aligned with TCEM's emphasis on digital literacy, it is recommended to implement structured guidance practices aimed at improving students' cognitive awareness during digital interactions. Furthermore, long-term instructional designs that promote balance in digital tool usage could contribute to attention management and the development of healthy digital habits.

In this context, and in alignment with TCEM's emphasis on digital literacy, it is recommended to incorporate structured guidance practices that enhance students' cognitive awareness during digital interactions. Additionally, long-term instructional designs that encourage balanced and purposeful use of digital tools may support attention regulation and the formation of healthy digital habits. Based on the results of the study, it is also advisable to provide teacher training programs focused on the pedagogical integration of augmented reality and gamification, ensuring educators can effectively facilitate student-centered digital learning. Moreover, curriculum developers could consider embedding collaborative, technology-rich tasks that align with real-world problem-solving, thereby strengthening students' engagement and transferable skills. Finally, further research is recommended to explore how these digital strategies influence different learner profiles over time, especially in diverse educational settings.

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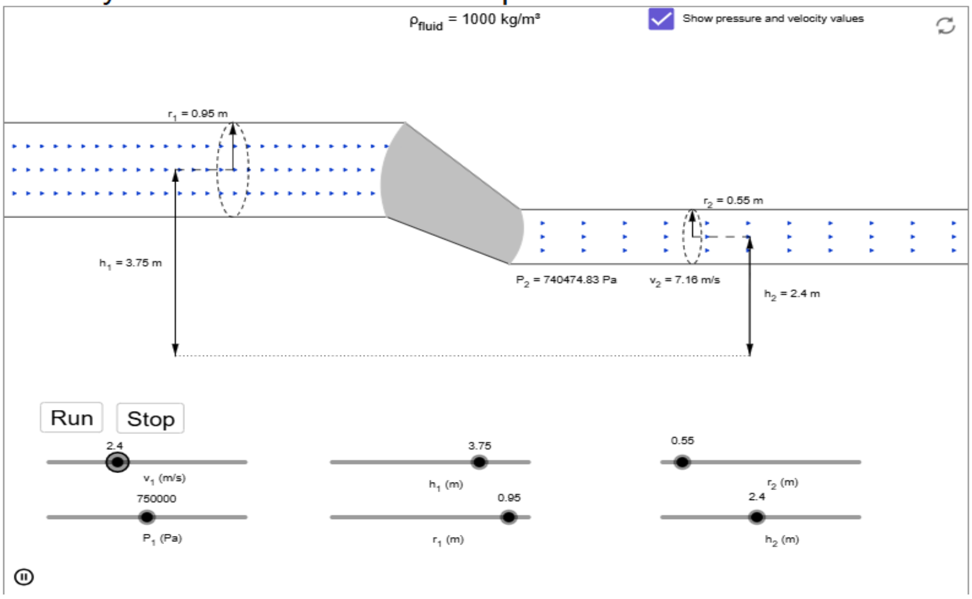
Appendix
Appendix 1.
Application Process
Day 1: 2 Class Hours
Topic: Bernoulli Principle Basic Concepts and Exploration with Interactive Simulations
Tool: oPhysics Simulation
Purpose: To establish the basis of conceptual understanding; to support visualization and estimation skills
Activity Flow:
Motivation – Introduction (10 min): Teacher provides examples from daily life regarding Bernoulli principle (e.g.: airplane wing, paper movement with hair dryer).
Interaction with Simulation (30 min): Students examine the effect of air flow on speed and pressure with oPhysics simulation.
Prediction and Observation (15 min): Students are asked to predict, observe and interpret experimental results.
Short Group Discussion (15 min): Students develop conceptual explanations.
Scoring criteria: Content accuracy, conceptual integrity, use of digital tools.
Day 2: 2 Class Hours
Topic: Bernoulli Principle Experimental Application and Deepening with Gamification
Tool: Floating Ping Pong – Instructables
Purpose: Developing scientific process skills and creative application skills
Activity Flow:
Experiment Design and Material Distribution (10 min): Students are given simple materials (pipette, ball, hair dryer, etc.).
Group Experiment (30 min): Students try to keep a ping pong ball in the air with the Bernoulli effect. They set up, run, observe and comment on the system.
Scientific Process Poster (20 min): Groups express their own experimental process with a poster: hypothesis, observation, result, comment.
Gamification Awards (10 min): Completed tasks are scored; badge, level, task card, leaderboard is updated.
Scoring criteria: Division of labor within the group, originality, scientific process, order.
Day 3: 2 Class Hours
Topic: Deep Understanding and Transfer with Augmented Reality
Tool: YouTube AR Activity & ARIEL Project applications
Purpose: To provide conceptual transfer with multi-model learning experience
Activity Flow:
AR Application Introduction (10 min): Teacher introduces Bernoulli principle application from ARIEL project.
Interaction with AR (25 min): Students observe air flow, pressure change, force relationship through AR video and take notes.
Application in New Situation (15 min): Students are presented with a new problem situation (for example: air flow in chimneys, spray can). They write their own explanations.
Closing and Evaluation (10 min): Group representatives share what they have learned. Students fill out self-assessment form.
Scoring criteria: Conceptual integrity, digital tool usage skills, transfer to new situation.
General Evaluation:
A graded scoring key was applied at the end of each activity.
The process was monitored with observation forms.
Student opinions will be collected through focus group interviews.
The entire process will be linked to TYMM’s student-centered, skill-based learning approach.

Simulation
Fluid Dynamics and the Bernoulli Equation
https://ophysics.com/fl2.html

Fluid Dynamics and the Bernoulli Equation



Appendix 2.
Rubric: Bernoulli's Principle Group Work

Criterion	4 (Very Good)	3 (Good)	2 (Can be improved)	1 (Inadequate)
Conceptual Understanding	Can apply Bernoulli's principle accurately, completely and in different contexts.	Understands the concept correctly, can explain in basic contexts.	Partially understands the concept, there are inconsistencies in explanations.	There are serious deficiencies in understanding the concept, resulting in incorrect explanations.
Adaptation to Task Sharing	Completes tasks by sharing them fairly and effectively.	Generally complies with task sharing, minor disruptions occur.	Task sharing is unbalanced, some members are not active.	There is no task sharing, no cooperation.
Effective Use of Digital Tools	Uses digital tools effectively in a creative and purposeful manner.	Uses digital tools appropriately and correctly.	Has difficulty in use, can progress with support.	Cannot use digital tools effectively, limited contribution.
Intra-Group Communication and Interaction	Communicates continuously, respectfully and solution-oriented.	Generally communicates positively, minor disagreements occur.	Interaction is limited, some members feel excluded.	Intra-group communication is insufficient, conflicts prevent learning.
Original Ideas and Creativity	Provides creative and original contributions to the event.	Occasionally presents original ideas.	Originality is limited, mostly relies on ready-made resources.	No original idea generation, progresses only with guidance.
Presentation Skills	Presents the topic clearly, fluently, visually supported and effectively.	The subject is generally clear, but presentation language and fluency are limited.	There are deficiencies in presentation and poor expression.	Insufficient presentation, no integrity of subject, and not eye-catching.