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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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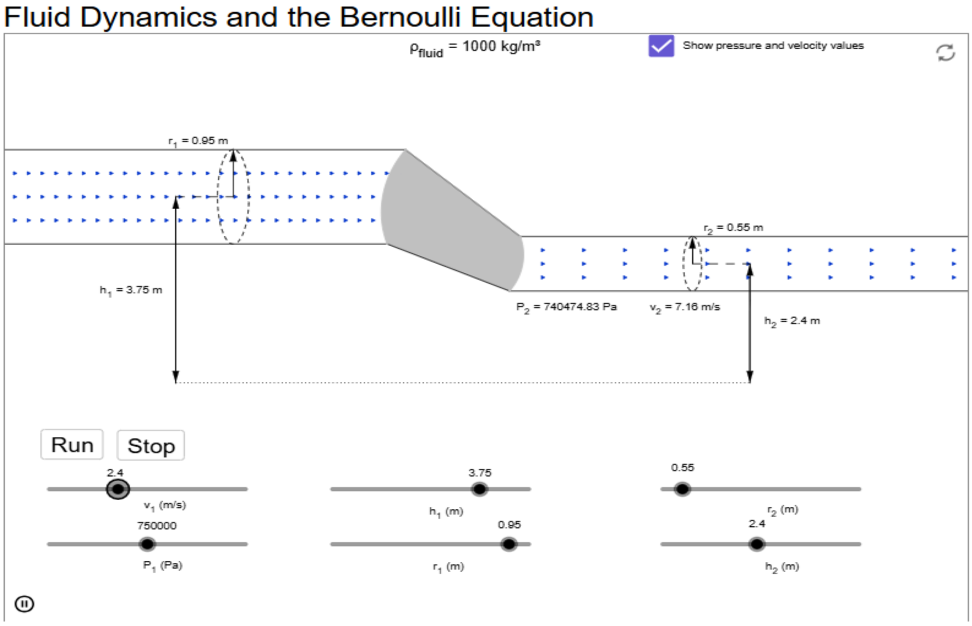
Appendix

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



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.