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The Effect of Socioscientific Issue-Based Digital Comics Design on Gifted Students' Attitude Towards Environment

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Abstract

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Keywords: Attitude towards environment, Gifted students, Digital comics, Socio-scientific issues

Introduction

Gifted individuals are trained to take the lead in social and scientific issues. They are expected to shape the future, think critically, make decisions, produce solutions to social issues, and to

relate scientific issues to society. Their ability to be creative citizens who bring society and science together, address social issues with a critical approach and produce scientific and lasting solutions may contribute to the creation of a livable society and world.

In order to create a better and fairer society, it is important to raise effective and efficient citizens who can discuss scientific issues and relate these issues to society and produce solutions to social problems. According to Hofstein et al. (2011), students can learn scientific subjects and achieve academic success in science courses by learning the laws of thermodynamics without realizing the social issue of climate change. However, this academic success may have been a success far removed from skills and values. Therefore, as stated by Eastwood et al. (2012), more important than having scientific knowledge and gaining academic success solely through knowledge is that individuals relate scientific issues to society and gain social meaning and sensitivity. As can be understood from these statements, socioscientific issues (SSI) are scientific and social issues that can help raise aware and sensitive citizens by addressing scientific issues at a social level. According to Topçu (2017), bringing SSI into the classroom and discussing it helps individuals become successful citizens in solving social problems and, therefore, in developing societies. So, SSI, which can be found in various fields (Johnson et al., 2021; Johnson et al., 2022), is also included in citizenship education. The way to embody citizenship education through science is to teach individuals SSI (Barrue & Albe, 2013). One of the goals of SSI teaching is to raise conscious citizens for the future (Demircioğlu & Uçar, 2014).

SSI, inclusive and controversial in nature, offers individuals the opportunity to become citizens who can relate issues to the real world and address these issues with values such as power, social justice, and equality (Johnson et al., 2021). Thus, it enables individuals to develop socially (Sadler & Zeidler, 2005) and helps create a citizen profile. According to Barrue and

Albe, (2013) The socio-scientific citizen profile is divided into four: A citizen engaged in socio-political action, a critical citizen being able to participate to public debate and decision making, a citizen having knowledge in science, a peaceful citizen, who resolves conflicts with peaceful way (p.1093). When these SSI citizen profiles are examined, it can be understood that individuals are defined as citizens who think critically, act responsibly, produce solutions and choose solutions with democratic values.

Comics can be used as an effective educational tool in raising individuals equipped with knowledge, skills and values in the context of the socio-scientific citizen profile. According to Ak, et al (2020) the use of comics within the scope of citizenship education is very significant. Printed or digital comics are the art of storytelling and are tools that develop readers' ability to interpret visual, auditory and verbal messages within the scope of this art (Eisner, 1985). Producing these images and messages and reading them is a kind of literacy skill. As McCloud (2018) stated, comics are educational tools that improve literacy skills. Reading or producing comics as a print resource can be addressed in many literacy perspectives, such as visual literacy, economic literacy, environmental literacy, and legal literacy. For example, producing and reading comics in a digital environment develops digital literacy skills (Kirchoff, 2017).

Today, comics have gained the feature of being digital with the start of the digital age and have diversified with names such as "web comics, interactive comics, animated comics, Webtoon and artificial intelligence comics.". Digital comics are comics in digital formats. While similar, digital comics offer greater flexibility and interactivity (Ünal, 2025). In addition, the use of comics in the digital environment with digital tools such as Pixton helps individuals to concretize and give meaning to values (Ak et al, 2020). One of the values that need to be concretized, developed and given meaning in individuals is a positive attitude towards the environment, that is, environmental sensitivity.

Educational comics providing cognitive and affective development are one of the effective materials in raising environmental awareness and sensitivity in schools (Topkaya & Doğan, 2020; Wolschke-Bulmahn & Gröning, 1994). Educational comics have a very important place in helping individuals gain awareness and responsibility towards environmental issues (Wolschke-Bulmahn & Gröning, 1994). One of the effects of educational comics on the sentimental domain is that they raise students' sense of curiosity to a higher level (Topkaya & Doğan, 2020). In other words, comics help develop the sentimental field by increasing the sense of curiosity in the process of gaining environmental awareness. In addition, as Tatalovic (2009) stated, comics increase children's interest in the lesson and motivate them by making the lesson fun and interesting. Comics also help students succeed with the texts and visuals they contain (Sones, 1944). Considering all these views, social issues and the impact of the digital age on today, the use of digital comics in teaching SSI, which requires citizens to examine social and scientific issues with a sense of curiosity and to discuss them by relating them to each other, constitutes an important point. There is a need to use digital comics focusing on different SSI topics in education so that individuals can see the effects of global warming, environmental pollution, nuclear power plants, and Genetically Modified Organism (GMO) food production on the environment, living beings, and public health within the scope of SSI, criticize them, be creative, produce solutions, and gain environmental awareness. Değirmenci and Doğru (2017) and Aydın and Kılıç Mocan (2019) suggest conducting research that includes different SSI in education, Farinella (2018) suggests conducting experimental research that investigates the effects of application-oriented comics on various variables in education.

Conceptual Framework

Socioscientific Issues (SSI) and Environmental Sensitivity

SSI is a field that involves scientific issues and social dilemmas, controversial and more political issues that concern society (Sadler & Zeidler, 2005). SSI, which helps individuals identify evidence-based arguments and counter-arguments (Albe & Gombert, 2012) and which refers to controversial scientific issues in society (Zeidler, 2014), consists of topics such as global warming, genetically modified organisms stem cells, human cloning, and nuclear power plants (Kapıcı & İlhan, 2016).

SSI is addressed with different topics in different educational fields and includes controversial SSI in the curriculum of many countries (Dawson, 2001). For example, in French schools, topics such as energy, environment and sustainable development, meteorology and climatology, statistical approach of the scientific world, health and safety are discussed in relation to society for citizenship education purposes. In France, these SSI topics are common to six subject matters forming the ‘‘wider scientific field’’: Mathematics, physics and chemistry, biology, technology, physical education, history, geography and citizenship education (Barrue & Albe, 2013). The common goal in teaching SSI, which can be covered in different courses, is to raise citizens who contribute to social development (Johnson et al., 2021; Johnson et al., 2022). In other words, SSI aims to encourage individuals to discuss issues such as nuclear energy, global warming, and environmental pollution, to find solutions, and to become sensitive and responsible citizens.

When the studies on SSI are examined, it is seen that GMO and nuclear energy issues are discussed more (Değirmencioğlu & Doğru, 2017). Nuclear energy, one of the SSI (Çiçek & Genç, 2024), was brought to the agenda all over the world after the Chernobyl disaster, which had serious effects on the environment and living things. In Türkiye also, the issue of nuclear energy is one of the SSI on the agenda (Eş et al., 2016). Global warming is also a frequently discussed topic within SSI (Barrue & Albe, 2013). In addition to global warming, SSIs such as

hydroelectric power plants, nuclear energy/power plants, GMO products, organ donation are issues with regional and global impacts that have long been a topic of debate in society (Topçu, 2017). These issues need to be addressed, discussed, and solutions developed. Because they have a close relationship and impact on the environment, nature, humans and animals. For example, as Özbek and Aslan (2024) stated, the negative impact of nuclear power plants on the environment has been discussed for years and is still a current issue. Although SSI, such as GMO products, which are one of the most debated topics in biotechnology, are mostly discussed from a health perspective, they also have very serious environmental impacts (Sönmez & Kılınç, 2012) and are open to ethical criticism. Therefore, SSI, providing ethical and moral development (Zeidler et al., 2005), needs to be discussed and environmental awareness should be raised. As Kurup et al (2021) stated, SSI such as global warming and climate change are environmental problems that every citizen should take responsibility for globally. In order to eliminate or minimize these problems, individuals must be sensitive to the environment.

Environmental sensitivity is the willingness of individuals to take responsibility for environmental problems, take action, and take positive initiatives (Çalışkan, 2002). SSI increases and improves individuals' environmental sensitivity (Macalalag et al, 2020). In other words, adressing SSI -such as nuclear energy and global warming- helps individuals take positive initiatives towards environmental problems and be willing to take responsibility and solve problems.

Digital Comics and Tools (Pixton and Canva)

Comics are actually deeply rooted in human history, dating back to prehistoric times. The pictures people drew on cave walls to describe an event/situation are the first attempts at comics, and their use in education dates back to ancient times (Eisner, 1974; İlhan & Oruç, 2019; McCloud, 2018). Today's modern comics were shaped by Töpffer, who is considered the father of modern comics (McCloud, 2018; Ünal, 2025). The use of comics in education dates back to the 20th century, the 1930s (Sones, 1944). Comics is a sequential art form that presents sequential and ongoing stories to readers through visual and verbal messages (Eisner, 1985). Comics is composed of sequential panels, characters, and speech bubbles (Waugh, 1991). Based on the definitions of comics in literature, Ünal (2025) states that people agree that comics is a sequential form of narration, bringing together images and texts, but as a result of the discussions, the form of narration cannot be standardized.

Comics, defined as entertaining texts (Sones, 1944), positively affects students' academic success, attitudes towards the course and democratic perceptions (Topkaya, 2016). Comics, which gained a new dimension on digital platforms in the 2000s, namely digitalization (Ünal, 2025), help students develop an understanding of science by simplifying complex concepts (Cha et al, 2021). Digital comics are visual, textual and auditory tools that increase motivation (Tatalovic, 2009; Toh et al, 2016), increase interest in scientific subjects (Farinella, 2018) and provide digital literacy (Kirchoff, 2017) empathy and creative thinking skills (Şeker, 2023).

There are many digital tools that support reading and creating digital comics (Goodbrey, 2013). The use of digital tools enriches the teaching of SSI, so the use of digital tools is important within the scope of SSI (Karışan & Zeidler, 2024). These digital tools include Pixton and Canva. Research has shown that Pixton is effective in learning, makes topics fun, promotes empathy, creativity, effective communication, and increases motivation in digital comic designs

(Alp & Coşkun Onan, 2023; Bas & Yıldırım, 2018; Cabrera et al. 2018; Çiçek Şentürk, 2020; Kohnke 2021; Şeker, 2023; Topkaya, 2014; Topkaya, 2016; Topkaya & Doğan, 2020; Tekin & İlhan, 2025). It can be said that comics prepared with Canva also have similar results. In the study on SSI conducted by Çiçek & Genç (2024), it was concluded that using Canva to address SSI caused students to find the topics more interesting and informative, and to gain awareness.

The Current Study

There are studies showing that SSI increases individuals' argument quality (Albe & Gombert, 2012; Atasoy & Yüca, 2021; Osborne, et al., 2004; Venville & Dawson, 2010) and environmental awareness (Macalalag et al. 2020); and improves scientific literacy (Macalalag et al., 2020), critical and analytical thinking (Çiçek & Genç, 2024; De Checchi et al. 2022; Sadler & Zeidler, 2005). However, although SSIs are used as tools and purposes, there is very little research examining the most appropriate pedagogical approaches for addressing and teaching them in schools (Topçu, 2017).

There are also studies that address SSI issues through comics (Abrori, et al. 2024; Abrori, et al. 2023; Alp & Coşkun Onan, 2023; Asli, 2025; Cha et al. 2021; Missiou & Stefos 2012; Lestari et al., 2021; Smith et al. 2019; Topkaya & Doğan 2020). There are many studies on the use of digital comics in many fields such as mathematics, social studies, history, geography, science, foreign language and citizenship education (Ak et al, 2020; Başar, 2022; Cabrera et al., 2018; Cha et al, 2021; Damopolii et al, 2022; İlhan & Şahin, 2019; Malau et al., 2021; Musa et al., 2020; Oliwe & Chao, 2022; Tekin & İlhan, 2025; Topkaya, 2014; Topkaya, 2016; Widyasari & Nurcahyani, 2021). In these studies, it was concluded that comics increase interest in the course, academic success, and make the course attractive. However, Abrori et al (2025) states that studies dealing with SSI-based comics in education and training activities are very new and recommends using digital comics as well as printed comics and considering

different SSIs in research on SSI. As McCloud (2018) stated, comics are not conceptually static and, the era they are in, gives them new meanings. Due to the dominance of the digital age, there is a need for researches addressing various SSIs with digital comics, which are much newer than the term comics.

On the other hand, there is a need for studies on the use of digital comics in the education of gifted individuals studying in science and art centers (SAC). They are expected to be creative, think critically and produce solutions to social problems in the light of scientific findings. Kersulov and Henze (2021) had gifted individuals design media literacy-focused comics as printed books in a non-digital environment. In their research, they concluded that students' creativity and communication skills improved.

Değirmenci and Doğru (2017), examining the studies involving SSI in Türkiye, stated that the studies mostly included nuclear energy and GMO foods. They suggest that studies to be conducted should include these as well as other SSI such as global warming, environmental pollution, cloning, and stem cells, which are the most controversial issues discussed in the world. Aydın and Kılıç Mocan (2019) concluded that although there are few studies on SSI in Türkiye, it has attracted increasing attention over the last 10 years and that the studies mostly focused on GMO products and interviews and surveys were conducted with prospective teachers and non-gifted secondary school students. Sönmez and Kılınç (2012) suggest that SSI, which has been on the agenda frequently lately, should be addressed by students, the decision makers of the future, and they should learn to make rational decisions. Tortop (2013) suggests that gifted students should be guided towards issues that are on the agenda of their country and concern their future, and that education should be planned in a way that will enable gifted individuals to be interested in these issues and actively participate in them. Akbaş and Çetin (2018) state that various SSI that affect the present and future of countries, such as global

warming, environmental pollution, nuclear power plants, and GMO products, are issues that affect societies and their future, and that gifted individuals should be interested in these issues. Within the scope of the studies and these recommendations, it is understood that studies should be carried out in secondary schools to develop positive attitudes towards the environment by designing SSI-based digital comics for gifted individuals. Therefore, the research problem question is "What is the effect of SSI-based digital comics design activities on gifted students' attitudes towards the environment?". In this context, answers to the following sub-problems were sought.

1. Is there a significant difference between the environmental attitudes of gifted students, participated in SSI-based digital comics design activities (Experimental Group) and those did not (Control Group)?
2. What kind of impact do SSI-based digital comics design activities have on gifted students' attitudes towards the environment?
3. What are the views of gifted students regarding the SSI-based digital comics design process and their attitudes towards the environment?

Method

Research Design

In this study, a mixed design combining "pre-test & post-test control group (CG) fully/strongly experimental design" and qualitative data collection methods was adopted in order to determine the effects of SSI-based digital comic book design activities on the environmental awareness of gifted students. This design provides a powerful framework for examining causal relationships (Creswell & Creswell, 2018) and provides an in-depth understanding of the process with qualitative data (Yıldırım & Şimşek, 2018). The research design of the study is presented in Figure 1.

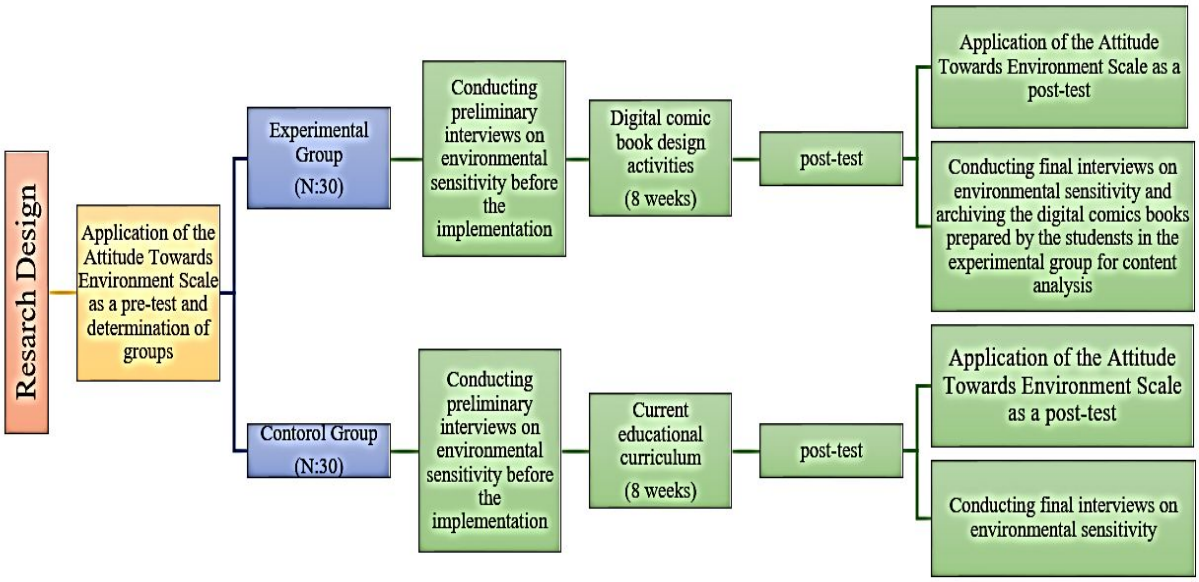

Figure 1. The research design of the study

Study Group

The study was conducted during the fall semester of the 2024–2025 academic year at a SAC located in the western region of Türkiye. In Türkiye, SACs offer support programs across various talent domains and design enriched, interdisciplinary workshops that consider students' individual differences (MoNE, 2022). These workshops are typically organized in small groups of around 10 students to foster active participation.

The study was carried out in an environmental workshop designed as a learning space that emphasizes values such as environmental awareness and sensitivity. This workshop includes 60 gifted students, aged between 11 and 12, who have been identified as eligible for support education. The research was conducted with students who regularly attend this workshop. Participants were selected on a voluntary basis, and informed consent forms were obtained from both the students and their parents.

Students were randomly assigned to either the experimental group (EG) (n = 30) or the control group (CG) (n = 30). Prior to this assignment, all students were administered an Environmental Attitude Scale. Based on their scores, students were ranked from 1 to 60. Students with odd numbers were placed in the EG, while those with even numbers were assigned to the CG.

To assess whether the two groups had similar baseline characteristics, demographic variables such as age, gender, grade level, duration of attendance at SAC, and area of giftedness were examined. The analysis revealed no statistically significant differences between the groups in these variables. This finding is considered an important factor in supporting the internal validity of the research results.

Data Collection Tools

Quantitative Data Collection Tool

In the study, the "Attitude Towards the Environment Scale" (ATES) developed by Yeşil and Turan (2020) was used to determine the environmental awareness levels of the students. It was developed to measure knowledge, feelings and attitudes towards the environment, and validity and reliability analyses were conducted. The KMO value of the scale was calculated as .845 and the Cronbach's Alpha reliability coefficient of the 20-item structure was calculated as .845. According to confirmatory factor analysis, it was seen that the construct validity of the scale was ensured. (X^2/df = 1,791; GFI = ,869; CFI = ,928; RMSEA = ,068). In line with these findings, it was stated that the scale consists of two upper factors; the first factor covers the dimension of knowledge and emotion towards the environment, while the other four sub-factors represent different aspects of environmental attitudes. In this study, this scale was used as a pre-test and post-test to determine the change in environmental awareness levels.

Qualitative Data Collection Tools

Semi-structured interviews were conducted with ten (10) students from each EG and CG in order to gain an in-depth understanding of the participating students' experiences of the process and the changes in their views on environmental awareness. They were determined using the purposive sampling method. Specifically, maximum variation sampling was used to represent students with different levels (high, medium, low), gender distribution, and interest levels in environmental issues according to the data on the environmental attitude scale. In this way, the data obtained were ensured to reflect different perspectives (Patton, 2015). Interview questions covered situations such as what the activities contributed to the students, the points they had difficulty with, and the changes in their perspective on the environment. Additionally, digital comics documents based on SSI designed by students were examined as a source of qualitative data. The content of these designs, their approaches to environmental problems, solution suggestions and creativity were evaluated using thematic analysis methods. The products were accepted as concrete indicators of students' learning and cognitive processes.

Experimental Process

Experimental Group Process

Thirty students in the EG (3 environmental workshop groups at the SAC, each consisting of 10 students) participated in SSI-based digital comic book design activities for 6 weeks, 2 hours per week, for a total of 12 lesson hours (80 minutes per lesson hour). The activities were carried out during the Environmental Workshop class hours at the SAC, under the direct guidance and active participation of the researcher. The SSI identified for the environmental workshop are:

Global Warming: The causes (e.g., fossil fuels, deforestation), environmental (e.g., melting glaciers, sea level rise) and social (e.g., climate migrations, food insecurity) consequences,

individual and societal impacts on daily life, and possible solutions at the national/international level (e.g., renewable energy, energy efficiency) are discussed.

Nuclear Power Plants: Energy production potential (nuclear fission), operational and safety risks (e.g. Chernobyl, Fukushima accidents), radioactive waste management problems and long-term effects on the environment (e.g. radioactivity, soil and water pollution) were evaluated.

Environmental Pollution (Air, Water, Soil): The main sources (e.g., industrial wastes, household wastes, exhaust gases), direct and indirect effects on human health (e.g., respiratory diseases, cancer) and ecosystems (e.g., biodiversity loss, habitat destruction), and strategies for preventing and reducing pollution (e.g., treatment plants, filter systems, conscious consumption) were examined.

Genetically Modified Organisms (GMO Crops): The aims of their development (e.g., increased yield, pest resistance), their potential benefits in terms of agricultural productivity and food security, and their possible ethical and environmental impacts on public health (e.g., allergies, antibiotic resistance) and biodiversity (e.g., gene flow, formation of superweeds) were discussed in multiple dimensions.

Effects of Pesticides on Public Health: The effects of pesticides commonly used in agriculture on human health (e.g., residue problems, neurological disorders), environmental damage (e.g., soil and water pollution, death of beneficial organisms) and alternative approaches for sustainable agriculture (e.g., organic farming, biological control) were examined.

Before the activities began, all necessary technical and administrative preparations for the Pixton and Canva platforms, which will be used in the digital comic design process, were

completed. For Pixton, each of students was assigned an individual user code and password by the researcher, ensuring seamless access to the platform (See Figure 2).

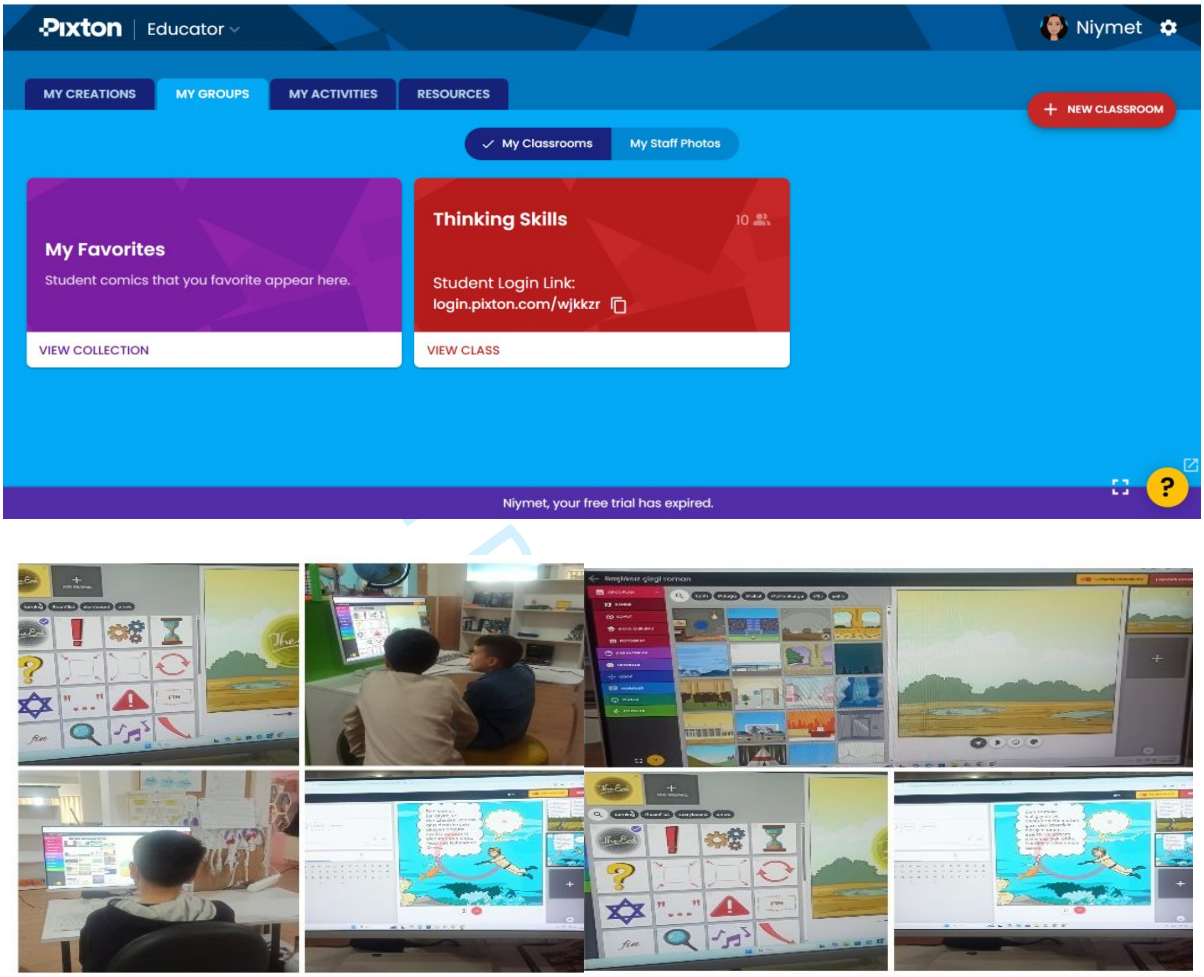

Figure 2. Interface and usage examples of the Pixton digital comics tool

In order to benefit from the premium features of the Canva platform, the researcher applied for a teacher account and, after approval, registered the students in the system (See Figure 3). These preliminary preparations allowed students to focus directly on the design process without encountering technical problems during class hours.

The main reason why Pixton and Canva are preferred in digital comics design activities is that these tools offer user-friendly and intuitive interfaces for gifted students. In this way, students can focus on their creativity without needing drawing skills and develop their visual

literacy and digital competencies. Additionally, Pixton's storytelling and Canva's visualization flexibility allow for complex SSI to be represented in an engaging and understandable way.

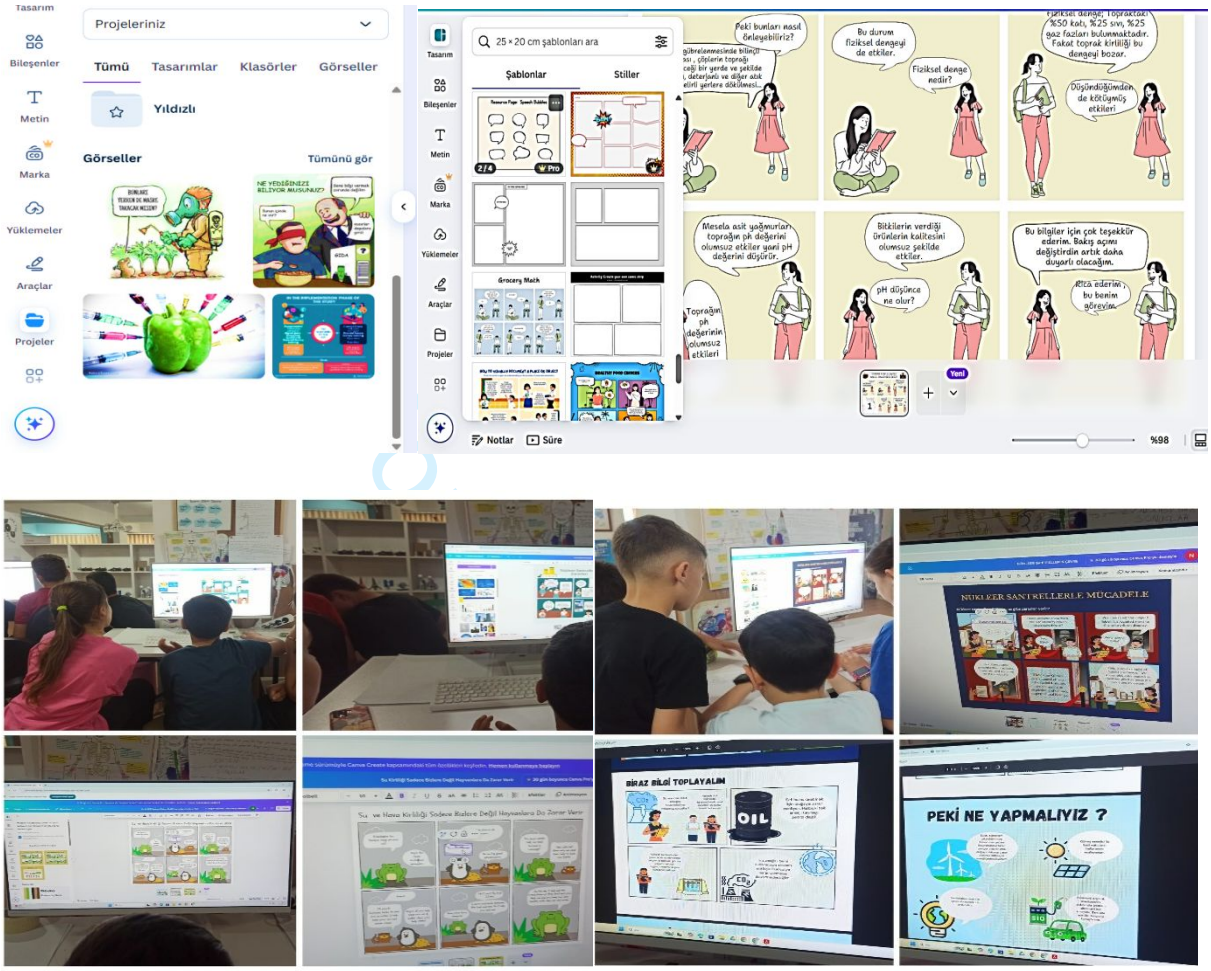

Figure 3. Classroom applications for designing comics using the Canva program

For each SSI, students were first provided with comprehensive information about the relevant topic, discussed different scientific and societal perspectives, and analyzed the multi-dimensional structure of the problem. At this stage, students collected relevant data by conducting their own research and observations from various sources (internet, books, documentaries). Following the information collection and analysis phase, students used the information they acquired to design digital comics detailing the SSI and offering original solutions to the problems, using digital design tools such as Pixton and Canva.

The researcher provided conceptual and technical guidance to the students throughout the process, facilitated group discussions, and provided the necessary technical support. The students' interactions throughout the process, the problem-solving approaches they used, and the cognitive progress they made were meticulously documented with detailed observation notes.

Control Group Process

Thirty students in the CG (3 environmental workshop groups at the SAC, each consisting of 10 students) continued their existing "Environmental Workshop" curriculum at the SAC during the same 6-week period in parallel with the EG. This curriculum includes structured activities to increase students' environmental and nature awareness within the framework of the Special Talented Students Support Education Program determined by the Ministry of National Education, General Directorate of Special Education and Guidance Services (MoNE, 2021). During this 6-week period, the CG participated in various activities such as:

Acquisition of Basic Environmental Knowledge: Lectures and presentations were given on basic environmental concepts such as ecosystem, biodiversity, natural resources, energy sources and outlines of environmental problems (e.g. water and air pollution, erosion). Students reviewed informational materials aimed at developing environmental literacy skills.

Recycling and Waste Management Practices: The importance of recycling, waste separation principles, and practical applications for reducing waste in daily life were emphasized. Students participated in simple recycling projects, such as creating new products from waste materials.

Environmental Awareness Activities: Students' environmental awareness was reinforced through activities such as watching environmentally themed short films, listening to

environmental songs, and preparing simple posters about environmental issues. A sense of environmental responsibility was emphasized through group discussions.

Reading and Discussion Activities: Environmentally themed storybooks or article excerpts were read, and then general discussions about these topics were held in the class.

The curriculum of the CG did not include SSI -based digital comic book design activities or similar digital creativity and modeling-focused projects constituting the experimental intervention of this study. The CG was not provided with any additional activities, materials, or special training other than the specific intervention applied to the EG. Students' current educational processes were not disrupted, and their course schedules and interactions with their teachers continued unchanged. This controlled approach helped isolate the true impact of the independent variable (SSI-based digital comic book design activities) on the dependent variable (environmental awareness) in order to increase the internal validity of the study. (Creswell & Creswell, 2018; Shadish, Cook, & Campbell, 2002). The presence of the CG provides a strong basis for comparison to determine that any changes observed in the EG are due solely to the intervention implemented.

After the completion of the 6-week experimental intervention period, the ATES was re-administered to both groups as a post-test. Post-test scores were analyzed to determine the changes in the students' environmental awareness levels after the intervention and to statistically compare the differences between the EG and the CG. Additionally, qualitative data (interviews, product portfolios) were collected from students in the EG and CG to gain an in-depth understanding of the intervention and a comprehensive perspective on students' experiences.

Data Analysis

Quantitative Data Analysis

The normal distribution of data, which is one of the basic assumptions of parametric statistical analyses, was examined for the Environmental Awareness Scale scores applied in the pre-test phase of the study. The number of students in each group (n=30) is considered sufficient to test the normality assumption (Büyüköztürk et al, 2020; Field, 2018).

Table 1 summarizes the normality test results for the ATES pre-test scores of the EG and CG:

Table 1. Pre-Test Values and Normality Analysis of the ATES Sub-Dimensions

Sub-Dimension	Group	M	SS	Skewness	Kurtosis	T	p	Normality
Knowledge/ Emotion	EG	4.43	0.49	-0.45	0.78	0.15	0.88	Normal
	CG	4.40	0.61	-0.38	0.82			Normal
Sensitive Behavior	EG	3.00	1.12	-0.29	0.45	0.13	0.90	Normal
	CG	2.90	1.04	-0.31	0.51			Normal
Attentive Behavior	EG	3.20	0.95	-0.42	0.68	-0.11	0.91	Normal
	CG	3.30	1.02	-0.39	0.65			Normal

Recycling	EG	3.00	1.15	-0.51	0.72	-0.17	0.86	Normal
	CG	2.95	1.03	-0.48	0.69			Normal

As seen in Table 1, as a result of the normality tests, it was determined that the skewness values for all sub-dimensions of the ATES were in the range of -0.51 to -0.29, and the kurtosis values were in the range of 0.45 to 0.82. As stated by George & Mallery (2001), skewness and kurtosis values being within ±2 indicate that the data have a normal distribution. These findings show that the normal distribution assumption was met in all sub-dimensions in the study and the data were suitable for parametric tests. According to the results of the independent sample t-test conducted to evaluate the initial equivalence of the groups, no statistically significant difference was found between the Environmental Awareness Scale pre-test scores ($p > 0.05$). This situation reveals that the EG and CG are equivalent in terms of initial environmental awareness levels and is a positive finding in terms of the internal validity of the study.

Analysis of Covariance (ANCOVA) was used to control for baseline differences between the groups and to more clearly measure the effect of the intervention on the experimental group. Prior to the analysis, the necessary assumptions for the correct application of ANCOVA were checked (Tabachnick & Fidell, 2019).

The data met all necessary assumptions for analysis across all dimensions. For the *Knowledge-Emotion* dimension, Levene's test confirmed homogeneity of variance ($p = 0.227$), while Pearson correlation revealed a strong linear relationship between pre-test and post-test scores ($r = 0.854$, $p < 0.01$). Box's M test indicated homogeneity of regression slopes ($p > 0.05$). Similarly, for the *Sensitive Behavior* dimension, variance homogeneity was established (Levene's $p = 0.137$), with a significant pre-post correlation ($r = 0.75$, $p < 0.01$) and

confirmed slope homogeneity (Box's M p > 0.05). The *Conscientious Behavior* dimension also showed homogeneous variances (Levene's p = 0.582), a moderate but significant pre-post correlation (r = 0.55, p < 0.01), and met the regression slopes assumption (Box's M p > 0.05). The Recycling dimension likewise met all necessary assumptions, demonstrating variance homogeneity (Levene's p = .915), a significant moderate pre-post correlation (r = .69, p < .01), and satisfactory regression slopes homogeneity (Box's M p > .05). All three dimensions were therefore deemed appropriate for subsequent ANCOVA analysis.

Following the fulfillment of these assumptions, the ANCOVA analysis was conducted to examine whether there was a statistically significant difference between the post-test scores of the experimental and control groups when the pre-test scores were controlled for. The eta-squared (η2) value was also calculated in the analysis to determine the magnitude of the intervention's effect. This value is interpreted as a small effect for values between 0.01-0.06, a medium effect for 0.06-0.14, and a large effect for values above 0.14 (Davey & Savla, 2010; Field, 2018). Thus, in addition to the difference between the groups, the strength of the applied intervention was also revealed. Quantitative data analysis was done with SPSS 20 program.

Qualitative Data Analysis

The data obtained from the interviews were analyzed with thematic analysis. The steps involved familiarizing ourselves with the data, creating initial codes, searching for themes, reviewing, defining, and reporting. The codes and categories obtained from the data analysis are presented in Table 2.

Table 2. Categories and Codes According to SSI and Environmental Awareness Themes

Main Theme	Categori	Code	Sample Student Expression
Socioscientific Perception	Definition	Science-society interaction	"Issues related to how science provides solutions to social problems"
		Current debates	"Controversial issues such as nuclear energy and GMO foods"
Environmental Awareness	Definition	Conscious observation	“Noticing changes in nature"
		Ecological balance	“Human-nature harmony is important"
Individual Impact	Behavior	Consumption habits	"I reduced my plastic use."
	Motivation	Concerns about the future	"We must leave a livable world for our children."
Societal Impact	Collective Action	Political influence	"Public awareness changes laws."
		Educational needs	“Environmental courses should be mandatory in schools”

Analysis of Student Product Files (Digital Comics)

The digital comics created by the EG were analyzed thematically.Various strategies were used to increase the validity and reliability of the qualitative findings. The findings were supported by triangulation using different data sources such as interviews and comics (Denzin & Lincoln, 2011). To ensure coding consistency, agreement between researchers was examined and participant confirmation confirmed that students' statements were accurately reflected. The findings are described in detail with direct quotations.

Findings

Quantitative Findings

Table 3 presents the ATES pre-test and post-test score analyses of the EG and CG:

Table 3. Pre-test and Post-test ATES Mean Scores of the EG and the CG

Factor	Grup	Test	N	(M)	SD	T	p	Cohen's d
Knowledge/Emotion	EG	Pre-test	30	4.43	0.49	3.21	0.002	0.82
	CG	Pre-test	30	4.40	0.61			
	EG	Post-test	30	4.90	0.30	4.56	<0.001	1.17
	CG	Post-test	30	4.45	0.50			
Sensitive Behavior	EG	Pre-test	30	3.00	1.12	2.89	0.005	0.74
	CG	Pre-test	30	2.90	1.04			
	EG	Post-test	30	4.40	0.81	5.12	<0.001	1.31
	CG	Post-test	30	3.20	0.92			
Attentive Behavior	EG	Pre-test	30	3.20	0.95	1.98	0.051	0.51

	CG	Pre-test	30	3.30	1.02		
	EG	Post-test	30	4.60	0.66	4.20	<0.001	1.08
	CG	Post-test	30	3.80	0.77		
Recycling	EG	Pre-test	30	3.00	1.15	2.10	0.039	0.54
	CG	Pre-test	30	2.95	1.03		
	EG	Post-test	30	4.50	0.86	5.45	<0.001	1.40
	CG	Post-test	30	3.30	0.95		

When Table 3 is examined, the knowledge/emotion scores of the EG showed a remarkable increase between the pre-test and post-test. The mean score, which was 4.43 in the pre-test, increased to 4.90 in the post-test, while this increase was much more limited in the CG (from 4.40 to 4.45). The statistically significant difference between the two groups ($p<0.001$) and the large effect size ($d=1.17$) reveal that the training program was extremely effective in strengthening the participants' knowledge levels and emotional bonds with the environment. These findings show that the process of writing digital comics related to SSI is successful in terms of theoretical knowledge transfer and emotional bonding.

The improvement in the sensitive behavior dimension of the EG is quite striking. The mean score, which was 3.00 in the pre-test, showed a significant increase, rising to 4.40 in the

post-test. The increase in the CG was much more modest (from 2.90 to 3.20). The fact that this difference between the groups is statistically significant ($p<0.001$) and has a very large effect size ($d=1.31$) shows that the process of writing digital comics related to SSI was extremely successful in increasing the environmental awareness of the participants and turning this into behavior.

Significant improvements were also noted in the EG's attentive behavior dimension. The mean score of the EG increased from 3.20 to 4.60, while the increase in the CG was more limited (from 3.30 to 3.80). The large effect size obtained ($d=1.08$) shows that the program is effective in ensuring that participants behave more carefully towards the environment in their daily lives. Especially considering the pre-test scores of $p=0.051$, the significance level of $p<0.001$ obtained in the post-test clearly demonstrates the effectiveness of the digital comic book writing process related to SSI in this area.

Progress in the recycling dimension has the highest effect size ($d=1.40$) among all dimensions. While the mean score of the EG increased from 3.00 to 4.50, the increase in the CG was quite limited (from 2.95 to 3.30). These results show that the program was significantly effective in improving participants' recycling habits.

The analyses show that the implemented program provides statistically significant and practically important improvements in all sub-dimensions of environmental awareness. Particularly large effect sizes ranging from 1.08 to 1.40 strongly support the effectiveness of the program.

In this study, Analysis of Covariance (ANCOVA) was conducted to control for initial differences (pretest scores) between the groups. The results of the analysis are presented in Table 4.

Table 4. ANCOVA Results of Adjusted Post-Test Scores on the ATES Based on Pre-Test Scores

Factor	**Source**	**Type III SS**	**df**	**Mean Square**	**F**	**Sig. (p)**	**Partial η²**
Knowledge/Emotion	Corrected Model	395,40[a]	3	197,70	83,11	<0.001	0.745
	Intercept	75,348	1	76,34	32,09	<0.001	0.360
	Group (EG)	395,40	2	197,70	**83,11**	<0.001	**0.745**
	Error	135,584	56	0.82			
Sensitive Behavior	Corrected Model	121,64[a]	3	40,45	24,39	<0.001	0.566
	Intercept	147,31	1	147,31	88,61	0.001	0.613
	Pre-test	8.09	1	8.09	4,87	0.003	0.08
	Group (EG)	42,10	1	42,10	**25,32**	<0.001	**0.31**
	Error	93,09	56	0.82			
Attentive Behavior	Corrected Model	282,433[a]	3	94,14	34,29	<0.001	0.648
	Intercept	536,38	1	536,38	195,36	0.001	0.777
	Pre-test	152,12	1	152,12	55,40	0.000	0.497
	Group (EG)	83,81	1	98,81	**30,52**	<0.000	**0.353**
	Error	153,75	56	0.82			

Recycling	Corrected Model	197,60[a]	3	65,86	32,08	<0.001	0.632
	Intercept	417,94	1	417,94	203,55	<0.001	0.784
	Pre-test	26,21	1	26,21	12,76	0.001	0.186
	Group (EG)	72,64	1	72,64	**35,38**	<0.000	**0.387**
	Error	114,97	56	2,05			

The detailed analysis of Table 4 clearly demonstrates the effects of digital comic activities on gifted students' levels of attitude towards environment. The ANCOVA results show that the experimental group exhibited statistically significant ($p<0.001$) and educationally meaningful performance compared to the control group across all sub-dimensions.

The results of the Analysis of Covariance (ANCOVA) revealed that the experimental intervention had a significant effect on all sub-dimensions of the ATES when pre-test scores were controlled for. The finding that the adjusted model was significant in the Knowledge/Emotion dimension ($F(3, 56) = 83.11$, $p < .001$) and accounted for 74.5% of the variance ($\eta 2 = 0.745$) indicates that the intervention was extremely effective in this area. In the Sensitive Behavior dimension, the fact that both the pre-test scores ($p = .003$) and the difference between the groups ($p < .001$) were significant indicates that the intervention was successful in increasing these behaviors.

In the Attentive Behavior dimension, despite the strong effect of the pre-test scores ($\eta 2 = 0.497$), significant differences were still found between the groups ($p < .001$). In Recycling behaviors, it was observed that the intervention group received significantly higher scores

compared to the control group ($p < .001$). The high partial eta-squared values obtained in all dimensions (0.31-0.745) reveal the strength of the intervention's effect.

In conclusion, it can be said that the experimental intervention provided a significant and positive change in both the cognitive-emotional and behavioral dimensions of environmental attitudes and behaviors. The observation of the strongest effects, especially in the dimension of environmental knowledge and emotional attachment, suggests that the intervention was successful in increasing participants' internal motivation related to the environment. The findings emphasize the importance of designing environmental education programs with a holistic approach.

Qualitative Findings

This section presents findings obtained through qualitative data collection methods (interviews with two groups and the EG's digital comic book designs) based on thematic analysis results. The analysis aimed to reveal intervention-related differences in the views of EG and CG on SSI and their levels of environmental awareness.

Socioscientific Perception

This theme examines how students define socio-scientific issues and how they relate them to everyday life. Significant differences were identified between the groups in the depth and expression of perception on the SSI. For example, both groups related SSI to science's ability to provide solutions to social problems. However, EG expressed this interaction with more concrete and action-oriented examples through digital comic book design activities. In their comics, they emphasized the role of scientists in actively creating solutions by narrating their research

"Scientists produced special bacteria for the seas to clean up factory waste. As we saw in the comics, when these bacteria cleaned the river, the fish returned..." (EG1-See Figure 4)

"Scientists hold conferences to raise public awareness about preventing global warming. Thus, science directly changes people's lives..." (EG3- See Figure 4)

Figure 4. EG's digital comics prepared to prevent global warming and raise people's awareness

While the control group shared their experience during the environmental education process;

"We learned from the text we read that global warming will harm us. Therefore, we must be careful. ..." (CG4)

"We should raise public awareness by placing recycling bins. I think this is important ....." (CG6)

With similar expressions, they took more general approaches compared to EG. EG students have further deepened their research and used their scientific process skills to reflect it in digital comics. A similar situation exists when discussing SSI, such as nuclear energy and GMO foods. Throughout the intervention process, EG students have better reflected different aspects of these debates (e.g., both the benefits and risks of GMOs) in their comics designs (Figure 5).

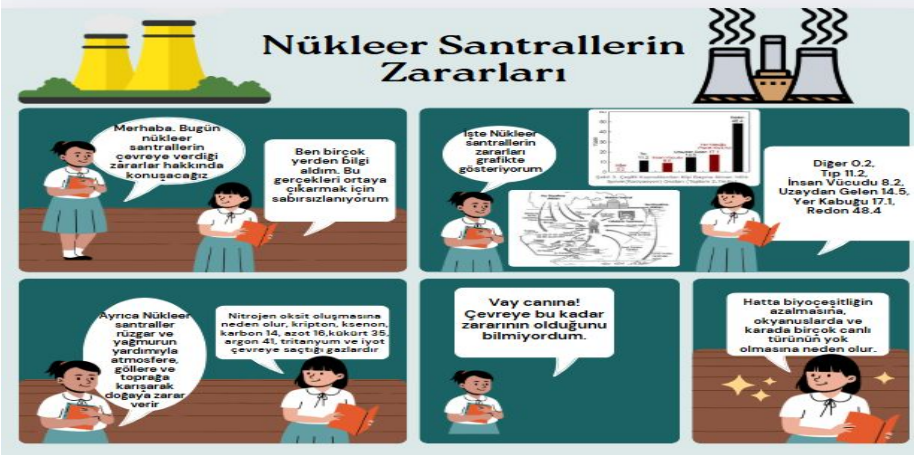

Figure 5. An example of a digital comic book about GMO products and nuclear power plants, which are SSI

The CG attempted to understand these SSI by watching documentaries. This difference is also evident in the interview statements:

"I don't know exactly what SSI are. I think global warming is a SSI. We watched a video about it." (CG7)

The EG, on the other hand, believes that it is necessary to deepen SSI and reflect scientific awareness to society, and that digital comics facilitate this:

"We studied many articles about the harm that nuclear power plants do to nature and humanity. We wrote the information we learned in these articles to the characters in the comics and aimed to raise public awareness by having them talk (...)" (EG1)

"Climate strikes raise awareness and we showed people coming together in our comics." (EG5)

As seen in the student statements, both groups have views on the importance of awareness and action. However, thanks to the knowledge and creativity they acquired during their comic book design, the EG provided more detailed and visionary examples of how these social movements could be organized or what effects they could create.

Environmental Awareness

This theme demonstrates how students understand the concept of environmental awareness and how they evaluate their own individual and societal impacts. The deepening of the environmental awareness and the richness of the views of the EG after the intervention are more evident compared to the CG.

In both groups, it was stated that sensitivity was related to "noticing changes in natüre". However, the EG transformed these observations into concrete environmental problems, such as a polluted river or withered trees, in their comics (Figure 4), demonstrating that their observation skills became more critical and sensitive. Although expressions such as "human-nature harmony is important" are common, the EG's comics have been seen to delve deeper into ecological awareness by telling the consequences of incompatibility through striking stories. For example, in Figure 6, the dialogues of an agricultural engineer about soil pollution and the conversations of animal characters were prepared with scientific data.

Figure 6. Examples of digital comics illustrating dialogues about soil, water, and air pollution with scientific data

Data supporting this situation were also found in the interviews:

"There's a lot of environmental pollution. One of these is soil pollution. We studied agricultural journals. We learned about the structure of the soil. I know scientifically what will happen to us as a result of pollution. For example, our metabolism is negatively affected, and we can become obese. I reflected this in the comic. This is interesting information." (EG5)

"I know that environmental pollution is air pollution. Factory chimneys cause it. We drew pictures about it in class. Is this a socio-scientific issue? I'm not sure." (CG10)

As seen in these statements, the EG's environmental awareness increased and they learned more deeply, basing all their studies on scientific data. The CG defined environmental pollution in more general terms.

Individual Impact

Students stated their environmentally friendly behaviors in daily life. Through the intervention, the EG conveyed these behaviors (e.g., "I reduced my plastic use") as a conscious lifestyle through comics characters, giving a more meaningful context to their own actions. But the behavioral patterns in the CG generally remained within a general framework.

While anxiety about the future and the desire to leave a livable world to future generations were the motivations of both groups, the EG showed that this motivation became a stronger consciousness by visualizing this anxiety with concrete scenarios in their comics, as in Figure 7.

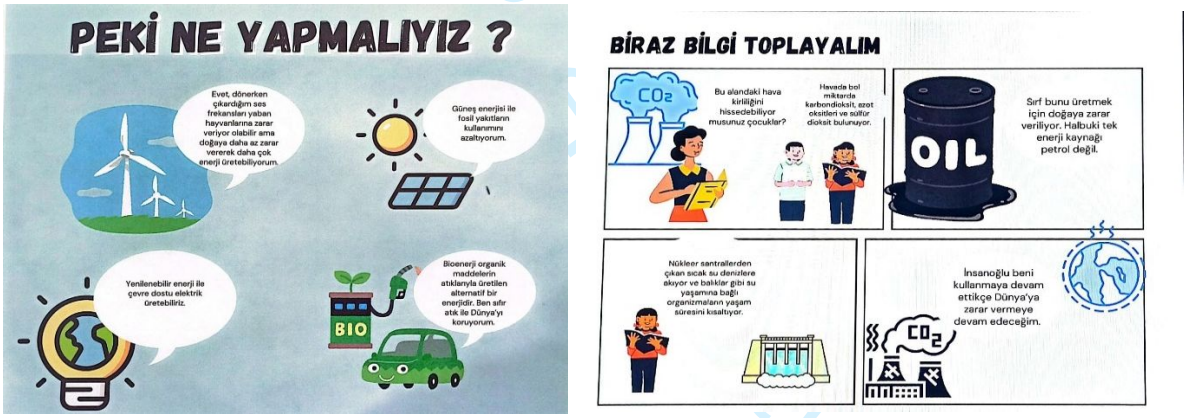

Figure 7. An example of a digital comic that expresses concern for the future and the desire to leave a livable world to future generations.

In the interviews, it was determined that the motivations of the EG were directed towards activities and concrete examples, while the CG only expressed opinions on this matter. For example;

"We must leave a livable world for our children, otherwise they will suffer just like us. I wanted to show this in the comic." (EG7)

"We must protect nature for future generations." (CG10)

Social Impact

The necessity of social and political actions was expressed in both groups. However, the EG's more frequent and emphatic references to the importance of political will and civic participation in their comics designs and opinions, with statements such as "*If society becomes more conscious, laws will change*" demonstrate that the intervention provided a more active stance against socio-scientific problems (See Figure 8).

Figure 8. Comics titled "If society becomes more conscious, laws will change" prepared for nuclear power plants.

In their comics, students took care to present information based on scientific data (e.g., "supporting the air emissions of nuclear power plants with graphics". See Figure 9). This is a result of the research and synthesis of information carried out during the intervention process.

Figure 9. An example of a digital comics that explains the air emissions of nuclear power plants, supported by graphics.

In the interviews, EG stated that while they were doing such studies for social impact in the process, CG mostly watched public service announcement videos in the role of passive receiver. For example;

"In this comic, we showed the effects of nuclear power plants on air pollution with graphics. People are more impressed when they see the data." (EG3)

"(...) Yes, simply saying "it's bad" without scientific evidence isn't enough. If society becomes more aware, policies will change."(EG6)

"Young people like us need to make their voices heard. (...) Should we share it on social media?" (EG9)

"We watched an informative video about environmental pollution. If others watch this video, they will become more aware." (CG5)

Conclusion and Discussion

In this study, the effect of the SSI based-digital comics design process of gifted middle school students on their environmental awareness and their opinions about this educational process were examined in depth using quantitative and qualitative methods. The findings clearly showed that the implemented program created significant and meaningful positive effects on students' environmental knowledge, emotions, sensitive and careful behavior and recycling habits. Particularly large effect sizes suggested that the intervention made a strong difference from a practical perspective. Topkaya and Doğan (2020) concluded that educational comics increased awareness of environmental problems and the environment, and there was a significant difference between the EG and CG. Topkaya (2016), examining the effect of the use of cartoons and comics on the environmental awareness value of 5th grade students, concluded that the group that used educational comics was more successful. Çiçek Şentürk (2020), investigating the effect of argumentation-supported comics on environmental interest, motivation, and academic achievement, concluded that the EG was much better in terms of environmental awareness, motivation, and academic achievement than the CG.

The fact that the digital comics writing process increased the environmental awareness of gifted students in all sub-dimensions (Knowledge/Emotion, Sensitive Behavior, Attentive Behavior and Recycling) at a statistically significant level reveals how effective this method is in terms of interdisciplinary and constructivist learning processes. In particular, the increase in the Knowledge/Emotion dimension showed that writing digital comics deepens students'

cognitive and affective learning about environmental issues. In their research on the use of digital comics in the 5th grade, Alp and Coşkun Onan (2019) concluded that students raise awareness about environmental problems and climate change and address current social issues in an aesthetic and creative way with Pixton. This can be explained by the fact that students construct knowledge through research, transform it into a creative product, and establish an emotional connection with scientific facts in the process. Similarly, the improvement in the dimensions of sensitive behavior and attentive behavior indicated that digital comics not only convey information but also strengthen behavioral intentions. These findings are consistent with other studies supporting the role of digital storytelling and creative writing processes in increasing students' environmental awareness. For example, in a study conducted by Asli (2025), a significant increase in the environmental attitudes of students, participating in digital storytelling activities, was observed. Similarly, Kadish (2023) stated that students' STEM-based digital story creation processes strengthen their intrinsic motivation and permanent learning regarding scientific subjects. Additionally, Alp and Coşkun Onan (2023) emphasized that designing digital comics increases students' critical thinking skills and emotional commitment to the subject. Topkaya et al (2023) found that digital novels have positive effects on academic achievement, attitude, cognitive and affective dimensions. İlhan and Oruç (2019) also concluded that using comics in lessons positively affects students' motivation and academic success and increases them more than lessons taught in traditional ways.

Another important contribution of the digital comics writing process was reflected in the increase in recycling behaviour. This can be associated with students gaining awareness of the importance of recycling while creating their stories and transferring this knowledge to their daily lives. As stated by Idayanti et al. (2022), constructivist learning environments allow students to experience scientific processes and integrate knowledge into real-life scenarios.

The qualitative findings deeply support the quantitative results and reveal the qualitative aspects of the current situation and change in the EG's views on environmental awareness and the socioscientifically supported comics design process. In the theme of socio-scientific perception, it is noteworthy that the EG expressed science-society interaction and current controversial issues (nuclear energy, GMO foods) in a more concrete, action-oriented way compared to the CG. This situation in the EG points to the potential of digital comics to visualize and make understandable complex SSI. This is consistent with the experimental research results of Tekin and İlhan (2025). This is also consistent with Abrori et al.'s (2025) view that digital comics create opportunities for students to discuss SSI. Moreover, students' portrayal of scientists as active actors of environmental solutions in their comics supports the impact of digital narratives in understanding science-society interaction, as highlighted by Abrori et al. (2024).

Students' critical processing of environmental issues and their integration of scientific data into their stories demonstrate that digital comics reinforce knowledge at an emotional and cognitive level. As stated in the study of Abrori (2023), digital comics help students concretize abstract concepts and establish emotional connections with scientific content. The transfer of knowledge, especially through animal characters and agricultural engineer dialogues, supports Apriani et al.'s (2025) findings that arts-based learning provides multiple representations.

The experimental group's reflection of their concerns about the future with statements such as "We must leave a livable world for our children" shows that digital comics increase their awareness of responsibility and sensitivity. This is in line with Septianita et al.'s (2023) arguments that environmental education should lead to behavior change. Additionally, students' graphical depictions of the impact of nuclear power plants and their efforts to raise public awareness reveal the role of digital comics in developing socio-scientific citizenship skills. As Jonsson and Grafström (2021) point out, students' use of scientific data for social justice is an important part of active citizenship education.

In summary, the findings of the study reveal that the digital comics writing process is an effective pedagogical tool in increasing gifted students' scientific literacy, environmental sensitivity, and social responsibility awareness. The results are directly parallel to Yulaichah et al.'s (2024) findings that digital storytelling supports interdisciplinary learning. Similarly, the studies of Altan and Tan (2021) and Aprilla et al. (2023) emphasize the importance of creative forms of expression in understanding the epistemological dimension of science, which strengthens our findings. This is an important finding in our study that supports the development of gifted students in the experimental process. The visual and narrative richness of digital comics has enabled students to grasp complex scientific concepts holistically and to relate this information meaningfully to daily life. Cha et al (2021) concluded that the use of comics can help students understand scientific concepts that are difficult to understand with the traditional teaching method.

Limitations and Suggestions for Future Research

This research has several limitations. First, the study was conducted with a limited sample of gifted students. This situation limits the generalizability of the findings to all students. Additionally, the study's sample was limited to a limited number of students in a specific geographic area, making the validity of the findings for students in different regions questionable. The limited duration of implementation makes it difficult to assess the extent to which improvements in environmental awareness are permanent. The data obtained from qualitative data collection tools are largely based on the students' products and the researcher's interpretations. This may amplify the impact of subjective interpretations. Furthermore, individual differences in students' use of digital tools, particularly their familiarity with platforms like Pixton and Canva, may directly impact their developments in environmental awareness.

All limitations should be carefully considered in interpreting research findings and planning similar studies. The research is limited to five socioscientific topics. Quantitative, qualitative, or mixed-design studies can be conducted that include different SSI. Comics studies including similar or different SSI can also be conducted with students with normal achievement.

Statements and Declarations

Competing Interests: We confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work.

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Data availability: The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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