JOURNAL
OF BALTIC
SCIENCE
EDUCATION

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

EXPLORING THE IMPACT OF HISTORY OF SCIENCE TEACHING ON SCIENCE PROCESS SKILLS, KNOWLEDGE OF SCIENCE CONCEPTS, AND ATTITUDES TOWARD SCIENCE

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Abstract. *Although integrating the history of science (HOS) into teaching has long been recommended in science education research, studies have revealed conflicting results on its effectiveness. These are mainly due to the need for more studies in this context. Therefore, this research aimed to explore the impact of HOS teaching on science process skills, knowledge of science concepts, and attitudes toward science. In this research, a quasi-experimental research design was employed. The HOS was contextualized into the topic of the circulatory system. Two intact classes were chosen as the experimental group (EG) and the two others as the control group (CG). The EG students were involved in HOS activities during the treatment, while the CG students followed the curriculum-driven activities. The findings indicated that the impact of HOS education was evident, as students in the EG outperformed those in the CG in retaining knowledge of science concepts and demonstrating positive attitudes towards science. However, HOS education and curriculum-driven instruction have similarly impacted the development of science process skills. These results support the conceptual premise that HOS teaching is an alternative and a worthy way of supporting students' scientific literacy.*

Keywords: *attitudes toward science, experimental research, history of science teaching, science education, subject matter knowledge*

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Introduction

In response to the complexities of modern society, scientific literacy (SL) has positioned itself as an essential component of contemporary education. In this regard, SL has become an essential vision of science education worldwide since the 2000s (Sharon & Baram-Tsabari, 2020). In order to meet this vision, it is critical to educate individuals as scientifically literate (Dillon, 2009; National Research Council [NRC], 1996). Therefore, individuals are anticipated to cultivate diverse skills across various domains (American Association for the Advancement of Science [AAAS], 1993, 1998; NRC, 1996, 2013; Organization for Economic Cooperation and Development [OECD], 2016, 2024). These skills have been identified in Science for All Americans (AAAS, 1998) as knowledge of science concepts (KoSC) and science process skills (SPS). Similarly, Bybee and McCrae (2011) emphasized that KoSC and attitudes toward science (ATS) are fundamental aspects of SL. Matthews (1994) argued that a scientifically literate individual should have the ability to understand basic science concepts, employ scientific reasoning in daily life situations, and have a positive disposition toward science learning. Criticism has been directed at schools for concentrating solely on KoSC while possibly neglecting other components of SL (Clough, 2006; Kim & Irving, 2010). Implementing appropriate teaching approaches that aim to develop multiple aspects of SL in schools is essential to enhance the SL level of all students.

An essential amount of theoretical papers have defended that HOS may serve as a fruitful teaching to achieve high levels of SL (Kolstø, 2008; Mamlok-Naaman et al., 2005; Rudge & Howe, 2009; Vincent, 2010; Yaru et al., 2020). The idea of teaching science by integrating its history dates back to the 1930s when Harvard University offered a Ph.D. program about HOS in 1936 (Klassen, 2002). In the late 1940s, the same university added HOS cases into the undergraduate program, and this was accepted as the next big step in this path (Russell, 1981). In the 1970s, a national curriculum development project based on HOS was initiated in the US (Rutherford et al., 1970). The project, namely Harvard Project Physics, was developed again at Harvard University, and some concise goals were set (Rutherford et al., 1970), which provided a good description of what might be gained by using HOS in science. These goals included the following: (1) help students acquire how to figure out the world by focusing on ideas instead of teaching some random facts; (2) help students appreciate that science develops in its particular tradition

https://doi.org/10.33225/jbse/24.23.449

and that science is a human activity by presenting the ideas and topic in its historical and social standpoints; (3) provide each student with an opportunity to have an immediate, satisfying experience in science even when the experience is beneficial either today or will be in the future.

It is important to note that both subsequent studies and internationally accredited reform documents have assertively emphasized the significant contribution of HOS teaching in the development of crucial aspects of SL (AAAS, 1993; Henke & Höttecke, 2015; Kim & Irving, 2010; NRC, 2013; Otero & Meltzer, 2017; Yaru et al., 2020). One of these aspects is science process skills. Many researchers have recognized SPS as a central aspect that should be acquired and practiced in science classes (Gizaw & Sota, 2023; Mushani, 2021; Setiadi & Fahmi, 2018; Winarti et al., 2019). SPS refers to scientists' transferable abilities to advance knowledge while conducting scientific research (Padilla, 2010). These skills fit into the following categories: *basic SPS* and *integrated SPS*. While "basic SPS include observing, measuring, inferring, predicting, classifying, and collecting and recording data, integrated SPS include interpreting data, controlling variables, defining operationally, formulating hypotheses, and experimenting" (Shaw, 1983, p. 615). Despite being simple to acquire, basic SPS serves as a foundation for integrated SPS (Padilla, 2010). Therefore, students should be given opportunities to develop these skills to help them understand the value of scientific inquiry in decision-making in science classes and everyday life (Wilke & Straits, 2005). Several studies have argued that learning science with its history improves SPS (Allchin, 1992; Dedes & Ravanis, 2008; Kolstø, 2008; Yaru et al., 2020; Yip, 2006). For instance, Allchin (1992) advocated that if students are allowed to repeat historical experiments conducted by reputed scientists of the past, they may develop process skills and learn how to apply those skills to other cases. The author also defended that teaching science with its history promotes students' SPS by allowing them to reflect more deeply on topics. Similarly, Yip (2006) asserted that by working on science with its history, students can understand how scientific ideas have developed over time, appreciate inherent characteristics of science such as making observations, drawing inferences, and collecting data, and ultimately enhance their SPS. Vincent (2010) designed research to advance students' SPS using HOS. The findings revealed that HOS teaching developed students' diverse SPS through data analysis, interpretation of results, and directing questions. These findings provide encouraging evidence that using HOS can be considered a method to develop SPS. However, more research is still needed to shed more light on the relationship between HOS and SPS.

Knowledge of science concepts is another core aspect of SL. It is possible to encounter a wide range of studies conducted on KoSC (e.g., Cansiz et al., 2020; Guo et al., 2015; Menon & Sadler, 2016; Wong et al., 2023). When the literature on science education is reviewed, it is realized that different teaching approaches have been suggested to improve students' KoSC. Project-based learning (Almulla, 2020), problem-based learning (Hestiana & Rosana, 2020), analogy (Cansiz et al., 2020), inquiry-based science teaching (García-Carmona, 2020), learning cycle (Marfilinda et al., 2020) are among these teaching approaches. Besides, some scholars have defended that HOS can also be utilized to develop students' KoSC (Galili & Hazan, 2000; Henke & Höttecke, 2015; Kim & Irving, 2010; Mathews, 2021; Rudge & Howe, 2009). Matthews (2021), for example, underlined that when students learn science with its history, they would develop a more advanced comprehension of science concepts since they would learn the concept more deeply. Chamany et al. (2008) authored an article arguing why HOS should be utilized in science lessons. The researchers advocated that HOS could provide students with a clear picture of how various scientists directly or indirectly interact on the same topic. They claimed that HOS can enable us to recognize that this interaction is sometimes a clash of ideas and, at other times, cooperation. Consequently, the use of HOS in science education has the potential to create a more productive classroom environment. Although the studies mentioned above have advocated that HOS teaching might help to understand KoSC better, empirical studies have yielded inconsistent results. While some studies have provided evidence that HOS teaching leads to a better understanding of KoSC, some other studies have yet to be able to support this relationship. In this context, Galili and Hazan (2000) found that students exposed to HOS teaching comprehended KoSC better than students exposed to traditional methods. Similarly, Lin (1998) found that HOS teaching effectively promoted a better understanding of chemistry topics. However, Irwin (2000) did not find enough evidence that HOS teaching leads to a better understanding of science concepts. As a result, it is noteworthy that more studies be conducted to unveil the relationship between HOS and KoSC.

Attitudes toward science, a fundamental construct in science education, is another critical aspect of SL. Although studies on attitudes received little attention in research on science education until the 1960s, critical studies have been conducted in this field since the 1960s (Bellová et al., 2023; Hsu et al., 2023; Kloos et al., 2018; Toma et al., 2019). Studies have consistently revealed that ATS impacts students' orientations and behaviours in science courses. For example, Maio et al. (2018) revealed that favourable ATS positively affects students' science performance. Similarly, Freedman (1997) found that ATS contributes to students' achievement in the classroom.

Researchers have utilized diverse teaching approaches to support students' favourable ATS. Although not limited to the following, some of these methods can be listed as such: laboratory-based science teaching (Nicol et al., 2022), science museums (Fazzi & Lasagabaster, 2021), and inquiry-based science teaching (Nzomo et al., 2023). Some studies have recommended HOS teaching to support ATS (e.g., Huybrechts, 2000; Mamlok-Naaman et al., 2005; Monk & Osborne, 1997; Solbes & Traver, 2003). For instance, Solbes and Traver (2003) designed a HOS course emphasizing how science progressed over history. The researchers contextualized HOS materials by emphasizing how dilemmas drive scientific knowledge in physics and chemistry. After a semester-long implementation, they reported a statistically significant improvement in students' ATS. Likewise, Mamlok-Naaman et al. (2005) tested the effects of HOS teaching on students' ATS. The result of the research indicated that students who received HOS teaching displayed significantly positive ATS. Although several studies have also reported the benefits of HOS teaching on students' ATS, an in-depth literature review revealed that our understanding of the relationship between HOS teaching and ATS is primarily based on limited studies. In other words, limited studies have explored the association between HOS teaching and ATS.

The use of historical materials in classrooms has been recommended by various researchers since long ago (Bertomeu-Sánchez, 2015; Brush, 1974; Clough, 2006; Conant, 1947; Ma & Wan, 2017; Matthews, 1994; Sarton, 1952; 1962). However, according to the discussion by Höttecke and Silva (2010), teaching and learning science through HOS has not been adequately covered in science education literature. This adequacy means there is a significant disparity between theory and practice when incorporating HOS into teaching. Matthews (1994, p. 70) defined two ways of incorporating HOS in science teaching, which were the "add-on" and the "integrated" method. In the former, the instructor provides information about the history of related content after teaching the subject knowledge. In contrast, the integrated approach combines the HOS into the corresponding content.

Research Aim and Research Questions

By employing an "integrated" approach, this research aimed to explore the impact of HOS teaching on three core aspects of SL: SPS, KoSC, and ATS. In line with this aim, it was attempted to answer the following research questions:

1. How does the history of science teaching impact the development of science process skills?
2. How does the history of science teaching impact the development of knowledge of science concepts?
3. How does the history of science teaching impact the development of attitudes toward science?

Research Methodology

General Background

This research utilized a quasi-experimental research design based on the guidance from Fraenkel et al. (2022). In experimental research, independent variables are manipulated by the researcher. In this research, the teaching methods were manipulated as the independent variables. Accordingly, the experimental group was educated with HOS, while the control group followed curriculum-driven teaching. Data collections and teachings were conducted in the spring semester of the 2021-2022 academic year.

Sample

The research enrolled participants from four intact classes, all consisting solely of sixth-graders from a public school situated in the northwestern region of Türkiye. Two intact classes were randomly designated as the experimental group [EG] (*n* = 51), while the remaining two served as the control group [CG] (*n* = 44). The statistical analysis to be conducted was considered when determining the sample size. Parametric tests require certain assumptions, such as normality, and it is essential to have at least 30 participants in each group to ensure these assumptions. Since it was decided to use a parametric test in data analysis, it was preferred that each group have more than 30 participants. The initial cohort comprised 95 students, including 48 girls and 47 boys, with a 12.08 average age. The mean science grades of the EG (3.47) and the CG (3.54) were notably similar. All groups received teaching from the same teacher. Before the implementation, the teacher underwent a two-week training session conducted by the researcher. This training focused primarily on the implementation process and highlighted essential considerations within its scope. Additionally, the researcher closely observed the entire process to ensure consistency in the implementation's essential aspects across both groups. The students participated voluntarily in the research. Before collecting data, the ethics committee permissions were obtained from Artvin Çoruh University Ethics Committee. Then, the parental consent form was obtained from the families of all students.

Instruments

In this research, three instruments were utilized. The first instrument is the Test of Science-Related Attitudes (TOSRA), developed by Fraser (1978), which was employed to track changes in students' attitudes throughout the research. This instrument evaluates students' ATS across seven subscales: "(1) social implications of science, (2) perceptions of scientists, (3) attitude towards scientific inquiry, (4) adoption of scientific attitudes, (5) enjoyment of science lessons, (6) leisure interest in science, and (7) career interest in science". The instrument's reliability was established with a Cronbach alpha value ranging from .64 to .93 (Fraser, 1978).

The research involved the development of a second instrument named the Circulatory System Concepts Test (CSCT). The primary objective of CSCT was to create a valid and practical instrument to evaluate knowledge of science concepts in the human circulatory system among Grade 6 students. Explaining the process for developing the instrument is beyond the scope of this paper. However, in brief, the development of CSCT consisted of the following steps: creating a table of specifications based on curriculum objectives; creating a pool of items depending on the table of specifications; experts' recommendations on the items; revision considering experts' recommendation; content knowledge analysis with a medical doctor (MD); further revision based on MD's suggestions; reaching consensus among research team; evaluation of the instrument regarding punctuation, and wording by a Turkish language expert; interviewing each stem, correct answer, and distracters with Grade 6 students to evaluate the appropriateness of the instrument for their levels; and pilot testing the instrument. Measured by Cronbach's alpha, the overall reliability of CSCT was found to be .74. This is accepted as satisfactory reliability for an instrument (Gronlund & Linn, 1990). An example question for this instrument is as follows:

Arda analyses the heart's structure and observes that the ventricles are more muscular than the atria. Based on this observation, which inference can Arda make?
A. The ventricles make more beats than the atria.
B. The ventricles pump more strongly than the atria.
C. The ventricles pump blood from the body to the atria.
D. The ventricles have a larger volume than the atria.

The final instrument, the Science Process Skills Test (SPST), was employed to assess the participants' SPS. This multiple-choice assessment measures students' SPS by evaluating their proficiency in "identifying variables, stating hypotheses, operationally defining concepts, graphing and interpreting data, and designing investigations" (Burns et al., 1985). Burns et al. (1985) reported a high level of reliability for the entire instrument (Cronbach's Alpha = .86).

Implementation

Both groups were taught about the circulatory system using the constructivist approach, which involves age-appropriate activities, discussions, and questions to facilitate learning. The only difference between the two groups was that the EG received HOS teaching contextualized within circulatory systems. In contrast, the CG received curriculum-driven teaching on the same topic without reference to the history of circulatory systems. Curriculum-driven teaching in CG followed the instructions specified in Türkiye's National Science Curriculum. A total of ten class hours were allocated to the implementation of these activities. For more information on these particular activities, please refer to the National Science Curriculum (Ministry of National Education, 2018). The activities and related objectives in the implementation process are outlined in Table 1.

https://doi.org/10.33225/jbse/24.23.449

Table 1
An Overview of the Activities and Their Corresponding Purposes in the Implementations

Activities	Purpose
Activity 1: The history of the hearth	*To show how the human heart was perceived differently in diverse communities and by various scholars.*
Activity 2: Mammalian Heart	To explore the composition and functional properties of the heart.
Activity 3: The history of the components of blood	*To show how knowledge of the structure and functions of blood has evolved and how technological development has boosted existing knowledge.*
Activity 4: Constituents of blood	To gain knowledge about the constituents of blood.
Activity 5: About the circulatory system	*To compare two competing theories about the circulatory system and some scientific methods used in history to support circulation theory.*
Activity 6: Two pathways from the heart	To describe the different kinds of vessels and illustrate the routes of blood in vessels.
Activity 7: Timeline of transfusion of blood	*To identify a few blood transfusion milestones and show how science has developed in history.*
Activity 8: Blood types	To categorize the core sorts of blood and underline the principles of blood transfusion.
Activity 9: William Harvey's experiments	*To show how William Harvey discovered the circulatory system.*
Activity 10. Blood donation	To develop a shared sense of blood donation and to raise awareness of the benefits of blood donation.

Note: Activities marked in italics were exclusively implemented in the EG.

Activity 1, the history of the hearth, describes what we have learned about the hearth. Throughout history, the heart has been seen as an important organ functionally and symbolically. Starting from ancient Indian societies who consider the hearth as the centre of the nervous system, even great scientists such as Empedocles, Hippocrates, and Aristotle –all of them have had a significant influence on other scientists and science for hundreds of years– hold similar misunderstanding on the structure and function of the hearth. The theories of those scientists, as well as Herophilus and Erasistratus's studies, were summarized to students. This story continues with how Galen's theory ruled research on treatments over sixteen centuries until the Renaissance.

Activity 2 focused on the structure and function of the heart. First, students are provided with a metaphor comparing and contrasting highway interchanges and vessels to help them better comprehend the heart's function. Then, students dissected a sheep's heart as a group of five, and they observed the outer and inner structures of a mammalian heart. During the activity, the teacher facilitated a group discussion about why blood needs to circulate in the body, how the heart functions, and why the ventricle walls are more muscular compared to the atrium walls.

Activity 3, the history of the components of blood, is about how our knowledge of blood has evolved over the centuries and how technological developments lead to augmenting our knowledge. With this activity, students learned about some critical milestones in the early discovery of blood components. Because of its colour, people thought blood consisted solely of red granules in prehistoric periods. After the invention of the microscope, the first scientific studies were carried out on the structure of blood. During this activity, students learned that in 1658, a biologist Jan Swammerdam first discovered red blood cells. Students are also provided with a picture of red blood cells drawn by Antoni van Leeuwenhoek in 1965, which has been accepted as the first known picture of red blood cells. Then, students reflected on the work of Professor Gabrial Andral and M. D. William Addison, who were first-time observers of white blood cells independent of each other.

Through Activity 4, students observed the components of blood under the microscopes, drew their observations, and discussed some distinctive features such as colour and relative quantity of white and red blood cells. Under the microscope, they observed white and red blood cells only. Students were asked to think about how the blood is liquid if it includes cells. In this way, students concluded that there should be a fluid portion of blood (plasma, which contains around ninety per cent of water). After a class discussion, students were introduced to detailed information about blood components.

In activity 5, students were allowed to compare and contrast Galen's and Harvey's circulation theory. Students were amazed to learn that Galen's theory had stayed the same and had not been questioned over sixteen centuries, even though it was almost entirely erroneous. They also learned about Harvey's methods for discovering blood circulation, including vivisection, dissection, and perfusion. Moreover, students learned that Harvey used a mathematical calculation to provide evidence that blood is not depleted within the human body, as Galen claimed.

Activity 6 focused on the lesser circulation and greater circulation. This activity consisted of two parts. During the former part, students developed their model of the lesser and greater circulation as a group of five using some accessible materials, e.g., cartons, flexible tubing, and paints. After completing their models, each group introduced them to the rest of the class and reflected on others' models. In the second part, they played a simple game designed to support them in envisioning the route of the blood during the lesser and greater circulation. The teacher initially drew a simple model of the lesser and greater circulation on the floor. This game required students to participate in a short tour (i.e., the lesser circulation) and a long tour (i.e., the greater circulation). This game aimed to visualize the blood's route during these two circulations.

Activity 7, Blood Transfusion Timeline, allowed students to study as a group and prepare the blood transfusion timeline from the XIV century to the present. After identifying the milestones of blood transfusion, groups prepared their timeline using classroom walls as the background. These timelines were filled with intriguing information, such as how young people's blood was believed to keep older people from ageing and weakness in the 15th and 16th centuries. In 1492, physicians even went so far as to transfuse the blood of three young children, ten years old, to the Pope, but unluckily, all four of them died. In 1665, Richard Lower became the first person to successfully transfuse blood from one dog to another, keeping the injured dog alive. In 1667, Jean-Baptiste Denis performed the first successful blood transfusion on a human by transfusing blood from a sheep to a man in a successful operation. James Blundell, in 1818, accomplished a blood transfusion from person to person, becoming the first in history to perform a successful blood transfusion between humans. The blood was transfused from her husband to a woman who had postpartum haemorrhage (bleeding after childbirth) … After creating their timelines, each group presented their findings to the class.

In Activity 8, the students were allowed to gain an understanding of the basics of blood transfusion and blood types. The teacher assigned them homework to study and take notes on the blood types of their relatives, which helped them connect the dots between theory and practical applications. During the class, the students shared their findings and engaged in a thought-provoking discussion on the prevalence of different blood types among their sample and the frequency of blood types across the country. Students were also introduced to four major blood types and the importance of the Rh factor in blood transfusion. Students learned about who can make blood transfusions to whom in their classroom.

Activity 9, William Harvey's Experiments, was based on a video by Wellcome Film (1971) about how William Harvey discovered the circulatory system. The film describes how Harvey formulated his theory of blood circulation in our body, how the heart functions, and how blood moves through arteries and veins using animated diagrams, vivisections, and dissections. The film is mainly based on Harvey's handwriting and notes. The film provides evidence for Harvey's conclusion by conducting some of his original experiments.

Activity 10 was about developing an awareness of the potential healthcare gains of blood donation to givers, recipients, and the public. Students studied as groups and developed and enacted a drama for their peers. Each group developed their drama about one of the following four topics: how blood donation is vital for those in need, the health benefits of donating blood, how recipients and their relatives feel when urgent blood need is met, how donating blood helps society and hospitals. The activity was completed by giving information about World Blood Donor Day.

Data Collection and Analyses

To measure how participants' SPS, KoSC, and ATS changed during the research, TOSRA, CSCT, and SPST were administered to them three times: before implementations (as pre-test), right after the completion of the implementations (as post-test) and five weeks after the completion of the implementations (as follow-up test). Since students' preexisting SPS, KoSC, and attitudes may be decisive in their post-test and follow-up scores, a one-way MANOVA was used to test if EG and CG students' pre-test scores differed significantly. After providing evidence that the students did not differ significantly in terms of these three variables before the research, a Repeated Measures MANOVA was used to assess the profiles of the EG and CG throughout the research.

Research Results

Before conducting the statistical test, the prerequisite assumptions, such as the required number of samples, normal distribution, and homogeneity of variance-covariance matrices, were evaluated. Evaluating these assumptions provided no major problem in conducting the statistical test. The result of one-way MANOVA indicated that EG and CG students' preexisting SPS, KoSC, and ATS did not differ from each other significantly, F (3, 89) = .30, p = .83, *Wilks' Lambda* = 1.00, partial η^2 = .01. This indicated that both groups had similar backgrounds regarding the variables under investigation. Table 2 presents the summary of descriptive statistics for pre-test scores.

Table 2
Some Pre-test Statistics of Experimental and Control Groups

Test	Group	*n*	*M*	*SD*
SPST	Experimental	50	13.04	4.08
	Control	43	12.88	4.82
CSCT	Experimental	50	14.28	3.93
	Control	43	14.70	4.29
TOSRA	Experimental	50	3.45	0.51
	Control	43	3.40	0.55

Table 2 shows that EG and CG had comparable levels of SPS, KoSC, and ATS before the implementations. Once it was established that there was no statistically significant difference between EG and CG at the beginning of the research, the main analysis was conducted. This research evaluated non-commensurate variables thrice, meaning three different dependent variables were measured thrice. The within-subjects part of the design included pre, post, and follow-up, and the multiple dependent variables, i.e., SPS, KoSC, and ATS, were analysed multivariate. This situation made the analysis doubly multivariate, a kind of profile analysis (Tabachnick & Fidell, 2012, p. 343). Tabachnick and Fidell (2012) recommend using repeated measures MANOVA for such designs.

Before conducting Repeated Measures MANOVA, it is crucial to assess various assumptions to ensure the accuracy and reliability of the findings. Thus, each assumption was examined individually. Firstly, regarding missing data, it was discovered that three students from the EG and two from the CG had missing scores. Given the small number of missing scores, the decision was made to exclude these cases from the analysis. Additionally, one student in the CG had special needs, and another student's scores deviated significantly from those of their peers in the EG. Consequently, these cases were also excluded from the dataset. Despite these exclusions, the remaining sample size remained sufficient for conducting Repeated Measures MANOVA. Furthermore, other assumptions were evaluated, such as univariate-multivariate outliers and the absence of multicollinearity. Fortunately, no significant concerns were identified regarding violating any of these assumptions.

A repeated measures MANOVA was conducted to assess how HOS and curriculum-driven teaching produced different patterns in cumulative DVs under the three test conditions. The relevant results are provided in Table 3.

Table 3
The Summary of Repeated-Measures MANOVA Analysis

Effect	Wilks' Lambda	Multivariate *F*	*p*	Partial η^2
Group	0.92	2.40	.074	0.08
Time	0.12	99.15	.000	0.88
Time*Group	0.76	4.17	.001	0.24

As shown in Table 3, the time by group interaction (deviation from parallelism) was statistically significant, multivariate F (6, 81) = 4.17, $p < .05$. This result suggested that EG students and CG students formed different profiles in the cumulative DVs under the three test conditions. Moreover, based on Cohen's (1988) criteria, there was

https://doi.org/10.33225/jbse/24.23.449

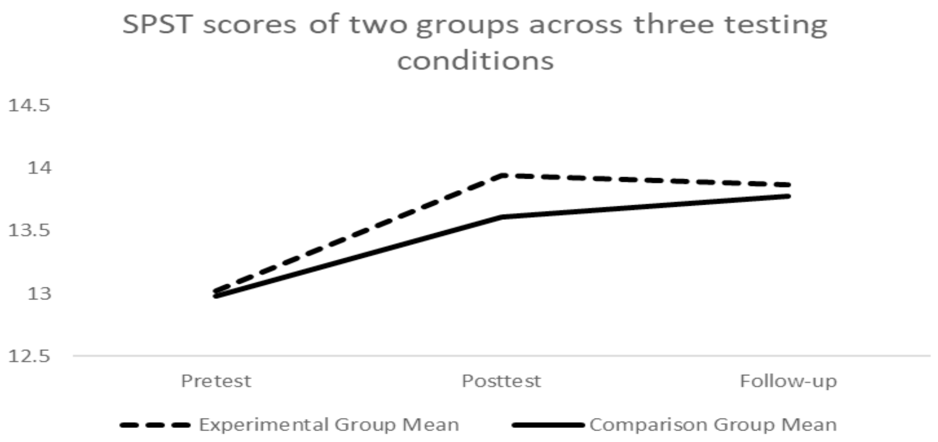
a large effect size (partial $\eta^2 = .24$). While the flatness test (group) yielded a statistically significant result, the level test did not. Nevertheless, Tabachnick and Fidell (2012) have argued that reporting hypotheses related to flatness and level is irrelevant when there is a significant time by group interaction. Therefore, the focus was directed on further analysis of significant parallelism.

According to Tabachnick and Fidell's (2012) recommendation, when parallelism and flatness tests are significant, and the level test is insignificant, simple-effects analysis should be used for further analysis. In such circumstances, the means need to be analysed independently for different dependent variables. As per their guidance, the groups were compared independently for each dependent variable. Bonferroni-type correction was applied when making the statistical judgment about the outputs in the next part in order to control the inflation in type I errors due to repeated comparisons.

Results for Science Process Skills

A mixed-model ANOVA was performed to determine the impact of HOS and curriculum-driven teaching on participants' scores on the SPS across three testing conditions. There was no significant time by group interaction, *Wilks* $\lambda = 1.01$, $F(2, 85) = .10$, $p > .05$, partial $\eta^2 < .001$. Similarly, the time effect (*Wilks* $\lambda = .96$ $F(2, 85) = 2.14$, $p > .05$, partial $\eta^2 = .05$) and the main effect for the two groups were not significant, $F(1, 86) = .03$, $p > .05$, partial $\eta^2 < .001$. These results mean that the two teachings gave students similar gains in SPS. Figure 1 demonstrates how the mean SPST scores of students changed across three testing conditions.

Figure 1
The Trends in Students' SPST Scores Across Three Testing Conditions



From Figure 1, it is evident that both EG and CG experienced an increase in their scores on SPST during the research than their SPST scores on the pre-test. Table 4 presents the mean CSCT scores of the groups throughout the research.

Table 4
SPST Scores of Two Groups Across Three Testing Conditions

Testing	EG (n = 47)		CG (n = 41)	
	M	*SD*	*M*	*SD*
Pre-test	13.02	4.01	12.98	4.74
Post-test	13.94	5.34	13.61	5.19
Follow-up	13.87	4.56	13.78	4.05

ISSN 1648-3898 /Print/
ISSN 2538-7138 /Online/

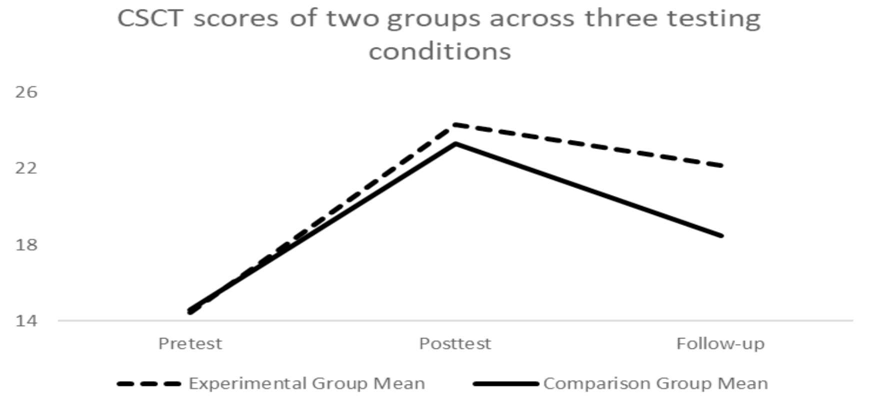
The data presented in Table 4 is noteworthy as it highlights that both groups achieved higher scores in their post-test and follow-up tests compared to their pre-test scores. This finding indicates an improvement, albeit not statistically significant, in their performance.

Results for Knowledge of Science Concepts

The mixed-model ANOVA results generated significant interaction among teaching types and time, with *Wilks* $\lambda = .83$, $F(2, 85) = 9.45$, $p < .001$, and partial $\eta^2 = .18$. This points out that the CSCT score changes across time was different between the EG and CG. Figure 2 depicts how the scores of students on CSCT changed across three testing conditions.

Figure 2

The Trends in Students' CSCT Scores Across Three Testing Conditions



The graph shows that although students' CSCT scores before and right after the teaching were similar in both groups, the students in the EG performed better than CG at follow-up. Statistical comparisons revealed that while there was no significant difference in CSCT scores of the two groups at post-test, $t(86) = 1.17$; $p = .244$, $\eta^2 = 0.02$; follow-up test scores of the EG were significantly higher than the CG, $t(86) = 3.84$; $p < .001$. Also, the eta squared statistic ($\eta^2 = .15$) displayed a large effect size based on Cohen's (1988) standards. In other words, 15% of the variance in the CSCT follow-up test scores might be attributed to teaching methods. Table 5 displays the mean CSCT scores of the groups during the research.

Table 5

CSCT Scores of Two Groups Across Three Testing Conditions

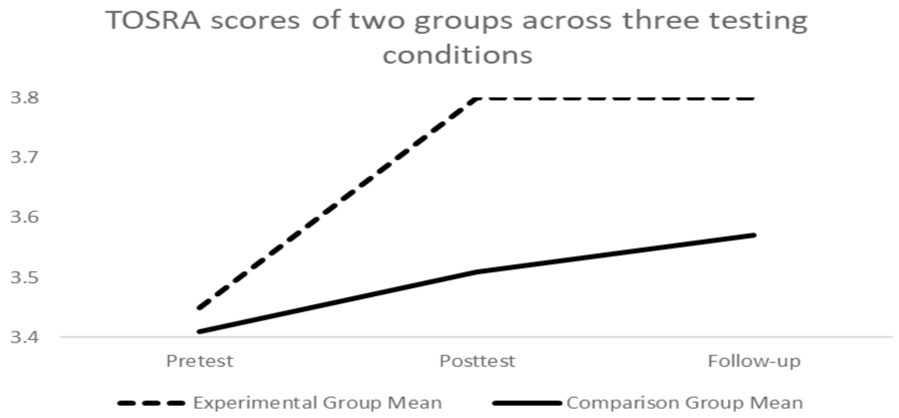
Testing	EG (*n* = 47)		CG (*n* = 41)	
	M	*SD*	*M*	*SD*
Pre-test	14.47	3.93	14.59	4.34
Post-test	24.30	4.19	23.29	3.79
Follow-up	22.17	4.72	18.46	4.28

The data presented in Table 5 show that the difference between the CSCT scores of the two groups widened significantly at the follow-up test compared to the other two testing conditions, favouring the EG.

Results for Attitudes Toward Science

Another mixed-model ANOVA was employed to assess the relative effectiveness of two teaching on students' ATS. The result indicated that the interaction was statistically significant, *Wilks* $\lambda = .94$, $F(2, 85) = 3.31$, $p = .042$, partial $\eta^2 = .07$. This meant that the change in TOSRA scores for both groups varied across the research. Figure 3 illustrates the trends in students' TOSRA scores.

Figure 3
The Trends in Students' TOSRA Scores Across Three Testing Conditions



It is apparent from Figure 3 that although both teachings led to an increase in TOSRA scores at the post-test, by far, the most significant increase is for the EG that received HOS teaching. The difference was noticeable even five weeks after the completion of the research, favouring the EG. Further statistical analyses confirmed that the mean scores of the two groups differed significantly from each other: $t\,(86) = 2.56$, $p = .012$, with a medium effect size ($\eta^2 = .07$). Likewise, follow-up test scores of the EG were better than the CG, $t\,(86) = 2.45$; $p = .016$, with a medium effect size $\eta^2 = .07$. Table 6 shows the mean TOSRA scores during the research.

Table 6
TOSRA Scores of Two Groups Across Three Testing Conditions

Testing	EG (*n* = 47)		CG (*n* = 41)	
	M	***SD***	***M***	***SD***
Pre-test	3.45	0.52	3.41	0.56
Post-test	3.80	0.49	3.51	0.57
Follow-up	3.80	0.39	3.57	0.48

The data presented in Table 5 show that the gap between the TOSRA scores of EG and CG widened significantly in the post-test and follow-up tests compared to the pre-test.

Discussion

The present research explored the impact of HOS teaching, contextualized into the human circulatory system, on developing three essential aspects of SL. The multivariate result revealed that the two teachings yielded different attainments regarding dependent variables being studied, although no significant preexisting difference was found between the two groups.

The research found that students who received HOS and curriculum-driven teaching showed similar achievement in SPS. However, the EG outperformed the CG in KoSC, specifically retaining key concepts of the circulatory system. Additionally, both groups improved their ATS, but the EG displayed significantly more positive ATS immediately after the teaching and even five weeks later.

The literature has suggested that HOS teaching may contribute to SPS (e.g., Allchin, 1992; Matthews, 1994; Vincent, 2010; Yip, 2006). Therefore, while it was hypothesized that students who received HOS teaching would score higher in science process skills, this did not occur. The absence of a significant difference between EG and CG can be partly explained by the students' prior SPS and the nature of the content of HOS activities. A close examination of students' pre-test SPST scores in both groups indicated that the number of correctly answered questions hovered around 13 out of 26, suggesting they had already had average SPS before receiving teaching. This finding is consistent with Aydınlı et al. (2011) and Delen and Kesercioğlu (2012), demonstrating that lower-secondary school students could exhibit moderate-level SPS even without specific interventions. In this research, the majority of participants in both groups were 12 years old, marking the onset of the formal operational stage in Piaget's cognitive development theory (Piaget, 1954). While individuals at this stage typically demonstrate an ability to comprehend concrete issues, they often struggle with grasping abstract and hypothetical concepts (Piaget, 1983). This finding is pertinent because SPS, particularly integrated ones, necessitate logical reasoning about abstract or hypothetical concepts. The participants in both groups exhibited a reasonable level of proficiency in meeting this requirement, indicating that HOS teaching did not significantly enhance the SPS of students who already possessed a decent level of proficiency in these skills. Another potential explanation for this somewhat unexpected finding could be related to the nature of the materials utilized in HOS activities. Unlike the CG, students in the EG read and interpret various SPS utilized by scientists to develop circulatory system knowledge. Through these activities, the intention was to familiarize students with scientific reasoning. However, they could not actively engage in the activities required for this process. The HOS activities did not provide students with firsthand experience regarding SPS. Consequently, it is plausible that students may have yet to develop their SPS significantly following HOS teaching. Much of the existing literature on SPS has emphasized inquiry-based teaching, wherein students participate in manipulative activities (Ma, 2023; Oliver et al., 2021). These and many other studies have concurred that involving students in firsthand, direct, manipulative experiences aids in the development of SPS. However, the abstract nature of the human circulatory system topic and its limitations regarding experimentations and providing manipulative materials restricted students' ability to engage in firsthand manipulative learning experiences through the HOS activities.

Regarding students' understanding of circulatory system concepts, the findings showed that both groups considerably increased their comprehension of circulatory system concepts following the interventions, and there was no discernible difference between the groups on the post-test. However, the follow-up scores of students in the EG were significantly higher than those of the CG. This result implies that the retention of circulatory system concepts is notably improved by HOS teaching. This noteworthy finding adds valuable insights to the existing literature. In contrast to earlier studies that reported HOS teaching did not effectively support comprehension of science topics (e.g., Irwin, 2000), this research enhances our insight into HOS teaching by providing evidence that its efficacy may only sometimes be immediately apparent after teaching. Therefore, it is recommended that researchers need to evaluate the effectiveness of HOS teaching longitudinally. Relying solely on post-test evaluations to assess the effectiveness of HOS teaching may lead to misleading conclusions.

One of the most significant benefits of HOS teaching for the EG pertains to ATS. It was found that students in the EG exhibited significantly higher ATS at the post-test and follow-up test compared to the CG despite having similar attitudes at the pre-test. Numerous studies in the literature have emphasized the potential role of HOS teaching in fostering positive ATS (Carvalho & Vannucchi, 2000; Jardim et al., 2021; Matthews, 1994; Monk & Osborne, 1997; Russell, 1981). However, fewer studies have provided concrete evidence of the relationship between HOS teaching and ATS. This finding appears to align with the latter category of studies, which have identified a positive relationship between HOS teaching and ATS (e.g., Alisir & Irez, 2020; Lin et al., 2010; Mamlok-Naaman et al., 2005; Solbes & Traver, 2003).

Conclusions and Implications

This research aimed to explore the efficacy of HOS teaching on science process skills, knowledge of science concepts, and attitudes toward science. In this context, it was found that although it did not provide a significant advantage in science process skills, it was more effective in improving the retention of science content knowledge and developing positive attitudes towards science. The combination of findings provided some support for the conceptual premise that HOS teaching is an alternative and a worthy way of supporting students' SL. Incorporating contextual historical resources into the classroom environment has the practical appeal of making the subject more exciting for students. In fact, EG students were relatively more active than the CG during activities when considering the entire process. The integration of HOS into science courses could enhance student engagement by considering the implementation process and findings together. This integration would positively impact students' science literacy when teachers incorporate more HOS materials into their lessons.

The results of this research have made some important contributions to the existing science education literature. The overarching conclusion drawn from this research is that contrary to some previous studies, incorporating historical materials into the circulatory system improves students' SL by promoting its basic aspects. As a result, it is recommended to both policymakers and teachers that contextual historical materials should be added to the science curriculum and utilized in classrooms. Besides, the findings indicated that if the effectiveness of HOS teaching in developing KoSC is to be tested, a follow-up test has to be employed; otherwise, inferences based only on the post-test may be misleading.

This research found that HOS education did not result in the projected improvement of SPS. This finding might be due to the nature of the activities undertaken within the scope of the research. For future research, exploring methods by which HOS education could more effectively support SPS holds significant potential for contributing to science education literature. Moreover, this research developed HOS materials that considered mammalian circulatory systems. Therefore, it is also suggested that the effects of integrating HOS materials into the classroom environment should be evaluated in other science topics to increase the generalizability of the results.

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Received: *March 25, 2024* Revised: *April 06, 2024* Accepted: *May 12, 2024*

Cite as: Cansız, M. (2024). Exploring the impact of history of science teaching on science process skills, knowledge of science concepts, and attitudes toward science. *Journal of Baltic Science Education*, *23*(3), 449–463. https://doi.org/10.33225/jbse/24.23.449

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