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The didactic potential of animation in developing conceptual understanding of the human circulatory system among high school students

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ABSTRACT

Background: Understanding the human circulatory system is challenging for high school students due to its abstract nature and complex interconnections. Traditional teaching methods often lead to misconceptions, such as misunderstandings of double circulation or the relationship between circulatory and respiratory systems. Animation-based teaching methods may enhance conceptual understanding by providing dynamic visualizations of biological processes.

Methods: A total of 161 second-year students from the Second Gymnasium and the Secondary Medical School Sarajevo participated in the study during the 2024/2025 academic year. Students were divided into control and experimental groups based on teaching method (receptive-lecture vs. animation-based) and educational track. Data were collected using the human circulatory system knowledge test (HCSKT) and an interactive post-test. Reliability was confirmed with Cronbach's α (0.89-0.93). Statistical analyses included descriptive statistics, t-tests, analysis of variance with Bonferroni correction, regression analysis, and effect size (Cohen's d).

Results: Gymnasium students achieved significantly higher scores than medical school students (Cohen's d = 0.68). Animation-based teaching produced very large effects compared to lecture-based methods (Cohen's d = -2.83). Educational track differences were significant in the gymnasium (information technology and natural sciences outperforming language), but not in the medical school. Subdomain analysis showed stronger performance in anatomy and physiology than in embryonic-evolutionary development. Regression analysis confirmed that school type and teaching method explained substantial variance in knowledge (R^2 = 0.103 and R^2 = 0.646, respectively), while gender had negligible influence.

Conclusion: Animation-based teaching significantly improves conceptual understanding of the circulatory system among high school students. Findings highlight the didactic potential of multimedia in biology education and suggest that curricula should integrate animation to reduce misconceptions and strengthen conceptual learning.

Keywords: conceptual understanding, human circulatory system, animation-based teaching, multimedia in biology education, misconceptions in science learning, high school students

INTRODUCTION

Understanding the human circulatory system represents a significant challenge for high school students, as it involves abstract processes and complex interconnections between organs and systems. Traditional teaching methods often lead to the development of misconceptions or alternative conceptions—scientifically unfounded beliefs that do not align with accepted scientific explanations (Malatyalı & Yılmaz, 2010; Yağbasan & Gülçiçek, 2003). Common misconceptions include misunderstandings of double circulation, closed circulation, the structure of blood, and the relationship between the circulatory and respiratory systems. Remarkably, some students even believe that humans possess a partially open circulatory system, a misconception that persists regardless of educational level (Alkhawaldeh, 2007; Arnaudin & Mintzes, 1985; Cömert, 2014; Sungur & Tekkaya, 2003; Sungur et al., 2001; Yip, 1998).

Animation has emerged as an innovative didactic method that integrates audio and visual materials into synchronized,

interactive content. Unlike static illustrations or verbal explanations, animation enables students to observe dynamic biological processes as they unfold over time, thereby facilitating the formation of accurate conceptual schemes (Amarin, 2016; Aremu & Sangodoyin, 2010; Zanin, 2015). This approach not only enhances flexibility in adopting new concepts but also motivates students to exchange ideas and engage in collaborative learning.

The integration of information and communication technologies into education further strengthens the role of animation. Platforms such as interactive resources for schools, interactive, interesting, fun, and inclusive, and edutorij provide teachers and students with access to high-quality interactive resources, including simulations, 3D models, and videos. These tools enrich the traditional didactic triangle of teacher-student-content into a didactic quadrilateral that incorporates digital resources, thereby stimulating creativity and improving knowledge acquisition (Alfirević et al., 2014; Daşdemir & Doymuş, 2012; Šabić et al., 2024).

At the regional level, and particularly in Bosnia and Herzegovina, research on students' conceptual understanding of the circulatory system remains limited. This study therefore aims to fill an important gap by examining the level of conceptual understanding among high school students in Sarajevo and identifying the presence of specific misconceptions. In doing so, it seeks to answer three central questions: What is the current level of students' understanding of the human circulatory system? Which misconceptions are most prevalent? And does the application of animation-based teaching methods improve conceptual understanding while reducing the occurrence of misconceptions? Addressing these questions is not only relevant for advancing biology education but also for guiding teachers in the effective integration of digital platforms into classroom practice. The findings may further inform curriculum adaptations related to the circulatory system unit and contribute to health education initiatives by promoting awareness of cardiovascular health and preventive habits among young people.

MATERIAL, METHODS, AND PARTICIPANTS

To determine the presence of misconceptions among students, it is very important to use an appropriate diagnostic test whose results will have high applicative value. When selecting a diagnostic test to assess students' conceptual knowledge, researchers must consider which research technique is incorporated into the test, as this determines the quality of students' responses and their confidence in them.

Diagnostic tests and methods for identifying students' misconceptions are numerous. In research on conceptual knowledge in the natural sciences, the use of diagnostic methods such as interviews, tests with open-ended questions, and multiple-choice tests is recommended (Peşman & Eryılmaz, 2010).

Multiple-choice tests require respondents to select the answer they believe to be correct from several offered options, some of which represent misconceptions. If we were to rely exclusively on multiple-choice tests to identify students' misconceptions about a particular topic, the results would not be reliable or applicable in the long term. Whenever a respondent is presented with a test containing multiple answer options and a single distractor, there is a greater likelihood that an incorrect response is not the result of a misconception, but rather of insufficient knowledge about the given topic (Arslan et al., 2012).

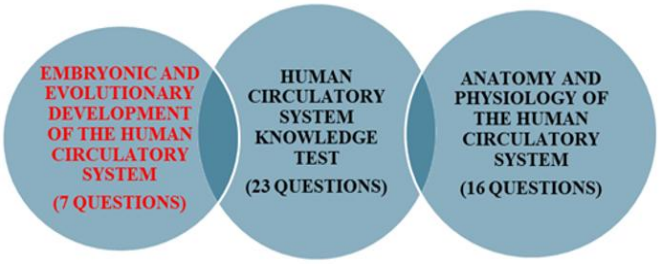

Figure 1. Structure of the modified HCSAT test for assessing conceptual knowledge of the human circulatory system (adapted from Cömert, 2014)

General Characteristics and Reliability of Research Instruments

In order to overcome these problems in identifying students' misconceptions, researchers have classified multiple-choice tests into two-tier, three-tier, and four-tier tests (Gaylan et al., 2024; Kaltakcı-Gurel et al., 2017). Prior to their use in the study of conceptual knowledge of the human circulatory system, Cronbach's alpha reliability coefficient was calculated for both tests. The reported coefficient for the questionnaire on the human circulatory system administered to secondary school students was 0.93.

Additionally, the Cronbach's alpha coefficient was calculated for the individual domains of the human circulatory system knowledge test (HCSKT). The Cronbach's alpha value for the domain anatomy and physiology of the human circulatory system was 0.91, while the value for the domain embryonic and evolutionary development of the human circulatory system was 0.92, which classifies it as an excellent instrument for this research. The Cronbach's alpha coefficient for the interactive test of knowledge of the human circulatory system was 0.89. This is an excellent result, considering that all items in the interactive test were independently designed by the researcher and, as such, have broad applicability.

Human Circulatory System Knowledge Test

The most well-known two-tier test for determining the presence of misconceptions about the human circulatory system is the human circulatory system achievement test (HCSAT). The test was originally developed by Arnaudin and Mintzes (1985) and then validated by Sungur (2004). In its original form after validation the HCSAT test contains 17 questions. For the purpose of application in this study and to improve the content of curricula dedicated to the human circulatory system, the test was modified by adding questions from the field of embryonic and evolutionary development of humans, as shown in **Figure 1**.

Table 1. Sample structure of students from the Second Gymnasium and the Secondary Medical School in Sarajevo

	Class/track	Teaching method	Number of students (N)
Second Gymnasium (total 69 respondents)			
Control group	2/language educational track	Receptive-lecture method	12
Experimental groups	2/general educational track	Animation method	18
	2/natural sciences educational track	Animation method	19
	2/IT educational track	Animation method	20
Secondary Medical School Sarajevo (total 91 respondents)			
Control group	2/pharmaceutical-cosmetic technician educational track	Receptive-lecture method	16
Experimental groups	2/medical nurse/technician educational track	Animation method	20
	2/laboratory technician educational track	Animation method	30
	2/sanitary-ecological technician educational track	Animation method	25

Interactive Test

The interactive knowledge test on the human circulatory system is designed as a post-test for the experimental group of students, i.e., the group of students who were taught about the human circulatory system using an animation-based teaching method. The interactive test consists of a total of 11 closed-ended multiple-choice questions. The tasks in the main part of the interactive test are adapted so that, in addition to the textual component, they also include a graphical and animated representation of the required answer. All of the above facilitates the respondents' selection of the correct answer from several options and encourages them to think critically about each task in the test. In its original form, the interactive test on the human circulatory system is an independent concept developed by the author of this paper and has significant practical applicability. For practical reasons, the main part of the interactive test is divided into three segments:

A. Composition of blood, structure and function of the heart and blood vessels,
B. Embryonic-evolutionary development of the human circulatory system,
C. Diseases and protection of human circulatory system.

Sample and Respondents

An interesting group for investigating conceptual knowledge of the human circulatory system consisted of students from general gymnasium schools and secondary medical schools in the Canton of Sarajevo. In accordance with the students' professional orientation (choice of secondary school), a non-probabilistic sample of a total of 161 participants was formed (the total number of students from both schools who completed both questionnaires). With regard to gender distribution, a total of 115 female students and 46 male students completed both questionnaires.

The participants in the survey research were second-year students of the Second Gymnasium and the Secondary Medical School Sarajevo. The research was conducted electronically from March to June of the 2024/2025 school year. For the purposes of the survey, students from both schools were divided into a control group and three experimental groups. The division of students into experimental groups was carried out according to the teaching methods used for instruction on the human circulatory system, as well as the educational tracks attended by the students. Four weeks after the completion of instruction, all participants took an online knowledge assessment.

Ethical Integrity of Participants

Minor participants took part in this research; therefore, special attention was given to protecting their ethical integrity. Approval for conducting the research was granted by the Ministry of Education of the Sarajevo Canton (approval number: 11-05/02-34-9018-1/25; issued on 27 March 2025). In addition, an internal agreement for conducting the research in the selected institutions was reached between the researcher and the biology teachers responsible for the subject. Furthermore, students from both schools had the right to choose whether they wished to participate in the study.

Students of the Second Gymnasium

Students of the Second Gymnasium who were taught the instructional unit ***"the human circulatory system"*** using the receptive-lecture method constituted the control group and attended the language educational track.

The experimental group of students was taught about the human circulatory system using the animation-based teaching method. The participants in the experimental group were subsequently divided into three subgroups according to the educational track they attended:

- **Experimental group 1** – General educational track
- **Experimental group 2** – Natural sciences educational track
- **Experimental group 3** – Information technology (IT) educational track

Students at the Secondary Medical School Sarajevo

With regard to the students at the Secondary Medical School Sarajevo, students from four available educational tracks participated in the survey. The participants attending the pharmaceutical-cosmetic Technician educational track were designated as the control group and were not included in instruction on the human circulatory system using the animation-based teaching method.

Students attending the medical nurse/technician, laboratory technician, and sanitary-ecological technician educational tracks were designated as experimental groups 1, 2, and 3, respectively. Accordingly, the instructional unit ***"the human circulatory system"*** was delivered to these groups using the animation-based teaching method.

The structure of the sample of Second Gymnasium and secondary medical school students will be presented in **Table 1**.

Table 2. Descriptive statistics results according to the school type

	Groups	Number of respondents (N)	M	SD	Standard error mean
School type	Second Gymnasium	69	80.68	28.59	3.44
	Secondary Medical School Sarajevo	91	63.65	22.12	2.32

Research Hypoteses

Based on data obtained from relevant literature sources, as well as an analysis of available theoretical insights on this topic, the following hypotheses were formulated:

H_{1a}: Students of the Second Gymnasium and the Secondary Medical School Sarajevo possess solid conceptual knowledge of basic concepts related to the circulatory system. There is no statistically significant difference in the conceptual understanding of circulatory system-related concepts between students of these two schools.

H_{1b}: Students of the Secondary Medical School Sarajevo possess better conceptual understanding of concepts related to the human circulatory system than students of the Second Gymnasium. There is a statistically significant difference between students of these two schools in their knowledge of basic circulatory system concepts.

H_2: Students of the Second Gymnasium taught using the animation-based method (general, natural sciences, and IT elective tracks) demonstrate better acquisition of concepts related to the human circulatory system than students of the Language elective track, who were taught using the receptive-lecture method. The differences in students' knowledge are statistically significant.

H_3: Students at the Secondary Medical School Sarajevo taught using the animation-based method (medical nurse/technician, laboratory technician, and sanitary-environmental technician tracks) demonstrate better acquisition of concepts related to the human circulatory system than students of the pharmaceutical-cosmetic Technician track, who were taught using the receptive-lecture method. The differences in students' knowledge are statistically significant.

H_4: The gender of the respondents does not have a statistically significant effect on students' conceptual knowledge of the human circulatory system.

Data Analysis

After the completion of the survey, all collected data were processed and analyzed using the statistical data processing and analysis software IBM SPSS Statistics 27 (IBM Corp, 2020). With regard to the statistical methods of data analysis, this study employed both descriptive and inferential statistical methods.

The aim of this research was to determine whether there were differences in the average scores achieved on the test of knowledge about the human circulatory system between students of the Second Gymnasium and the Secondary Medical School, and whether these differences were statistically significant. Differences in the average number of points achieved on the knowledge test were analyzed with respect to the applied teaching methods and the type of secondary school attended.

In addition to the aforementioned variables, gender and the educational track attended by the students were also included in the analysis of differences in students' knowledge. As the first step in data analysis, descriptive statistical methods were applied. For the purpose of describing the obtained data, the following values were calculated: the arithmetic mean (M), the standard deviation (SD), and Cohen's d independent samples effect sizes test.

The statistical tests used for data analysis included the independent-samples t-test (to examine whether the type of secondary school and students' gender affected their conceptual knowledge). To determine whether there were statistically significant differences in students' knowledge with respect to their selected educational track (four educational tracks were included in the research), a one-way analysis of variance (ANOVA) was used. Linear regression analysis was applied to examine the extent to which the examined variables (gender, school type, teaching method, and educational track) influenced students' conceptual knowledge of the human circulatory system.

The level of significance for all applied tests was set at 0.05 (Fraenkel et al., 2011; Petz, 2007).

RESULTS

In the results chapter, we present the findings of a survey focused on students' conceptual understanding of terms related to the circulatory system, as achieved by students of the Second Gymnasium and the Secondary Medical School in Sarajevo. The results obtained will be briefly explained, and statistically significant differences, if any, will be highlighted.

Descriptive Statistical Methods

In this subchapter, we present the results of the descriptive statistical analysis conducted to determine whether there is a difference in the average number of points achieved on the test of knowledge of basic concepts related to the circulatory system between students of the Second Gymnasium and the Secondary Medical School in Sarajevo. The results of the descriptive statistics that address school type students attend are presented in **Table 2**.

Subsequently, we calculate the average score achieved by students on the same test, considering the variable that includes the teaching method used during the implementation of the teaching unit ***"the human circulatory system"*** (see **Table 3**). According to the descriptive statistical analysis presented below students of the Second Gymnasium achieved significantly higher scores on the test of knowledge about the human circulatory system than students at the Secondary Medical School. Differences in SD values between the two samples indicate greater variability in students' results. The larger sample size of the Secondary Medical School reflects a higher level of student participation in completing the questionnaire.

Table 3. Descriptive statistics results achieved on knowledge tests about the human circulatory system according to the teaching method

	Groups	Number of respondents (N)	M	SD	Standard error mean
Teaching method	Receptive-lecture method	56	42.09	8.75	1.17
	Animation-based method	104	86.56	18.39	1.80

Table 4. Descriptive statistics according to the selected educational tracks for students for students of Second Gymnasium and Secondary Medical School Sarajevo

School		Language educational track (receptive-lecture method)	General educational track (animation-based method)	Natural sciences educational track (animation-based method)	IT educational track (animation-based method)
Second Gymnasium	Number of respondents (N)	12	18	19	20
	M	35.33	36.78	39.05	44.30
	SD	11.00	8.26	8.45	6.15
		Pharmaceutical-cosmetic technician educational track (receptive-lecture method)	Medical nurse/ technician educational track (animation-based method)	Laboratory technician educational track (animation-based method)	Sanitary-ecological technician educational track (animation-based method)
Secondary Medical School Sarajevo	Number of respondents (N)	16	20	30	25
	M	42.88	44.30	42.40	40.16
	SD	14.86	6.15	6.88	9.99

Table 5. Descriptive statistics according to the subdomains related to the human circulatory system

Schools	Subdomain related to the human circulatory system	Mean score according to subdomain	SD according to subdomain
Second Gymnasium	Anatomy and physiology	64.58	13.84
Secondary Medical School Sarajevo		60.08	10.06
Second Gymnasium	Embryonic-evolutionary development	28.51	6.34
Secondary Medical School Sarajevo		19.69	6.51

The following section of this paper presents the results of the descriptive statistical analysis with respect to the teaching methods used to instruct students from the Second Gymnasium School and the Secondary Medical School in Sarajevo about the human circulatory system.

Students of the Second Gymnasium and the Secondary Medical School Sarajevo who were taught about the human circulatory system using the animation-based teaching method achieved higher average number of points on the knowledge tests than students taught using the receptive lecture-based method. SD values for both teaching methods indicated that students who were taught about the human circulatory system using animation method showed more variability in sample size (higher SD values).

The following section of this paper presents the results of the descriptive statistical analysis with respect to the teaching methods used to instruct students from the Second Gymnasium School and the Secondary Medical School in Sarajevo about the human circulatory system.

Since four educational tracks from each school were included in the research on knowledge of the human circulatory system, in **Table 4** we are presenting the results of descriptive statistics for students of Second Gymnasium and the Secondary Medical School Sarajevo.

Based on results available below it can be concluded that students of the Second Gymnasium (general, natural sciences, and IT tracks) achieved higher average scores on tests assessing knowledge of the human circulatory system than students of the language track. Additionally, students at the Secondary Medical School Sarajevo enrolled in the programs of medical nurse/technician, laboratory technician, and sanitary-environmental technician achieved higher average results than students of the pharmaceutical technician program. The results of the descriptive statistical analysis indicate that students of the Second Gymnasium possess better general knowledge of the human circulatory system, which can be explained by the fact that gymnasium students have stronger general academic preparation, as well as by the significant role played by different teaching methods. According to SD values for both Second Gymnasium and Secondary Medical School, the higher variability between groups we can see among students of language educational track (gymnasium) and students of pharmaceutical-cosmetic technician educational track (medical school).

For easier identification of potential statistically significant differences in students' knowledge according to the Subdomains studied within the teaching unit ***"the human circulatory system"***, the results of the HCSKT test are divided according to the relevant subdomains (see **Table 5**).

The results of the descriptive statistical analysis according to the variable of subdomains studied within the teaching unit ***"the human circulatory system"*** indicate a better overall preparedness of Second Gymnasium students with regard to conceptual knowledge in both subdomains. However, what should be emphasized is that both groups of students achieved better results in the subdomain of anatomy and physiology of the human circulatory system. These results were expected,

Table 6. Results of independent t-test and Cohen's d independent samples effect sizes test for variable school

Independent samples test										
		Levene's test of variances		t-test for equality of means					95% CID	
		F	Sig.	t	df	Sig. (2-tailed)	MD	SED	LL	UL
School	Equal variance assumed	11.53	< .001	4.25	158	< .001	17.03	4.01	9.12	24.95
	Equal variance not assumed			4.10	124.347	< .001	17.03	4.15	8.82	25.25
Independent samples effect sizes										
		Standardizer[a]		Point estimate		95% CI lower level		95% CI upper level		
School	Cohen's d	25.11		.678		.356		.999		
	Hedges' correction	25.23		.675		.354		.994		
	Glass's delta	22.12		.770		.436		1.101		

Note. CID: Confidence interval of differences; MD: Mean difference; SED: Standard error difference; LL: Lower level; UL: Upper level; [a]Denominator used in estimating the effect sizes; Cohen's d uses the pooled SD; Hedges' correction uses the pooled SD, plus a correction factor; & Glass' delta uses the sample SD of the control group

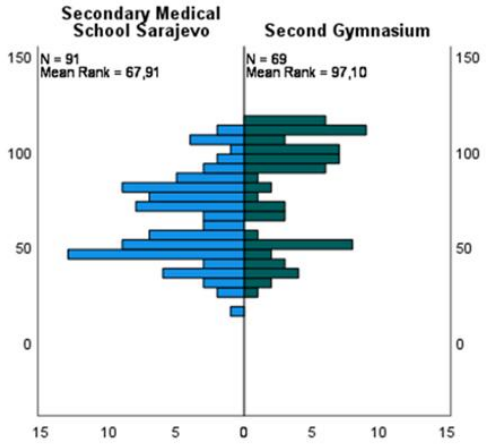

Figure 2. Results of the Mann-Whitney U test for students of Second Gymnasium and Secondary Medical School (the authors' own work)

given that teaching content related to the embryonic and evolutionary development of the human circulatory system is very sparsely represented in the curricula for gymnasium schools and secondary medical schools.

Methods of Inferential Statistics

When discussing inferential statistical methods, the following tests were used in this study: the independent samples t-test, one-way ANOVA, and linear regression analysis. Independent samples t-tests were applied to determine whether there were statistically significant differences in students' knowledge of the human circulatory system based on the school they attend and the teaching method used. For each t-test used in this research we computed Mann-Whitney U test.

Since the study included students from four different educational tracks at both secondary schools, a one-way ANOVA was conducted, along with the Bonferroni correction of p-values. These statistical tests were used to determine whether statistically significant differences in knowledge existed with respect to the selected educational track, as well as to identify which specific groups differed from each other.

Finally, linear regression analysis was applied to examine whether variables such as the secondary school attended, educational track, teaching method, and students' gender influence their knowledge of the human circulatory system. We will start this subchapter with results of independent samples t-test according to variable school (**Table 6**).

Results of Mann-Whitney U test for variable school are available in **Figure 2**.

As shown in **Table 6**, and **Figure 2** the independent samples t-test and the Mann-Whitney U test for the variable school indicate a statistically significant difference in knowledge between students of the Second Gymnasium and the Secondary Medical School. Furthermore, the results of Cohen's d effect size analysis suggest that school type has a medium to large effect on students' knowledge (Cohen's d for school type = 0.68). The difference is statistically significant at the .05 level ($p = 0.01 < .05$); therefore, the null hypothesis is rejected and the alternative hypothesis is accepted. According to the descriptive statistics (see **Table 2**), students from the Second Gymnasium demonstrated higher levels of knowledge about the human circulatory system compared to students from the Secondary Medical School.

Table 7 presents the results of the t-test according to the teaching method used to instruct students of the Second Gymnasium and the Secondary Medical School Sarajevo on the human circulatory system.

Table 7. Results of independent t-test and Cohen's d independent samples effect sizes test for variable teaching method

Independent samples test										
		Levene's test of variances		t-test for equality of means					95% CID	
		F	Sig.	t	df	Sig. (2-tailed)	MD	SED	LL	UL
Teaching method	Equal variance assumed	39.10	< .001	-17.07	158	< .001	-44.47	2.60	-49.61	-39.72
	Equal variance not assumed			-20.70	156.120	< .001	-44.47	2.15	-48.71	-40.22
Independent samples effect sizes										
		Standardizer[a]		Point estimate		95% CI lower level		95% CI upper level		
Teaching method	Cohen's d	15.72		-2.83		-3.28		-2.38		
	Hedges' correction	15.79		-2.82		-3.26		-2.37		
	Glass's delta	18.39		-2.42		-2.88		-1.95		

Note. CID: Confidence interval of differences; MD: Mean difference; SED: Standard error difference; LL: Lower level; UL: Upper level; [a]Denominator used in estimating the effect sizes; Cohen's d uses the pooled SD; Hedges' correction uses the pooled SD, plus a correction factor; & Glass' delta uses the sample SD of the control group

Table 8. Results of independent t-test and Cohen's D independent samples effect sizes test for the anatomy and physiology subdomain

Independent samples test										
		Levene's test of variances		t-test for equality of means				95% CID	
		F	Sig.	t	df	Sig. (2-tailed)	MD	SED	LL	UL
Results for the anatomy and physiology subdomain	Equal variance assumed	2.51	.12	1.89	102	.06	4.51	2.38	-.22	9.23
	Equal variance not assumed			1.90	94.98	.06	4.51	2.37	-.19	9.20

Independent samples effect sizes					
		Standardizer[a]	Point estimate	95% CI lower level	95% CI upper level
Results for the anatomy and physiology subdomain	Cohen's d	12.14	.371	-.017	.758
	Hedges' correction	12.23	.369	-.017	.753
	Glass's delta	10.06	.448	.052	.840

Note. CID: Confidence interval of differences; MD: Mean difference; SED: Standard error difference; LL: Lower level; UL: Upper level; [a]Denominator used in estimating the effect sizes; Cohen's d uses the pooled SD; Hedges' correction uses the pooled SD, plus a correction factor; & Glass' delta uses the sample SD of the control group

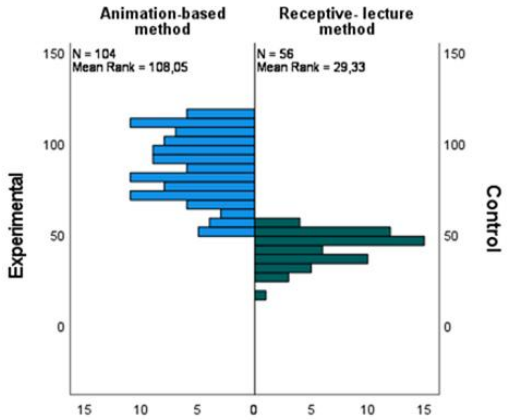

Figure 3. Results of the Mann-Whitney U test according to the teaching method (the authors' own work)

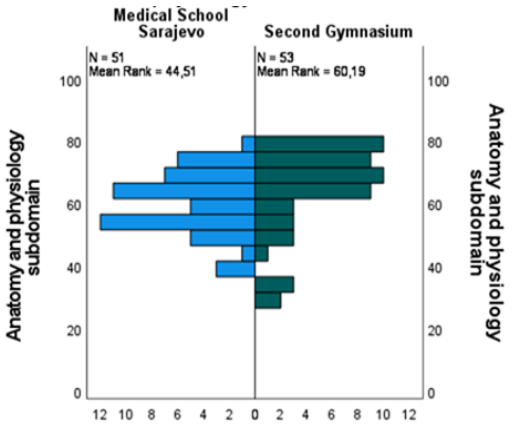

Figure 4. Results of the Mann-Whitney U test for the anatomy and physiology subdomain (the authors' own work)

Table 9. Results of independent t-test and Cohen's d independent samples effect sizes test for the embryonic-evolutionary development subdomain

Independent samples test										
		Levene's test of variances		t-test for equality of means				95% CID	
		F	Sig.	t	df	Sig. (2-tailed)	MD	SED	LL	UL
Results for the embryonic-evolutionary-development subdomain	Equal variance assumed	.006	.939	7.00	102	< .001	8.82	1.26	6.32	11.32
	Equal variance not assumed			7.00	101.57	< .001	8.82	1.26	6.32	11.32

Independent samples effect sizes					
		Standardizer[a]	Point estimate	95% CI lower level	95% CI upper level
Results for the embryonic-evolutionary-development subdomain	Cohen's d	6.42	1.37	.943	1.80
	Hedges' correction	6.47	1.36	.936	1.79
	Glass's delta	6.51	1.36	.884	1.82

Note. CID: Confidence interval of differences; MD: Mean difference; SED: Standard error difference; LL: Lower level; UL: Upper level; [a]Denominator used in estimating the effect sizes; Cohen's d uses the pooled SD; Hedges' correction uses the pooled SD, plus a correction factor; & Glass' delta uses the sample SD of the control group

In addition to the t-test results, **Table 8** also includes the results of Cohen's d, which takes sample size into account and thus determines the practical significance of the obtained results.

Furthermore, **Figure 3** provides the results of the Mann-Whitney U test for the variable teaching method, which assesses the homogeneity of variances between the two samples.

The following paragraphs are devoted to the results of the t-test and Cohen's d according to the subdomains studied within the teaching unit ***"the human circulatory system"***. **Table 8** presents the results of the t-test and Cohen's d for the subdomain anatomy and physiology of the human circulatory system.

Figure 4 shows the results of the Mann-Whitney U test for this subdomain.

As for the results related to the subdomain embryonic-evolutionary development of the human circulatory system, they are presented in **Table 9** and **Figure 5**.

The results of the t-test and Cohen's d test for the subdomain of embryonic-evolutionary development of the circulatory system indicate that there is statistically significant difference between gymnasium students and medical school students in terms of knowledge in the subdomain of embryonic-evolutionary development (see **Table 9**).

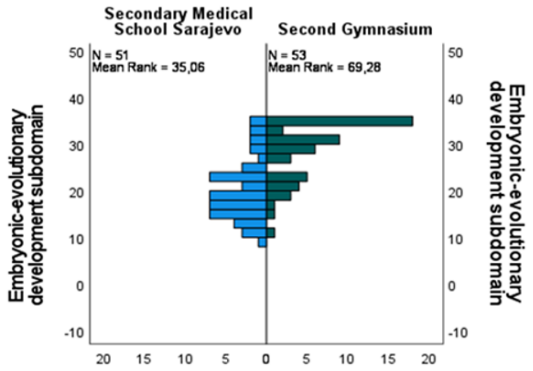

Figure 5. Results of the Mann-Whitney U test for the embryonic-evolutionary development subdomain (the authors' own work)

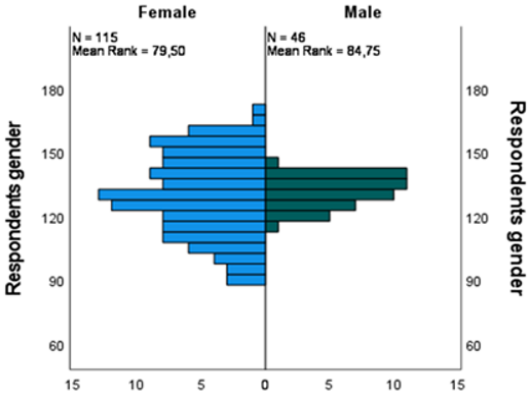

Figure 6. Results of the Mann-Whitney U test for the respondents gender (the authors' own work)

Table 10. Results of independent t-test and Cohen's d independent samples effect sizes test for variable gender

Independent samples test									
		Levene's test of variances		t-test for equality of means				95% CID	
		F	Sig.	t	df	Sig. (2-tailed)	MD	SED	LL	UL
Gender	Equal variance assumed	39.87	< .001	-.617	159	.538	-1.78	2.89	-7.49	3.92
	Equal variance not assumed			-.872	157.767	.385	-1.78	2.04	-5.82	2.26
Independent samples effect sizes										
		Standardizer[a]		Point estimate		95% CI lower level		95% CI upper level		
Gender	Cohen's d	16.56		-.108		-.450		.235		
	Hedges' correction	16.63		-.107		-.448		.234		
	Glass's delta	6.84		-.261		-.605		.087		

Note. CID: Confidence interval of differences; MD: Mean difference; SED: Standard error difference; LL: Lower level; UL: Upper level; [a]Denominator used in estimating the effect sizes; Cohen's d uses the pooled SD; Hedges' correction uses the pooled SD, plus a correction factor; & Glass' delta uses the sample SD of the control group

The value of Cohen's d effect size suggests that the difference in the average number of points achieved for this subdomain is not only statistically significant but also gives a large practical effects to the results (d = 1.37).

The results of Mann-Whitney U test for the embryonic-evolutionary development subdomain indicates a non-normal distribution of results, which can be seen in **Figure 5**.

Table 10 presents the results of the independent samples t-test and Cohen's d effect size by gender, while **Figure 6** presents the results of the Mann-Whitney U test.

The results of the t-test and Cohen's d test according to the gender variable for students of the gymnasium and the secondary medical school indicate that there is no statistically significant difference in students' knowledge of the human circulatory system with respect to the respondents' gender (p = .538 > .05). The value of Cohen's d for the gender variable indicates a very small to negligible effect of gender on students' knowledge (d = -0.108).

Results of the Mann-Whitney U test for variable gender indicate that there is no statistically significant difference in students knowledge according to the gender variable.

In the following paragraphs we will present the results of one factor ANOVA according to the variable educational track for students at both high schools. We will start with the results of one-factor ANOVA and Bonferroni post-hoc test for students of the Second Gymnasium and Secondary Medical School Sarajevo (see **Table 11** and **Table 12**). Based on the results of the one-way ANOVA test presented in **Table 11**, we can conclude that students of the Second Gymnasium differ statistically significantly in their knowledge of basic concepts related to the human circulatory system depending on the academic track they attend (p = .01 < .05).

To determine between which specific tracks these differences occur, a Bonferroni post-hoc correction of p-values was performed. According to the results obtained, statistically significant differences in knowledge were found between students enrolled in the Language and IT tracks, as well as between those in the general and IT tracks. Regarding the adjusted p-values, for students in the language track the corrected p-value was p = 0.026, while for students in the general track it was p = 0.042. This indicates statistical significance at the .05 level.

Students enrolled in the IT track scored 8.97 points higher on the test assessing knowledge of the human circulatory system compared to students in the language track, and 7.52 points higher compared to students in the General track.

The results of the one-way ANOVA and the post hoc Bonferroni test according to the variable educational track for students at the secondary medical school indicate that the program they attend does not have a statistically significant effect on students' knowledge of the human circulatory system (see **Table 12**).

At the end of the Results chapter, special attention will be given to the results of the linear regression analysis according to the following variables: school, teaching method, students' gender, and the educational track attended by students at the Second Gymnasium and Secondary Medical School Sarajevo. In the following section, we present the results of the linear regression analysis according to selected secondary school.

Table 11. Results of the one factor ANOVA and Bonferroni post-hoc test according to the variable educational tracks for students of the Second Gymnasium

ANOVA**						
	SS	df	MS	F	Sig.	
Between groups	804.41	3	268.14	3.88	.013	
Within groups	4,494.93	65	69.15			
Total	5,299.33	68				
Multiple comparisons (Bonferroni)***						
(I) Groups	(J) Groups	MD (I-J)	SE	Sig.	95% CI	
					LL	UL
Language educational track	General educational track	-1.44	3.10	1.00	-9.88	6.99
	Natural sciences educational track	-3.72	3.07	1.00	-12.06	4.63
	IT educational track	-8.97*	3.04	.026	-17.23	-.70
General educational track	Language educational track	1.44	3.10	1.00	-6.99	9.88
	Natural sciences educational track	-2.27	2.74	1.00	-9.72	5.17
	IT educational track	-7.52*	2.70	.042	-14.87	-.17
Natural sciences educational track	Language educational track	3.72	3.07	1.00	-4.63	12.06
	General educational track	2.27	2.74	1.00	-5.17	9.72
	IT educational track	-5.25	2.66	.319	-12.50	2.00
IT educational track	Language educational track	8.97*	3.04	.026	.70	17.23
	General educational track	7.52*	2.70	.042	.17	14.87
	Natural sciences educational track	5.25	2.66	.319	-2.00	12.50

Note. SS: Sum of squares; MS: Mean squares; MD: Mean difference; SE: Standard error; CI: Confidence interval; *The MD is significant at the 0.05 level; **Educational tracks: Second Gymnasium; & ***Dependent Variable: Educational tracks

Table 12. Results of the one factor ANOVA and Bonferroni post-hoc test according to the variable educational tracks for students of the Secondary Medical School Sarajevo

ANOVA**						
	SS	df	MS	F	Sig.	
Between groups	255.25	3	85.08	.956	.417	
Within groups	7741.32	87	88.98			
Total	7996.57	90				
Multiple comparisons (Bonferroni)***						
(I) Groups	(J) Groups	MD (I-J)	SE	Sig.	95% CI	
					LL	UL
Pharmaceutical-cosmetic technician educational track	Medical nurse technician educational track	-1.21	3.11	1.00	-9.61	7.20
	Laboratory technician educational track	1.13	2.86	1.00	-6.60	8.86
	Sanitary-ecological educational track	3.42	2.99	1.00	-4.65	11.49
Medical nurse technician educational track	Pharmaceutical-cosmetic technician educational track	1.21	3.11	1.00	-7.20	9.61
	Laboratory technician educational track	2.33	2.72	1.00	-5.02	9.69
	Sanitary-ecological educational track	4.63	2.86	.65	-3.09	12.34
Laboratory technician educational track	Pharmaceutical-cosmetic technician educational track	-1.13	2.86	1.00	-8.86	6.60
	Medical nurse technician educational track	-2.33	2.72	1.00	-9.69	5.02
	Sanitary-ecological educational track	2.29	2.58	1.00	-4.68	9.27
Sanitary-ecological educational track	Pharmaceutical-cosmetic technician educational track	-3.42	2.99	1.00	-11.49	4.65
	Medical nurse technician educational track	-4.62	2.86	.65	-12.34	3.09
	Laboratory technician educational track	-2.29	2.58	1.00	-9.27	4.68

Note. SS: Sum of squares; MS: Mean squares; MD: Mean difference; SE: Standard error; CI: Confidence interval; *The MD is significant at the 0.05 level; **Educational tracks: Secondary Medical School Sarajevo; & ***Dependent Variable: Educational tracks

Based on the obtained results of the linear regression analysis for the variable school (R^2 = .103), we can conclude that 10.3% of the variance in students' knowledge about the human circulatory system can be explained by the selected type of secondary school.

According to the ANOVA test results for the given model, the difference in students' knowledge with respect to the selected secondary school is statistically significant (p = .01 < .05).

We present the results of the linear regression analysis and the ANOVA test according to the teaching method variable. We also provide the results according to the variables educational track and participants' gender.

As we can see in **Table 13**, R^2 for teaching method is .646 which means that total of 64.6 % of variance in students knowledge can be explained by applied teachig method. ANOVA test results for teaching teaching method indicate statistically significant difference between groups according to the teaching method (p = .01 < .05).

According to the results of the linear regression analysis in **Table 14**, the study track attended by students of the Second Gymnasium explains 13.9% of the variance in respondents' knowledge about the human circulatory system.

According to ANOVA test results (**Table 15**), difference in students' knowledge is statistically significant (p = .002 < .05).

Table 13. Results of the linear regression analysis according to the school type attended by students

Model summary*						
Model		R	R^2	Adjusted R^2		Standard error of the estimate
1		.320[a]	.103	.097		.472
ANOVA[a]						
Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	4.03	1	4.03	18.06	.000[b]
	Residual	35.22	158	.22		
	Total	39.24	159			

Note. *Predictors: (Constant), school; [a]Dependent variable: Group; & [b]Predictors: (Constant), school

Table 14. Results of the linear regression analysis according to the teaching method for students of the Second Gymnasium and the Secondary Medical School Sarajevo

Model summary*						
Model		R	R^2	Adjusted R^2		Standard error of the estimate
1		.805[a]	.648	.646		.285
ANOVA[a]						
Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	23.60	1	23.60	291.43	.000[b]
	Residual	12.80	158	.081		
	Total	36.40	159			

Note. *Predictors: (Constant), method; [a]Dependent variable: Group; & [b]Predictors: (Constant), method

Table 15. Results of the linear regression analysis according to the educational tracks for students of the Second Gymnasium

Model summary*						
Model		R	R^2	Adjusted R^2		Standard error of the estimate
1		.373[a]	.139	.126		1.01
ANOVA[a]						
Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	10.99	1	10.99	10.83	.002[b]
	Residual	68.00	67	1.01		
	Total	78.99	68			

Note. *Predictors: (Constant), tracks; [a]Dependent variable: Group; & [b]Predictors: (Constant), tracks

Table 16. Results of the linear regression analysis according to the educational tracks for students of the Secondary Medical School Sarajevo

Model summary*						
Model		R	R^2	Adjusted R^2		Standard error of the estimate
1		.151[a]	.023	.012		1.06
ANOVA[a]						
Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	2.33	1	2.33	2.08	.153[b]
	Residual	99.78	89	1.12		
	Total	102.11	90			

Note. *Predictors: (Constant), tracks; [a]Dependent variable: Group; & [b]Predictors: (Constant), tracks

With regard to the students at the Secondary Medical School Sarajevo, the proposed regression model (the educational track attended by the students), presented in **Table 16**, explains 2.3% of the variance in students' knowledge.

The ANOVA test results indicate that the observed difference in students' knowledge is not statistically significant ($p = .153 > .05$).

As shown in **Table 17**, respondents' gender explains only 2% of the variance in students' knowledge about the human circulatory system.

The results of the ANOVA test indicate that the difference in knowledge observed in the regression model is not statistically significant ($p = .538 > .05$).

DISCUSSION

Conceptual understanding of the human circulatory system among high school students presents a challenge for both students and teachers. The concepts that students encounter for the first time while studying the teaching unit on the human circulatory system are abstract, and therefore the integration of multimedia tools into biology teaching is not a choice but a necessity (Bilginer & Uzun 2022; Orhan Özen, 2017).

One of the most widely used approaches to teaching that promotes learning through practical and cognitive activities is known as the learning cycle (Rogers et al., 2023). The most well-known 7E learning model was presented by Mekonnen et al. (2024). The 7E learning cycle model includes seven phases

Table 17. Results of the linear regression analysis according to the respondents gender

Model summary*						
Model		R	R^2		Adjusted R^2	Standard error of the estimate
1		.049[a]	.002		-.004	.454
ANOVA[a]						
Model		Sum of squares	df	Mean square	F	Sig.
1	Regression	.079	1	.079	.381	.538[b]
	Residual	32.78	159	.206		
	Total	32.86	160			

Note. *Predictors: (Constant), gender; [a]Dependent variable: Group; & [b]Predictors: (Constant), gender

described in the literature as: elicit (the process of assimilation in the cognitive process); engage (engagement and the formation of mental operations); explore (investigation involving pronounced perceptual activities through sensory observation); explain (explanation through the use of mental operations such as analysis and synthesis); elaborate (a process that involves clarifying and deepening the acquired knowledge); and extend (the process of accommodation, i.e., upgrading existing knowledge with new knowledge).

As stated by Eisenkraf (2003), Abdullahi et al. (2021), Teplá et al. (2022), each learning cycle takes place through the following stages:

- ✓ Eliciting students' prior knowledge
- ✓ Engaging students by using an unexpected or problem-based event to stimulate their interest
- ✓ Exploring students' skills and knowledge
- ✓ Explaining new concepts by enabling students to verbalize and clarify the concept
- ✓ Deepening newly acquired concepts through questioning
- ✓ Evaluating learning outcomes through formative assessment
- ✓ Extending knowledge by helping students connect the concept to different contexts, that is, transferring knowledge to other situations

The analysis shows that students of the Gymnasium achieved significantly better results on tests of knowledge about the circulatory system compared to students at the Secondary Medical School, confirming differences in general academic preparation. The use of animation as a teaching method had a very strong impact on understanding, with effect sizes indicating substantial practical importance compared to traditional lecturing. Results by educational tracks reveal that Gymnasium students in natural sciences and IT tracks performed better than those in the language track, while differences between programs in the Medical School were not statistically significant. Analyses by subdomains indicate that both groups of students mastered anatomy and physiology more successfully than embryonic-evolutionary development, which aligns with curricular emphasis. Finally, regression analysis confirms that school type and teaching method significantly explain variance in knowledge, while gender and educational track in the Medical School have negligible influence.

As part of improving the curriculum content dedicated to the teaching unit ***"the human circulatory system"***, we propose enriching the material by introducing topics from the subfield of the embryological and evolutionary development of the human circulatory system, in order to enhance learning outcomes.

Regarding didactic and methodological adaptations in the implementation of this teaching unit, the benefits of using animations in pedagogical practice have been demonstrated through their ability to redirect students' attention and to facilitate the clear presentation of changes within a dynamic system or structure (Unsworth, 2020). For this reason, it would be desirable for teachers to recognize the importance of using animations in biology education and to use the results of this research as a cognitive "tool" for mastering the basic functions of the proposed educational online platforms.

Regardless of the very promising research results and the high practical value of the findings, we must also emphasize the limitations encountered during its implementation.

The study on knowledge of the human circulatory system among high school students from the Sarajevo Canton was conducted from March to June of the 2024/2025 academic year. This fact limits the collected results to a time period of only one academic year, which should encourage future researchers to extend the duration of data collection. Since only students from the Sarajevo Canton participated in the research, there is room to expand the sample to the local, regional, and international levels. Although students from gymnasium schools and medical schools took part in the study of conceptual understanding of the human circulatory system, the questionnaires used in this research could, with certain modifications, also be applied to assess knowledge of the human circulatory system in schools with related educational profiles (such as dental technician and agricultural schools).

CONCLUSIONS

This study demonstrates that animation-based teaching methods significantly enhance high school students' conceptual understanding of the human circulatory system. Compared to traditional lecture-based approaches, animation produced very large effect sizes, confirming its strong didactic potential in reducing misconceptions and supporting deeper learning. Gymnasium students generally outperformed Medical School students, reflecting differences in academic preparation, while educational track differences were significant only within the Gymnasium. Subdomain analysis revealed that both groups of students achieved higher scores in anatomy and physiology than in embryonic-evolutionary development, consistent with curricular emphasis. Regression analysis further confirmed that school type and teaching

method explained substantial variance in knowledge, whereas gender and program type in the Medical School had negligible influence.

The findings highlight the importance of integrating multimedia resources into biology curricula to address abstract concepts and persistent misconceptions. By adopting animation-based methods, teachers can foster more accurate conceptual frameworks and improve student engagement. Future research should expand the sample to regional and international contexts and explore the long-term impact of multimedia integration on science learning outcomes.

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AI statement: The authors stated that no generative AI or AI-based tools were used during the writing process of this article.

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