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IMPROVING HIGH-SCHOOL STUDENTS' CONCEPTUAL UNDERSTANDING AND FUNCTIONALIZATION OF KNOWLEDGE ABOUT DIGESTION THROUGH THE APPLICATION OF THE INTERDISCIPLINARY TEACHING APPROACH

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Abstract. *Adolescents are considered as a nutritionally vulnerable subgroup because of their alimentary behaviours. Considering that alimentary habits are strongly influenced by knowledge about digestion, an experiment was conducted with aim to determine whether conceptual understanding and functionalization of this knowledge can be improved by the interdisciplinary teaching approach. The experiment encompassed 258 students attending the fourth year of high school. No statistically significant difference in the level of the previously acquired chemistry, biology and physics knowledge concerning digestion between the two groups was determined on the pre-test. Conversely, the students in the experimental group significantly outperformed those in the control group on the post-test that required a deep understanding and the application of knowledge about digestion in solving real-life problems. Therefore, it was concluded that high-school teachers can be advised to apply the interdisciplinary teaching approach in order to improve their students' knowledge about this process.*

Key words: *conceptual understanding, process of digestion, functionalization of acquired knowledge, interdisciplinary teaching approach.*

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Introduction

Healthy nutrition is important at any age, and adolescence is no exception. The body of an adolescent goes through important physiological changes during this time, and it has to be fueled, on daily basis, by the adequate type and amount of nutrients, in order to complete these changes successfully. However, it seems that adolescents are not aware of the importance of a healthy diet. In fact, they are considered as a nutritionally vulnerable subgroup because of their alimentary behaviours (World Health Organization, 2005). On the one hand, adolescent obesity and associated chronic diseases (cardiovascular and gallbladder diseases, as well as type 2 diabetes) are increasing at a rapid rate. As opposed to this, many adolescent girls, self-conscious about their body image, excessively restrict their energy intake out of a desire to be thin, which represents another prominent factor of health risk (Forthing, 1991; Perry-Hunnicuft & Newman, 1993).

Community trials suggest that nutrition education represents an accessible and effective tool for promotion of healthy dietary habits (Perez-Rodrigo & Aranceta, 2001). High school in particular represents an ideal time to teach about nutrition because adolescents are in the process of setting lifelong behaviors. Their personal choices gain priority over the eating habits acquired in the family, and they have progressively more control over what, when and where they eat (Shepherd & Dennison, 1996; Spear, 1996; Thomas, 1991). Consequently high-school science courses have the potential to become a very powerful medium for introducing students to the knowledge and skills which promote health and prevent diseases (Elders, 1993). However, high-school science is weakly connected to life in the modern world. Although the students show great interest in acquiring scientific knowledge that is relevant to their lives, the activities that they take part in are typically not tied to authentic experiences or problems (Aikenhead, 2006; Ebenezer & Zoller, 1993; Van Berkel, Pilot & Bulte, 2009). This in turn limits the students'

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understanding of scientific concepts and leaves them completely unaware of their real-life application (Riskowski, Todd, Wee, Dark & Harbor, 2009).

In order to promote understanding and functionalization of scientific concepts, the teachers must provide their students with meaningful and integrated learning experiences, as well as opportunities for knowledge application in solving real-life problems. Interdisciplinary teaching is considered to be one of the most effective teaching approaches to meet such educational aims (Chen, Cone Purcell & Cone, 2007; Lancaster & Rikard, 2002; Lipson, Valencia, Wixson & Peters, 1993).

Interdisciplinary teaching can be defined as "a knowledge view and curriculum approach that consciously applies methodology and language from more than one discipline to examine a central theme, issue, problem, topic, or experience" (Jacobs, 1989, p. 8). More specifically, the three strategies for interdisciplinary teaching are defined as contextualizing, conceptualizing and problem-centering. Contextualizing presupposes embedding disciplinary content in the framework of the time, culture, and personal experience. Conceptualizing involves identifying and establishing a quantifiable connection between core concepts that are central to two or more disciplines. Problem-centering, on the other hand, involves linking the knowledge and modes of thinking in several disciplines in order to solve complex real-life problems (Nikitina, 2006).

Within the framework of each of these strategies, inquiry processes and thinking skills are embedded into authentic learning concepts, topics, themes, or problems. As a result, the students' motivation toward learning is enhanced through recognizing that knowledge acquired in the classroom is relevant to real life (Davenport & Jaeger, 1995; Davison, Miller & Metheny, 1995). Further positive educational outcomes of the application of the interdisciplinary teaching approach include (Mathiason & Freeman, 1997):

- an improvement in understanding, retention, and application of knowledge
- better overall comprehension of global interdependencies
- development of multiple perspectives and points of view
- increased ability to make decisions, think critically and creatively and synthesize knowledge from various disciplines
- increased ability to identify, assess and transfer significant information needed for solving new problems.

Within the interdisciplinary teaching approach the collaboration of teachers from various fields of expertise is extremely important, as it was shown that it fosters learning and improves students' achievement in each of the fields (Jones, Rassmussen & Moffit, 1997). Through collaboration individual teacher's competencies are deepened, the exchange of examples of good teaching practice is promoted, and overall communication and collaborative skills of all teachers are improved. All of this, on the other hand, insures the greater quality of students' subject and inter-subject competence development (Lamanauskas, 2014). A good example of an interdisciplinary project which promotes collaboration of science and mathematics teachers is the *Materials for Teaching Together: Science and Mathematics Teachers collaborating for better results* project (Mat2SMC). The project is focused on preparing concrete materials (scenarios of lessons and other educational activities) by experts from several countries, that will be published and made freely available to all interested teachers (more information available at http://www.mat2smc-project.eu/index.asp?lang=en). By addressing the collaboration of science and mathematics teachers' this project also raised several important questions such as how to plan and develop the collaboration process, how to collaborate successfully in order to promote students' learning, how to organize collaborative nets seeking teachers' work and students' educational success, and how to rally collaborating teachers. The teachers' willingness and interest in collaboration, as well as the importance of the role of the school administrator were recognized as important factors for ensuring successful collaboration of experts from different fields (Lamanauskas, 2014).

Considering all of the previously stated beneficial outcomes of its' application, interdisciplinary teaching has been recognized as one of the key approaches for introducing adolescents to healthy alimentary habits (World Health Organization, 2005).

For example, with the proliferation of pathogenic microbes and their eating habits being as they are, today's adolescents are more at risk of contracting a foodborne illness than the previous generations (American Dietetic Association, 1997; Byrd-Bredbenner, Maurer, Wheatley, Schaffner, Bruhn & Blalock, 2007; Coulston, 1999). Therefore, interdisciplinary curriculum called *Food Safety in the Classroom Curriculum* aimed to address food safety concerns through all the core subject classes (science, mathematics, social studies, and language arts). The curriculum's effectivity was tested in five high schools, and the results showed that it was effective in raising students' knowledge (a 21% gain) and improving their food handling behaviors (an 8.47% gain) (Richards, Skolits, Burney, Pedigo & Draughon, 2008).

The Planet Health Interdisciplinary Curriculum represents an additional example of an interdisciplinary curriculum which combines knowledge of language arts, mathematics, science and social skills. It was designed in order to teach high-school students about healthy nutrition and physical activity (Carter, Wiecha, Peterson, Nobrega & Gortmaker, 2007).

Increasing fruit and vegetable consumption as a means of increasing fiber and antioxidant intake for chronic disease prevention represents an important aspect of dietary guidelines (World Health Organization, 2005), and another interdisciplinary program provided a model to show that it is possible to modify the dietary habits of high-school students through positive media messages, increased exposure to targeted foods, appropriate classroom activity and parental support (Nicklas, Johnson, Farris, Rice, Lyon & Shi, 1997).

Additionally, an evaluation of the teachers' implementation and perceptions of the application of the high-school interdisciplinary nutrition curriculum called *Mid-LINC* has been presented (Probart, McDonnell, Achterberg & Anger, 1997). Overall, the teachers' response to such a curriculum was highly favorable, with teachers rating it easy to use, flexible, and complete. The perceived importance of team teaching, the extent to which the teacher felt informed about nutrition, and the perceived importance of nutrition in the high-school curriculum were significant predictors of comfort with the curriculum.

It has been recognized that the students' nutritional habits are strongly influenced by their knowledge about digestion, as a sound understanding of this process helps them to gain a healthy attitude to nutrition and, in the long term, have a healthier life (Ozsevgec, Artun & Ünal, 2012). However, previous research determined numerous high-school students' misconceptions concerning this topic (Aydin, 2016; Granklint Enochson & Redfors, 2012; Soyibo & Evans, 2002). It has been concluded that, within a successful teaching about any physiological process, the knowledge of biology builds on the knowledge of chemistry and physics, and that students' understanding of that disciplinary knowledge has a great impact on their learning about the process of interest. Consequently, effective teaching about a physiological process must target misconceptions from all three disciplines (Michael, 2006). These conclusions imply that the interdisciplinary teaching approach could be a very effective tool for facilitating high-school students' learning about digestion. However, the literature review produced no experimental research that reported the effects of the application of an interdisciplinary intervention on high-school students' conceptual understanding or real-life application of knowledge concerning this physiological process. Given that high-school students' nutritional habits have to be improved and that the interdisciplinary teaching about digestion seems to be a good way to achieve this, not having any previous experimental research that either confirms or denies the effectiveness of the interdisciplinary approach when it comes to teaching high-school students about this process, represents the problem at the core of the research. Since no previous attempts to solve this problem have been made, the research aimed to determine the effectiveness of the interdisciplinary approach when it comes to improving high-school students' conceptual understanding and functionalization of knowledge about digestion. In accordance with this aim, the following research questions have been posed:

- Is there a significant difference in the effectiveness of the interdisciplinary teaching approach when it comes to improving high-school students' conceptual understanding of the teaching topic *Digestion,* in comparison to the disciplinary approach?
- Is there a significant difference in the effectiveness of the interdisciplinary teaching approach when it comes to improving high-school students' ability to apply the acquired knowledge concerning the teaching topic *Digestion* in real-life, in comparison to the disciplinary approach?

It is hoped that, through finding answers to these research questions, the effectiveness of the interdisciplinary approach when it comes to improving high-school students' understanding and functionalization of knowledge about digestion will be determined, so that the high-school teachers can be advised accordingly on whether or not they should apply this approach in order to improve their students' knowledge about this process and, ultimately, their alimentary habits. However, given that this is the first experimental research that aims to determine the effectiveness of the interdisciplinary approach when it comes to teaching about digestion in high school, its' main limitation is that more results of similar research that confirm its' findings are needed in order to make them more readily generalizable.

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Methodology of Research

Research design

In order to obtain answers to the research questions, a pedagogical experiment with parallel groups was conducted in the spring semester of the 2015/2016 academic year. Experimental research is considered as an appropriate research design for comparing the effectiveness of the two teaching approaches (Cohen, Manion & Morrison, 2007). Work with students from both groups encompassed a total of four lesson periods lasting 45 minutes, two such periods per week. The general outlines of the research design are presented in Table 1.

Table 1. The research design

Lesson period number	Activities in the experimental group	Activities in the control group
1.	Pre-testing	Pre-testing
2. 3.	Dealing with the teaching topic Digestion according to the principles of the interdisciplinary teaching approach	Dealing with the teaching topic Digestion according to the disciplinary approach
4.	Post-testing	Post-testing

Research Sample

A total of 258 fourth year high-school students (aged 18) from three high schools in Serbia participated in the experiment. Two of these high schools are located in Belgrade, whilst the third one is in Pančevo. The three high schools were selected for the reason of convenience. Four fourth year classes from each of the schools took part in the experiment, with the two classes from each school being randomly selected to be a part of the experimental group, whilst the other two formed the control group. In this way the experimental group was made up of 125 students, whilst the control group encompassed 133 students. When it comes to the sample size in quantitative research, a sample size between 30 and 500 at 5% confidence level is generally considered as sufficient for a given quantitative research to be considered as reliable. However, in an effort to further increase the reliability of quantitative research, the sample size should be made as big as possible, with many researchers preferring it to be over 250 (Delice, 2010). Additionally, as the sample size increases from 30 to approximately 80, the sampling error and the standard error of measurement, which represent the two main causes of the unrepresentativeness of a sample, decrease. Although further increase of sample size has little effect on these two parameters (Cohen, Manion & Morrison, 2007), the sample of 258 high-school students can be considered as the representative sample of research, as well as the sample that insures the high reliability of the research. Furthermore, when t-test calculations are made, the minimal valid sample size is considered to be 30, and when chi-square statistics are used, sample size is considered as valid if it ensures that there is a minimum of five cases per cell, in 80% of cells in a given contingency table (Cohen, Manion & Morrison, 2007). Given its' size and the distribution of cases in the 2 X 2 contingency tables presented in the Results of research section, the sample of 258 high-school students be considered as valid for these types of calculations.

Ethical considerations

The written consent for conducting the research has been obtained from the director, government and science committee from each of the schools. All the students in the sample of research were volunteers. They accepted to take part in the research after they have been assured that their decision not to participate will have no negative consequences, whilst the participation will not bring them any benefits. Also, if they decide to take part in the experiment but at some point during it change their mind about participation, they can drop out of the experiment without any repercussions.

Interdisciplinary vs. disciplinary teaching about digestion

Within the experiment, the students in the experimental and the control groups were taught by one of the researchers. The content taught to the students in both groups is presented in Table 2.

Table 2. The content taught to the students in the experimental and control group.

Content type	Content specifics
The taste of various nutrients	Substances that cause the tastes of sweet, sour, salty and bitter
Digestive enzymes	Which digestive enzymes are active in the mouth, stomach and small intestine Which types of food digestive enzymes break down and what are the products of this breakdown Optimal conditions for the activity of the digestive enzymes Why digestive enzymes of the stomach and the small intestine are synthesized in the form of inactive proenzymes
Absorption of nutrients	Absorption of monosaccharides, amino acids and fatty acids in the small intestine Absorption of water in the large intestine Absorption of alcohol in the stomach, types of food that can slow down or accelerate this process
Pathological states of the digestive tract	Hearthburn, food intolerance, gallstone formation, pancreatitis

The students in the control group were taught about the content presented in Table 2 according to their chemistry textbook for the fourth year of high school. On the other hand, according to the principles of the interdisciplinary teaching approach, the students in the experimental group acquired the same knowledge about the process of digestion as the students in the control group, by linking it with their previously acquired biology, and in case of the nutrient absorption, physics knowledge. The interdisciplinary intervention was based on the relevant literature about digestion (Guyton & Hall, 2006; Sullivan, 2004).

When it comes to the teaching about digestive enzymes of the mouth and the taste of various nutrients, the students in the experimental group were first reminded of the anatomy of the mouth, the function of teeth, tongue and the saliva production by the three types of the salivary glands. It was explained that the saliva contains digestive enzymes responsible for the initial breakdown of starch and lipids. It also contains bicarbonate ions that provide the alkaline conditions necessary for the activity of these enzymes. The students were explained that the individuals perceive the tastes of sweet, sour, salty, and bitter caused by the substances such as glucose, ethanoic acid, various inorganic salts, or some alkaloids respectively, owing to the taste buds located in the tongue tissue.

When it comes to teaching about the digestive enzymes of the stomach, the students in the experimental group were reminded of its anatomy, and explained that the chief components of the stomach gastric juice, the hydrochloric acid and the proteolytic enzyme pepsin, are the products of various types of cells of the stomach mucosa. It was explained that the presence of the hydrochloric acid in the gastric juice is essential for providing the strongly acidic conditions that are necessary for the transformation of inactive pepsinogen to pepsin, the activity of this enzyme, as well as the denaturation of food proteins. Within the framework of the elaboration of digestion in the stomach, the pathological condition heartburn was also considered.

When it comes to teaching about the digestive enzymes in the small intestine, digestion in its starting portion, the ileum, was considered first. It was explained that digestion in the ileum requires the presence of pancreatic juice, which contains the digestive enzymes responsible for further breakdown of starch, proteins and lipids. It also contains bicarbonate ions that neutralize the acidic content coming to the ileum from the stomach and, following this, create the alkaline conditions needed for both the transformation of inactive pancreatic juice proenzymes into active enzymes, as well as the activity of these enzymes. When it comes to lipid digestion in the ileum, it was explained that the presence of food in this portion of the small intestine causes the gallbladder to secret bile, whose chief components are bile salts. This was followed by the explanation of how bile salts break down large lipid aggregates into small micelles, and why this emulsification process is essential for lipid digestion catalyzed by pancreatic lipase. Additionally, it was explained that because of this, digestion of foods rich in lipids takes more

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time than digestion of foods rich in carbohydrates or proteins to be completed. Within the framework of the elaboration of digestion in the small intestine, pathological conditions such as pancreatitis, bile stone formation and intolerance to certain types of foods were also considered.

To end with, the topic of nutrient absorption was considered. First of all, the students were reminded of the anatomy of the final portion of the small intestine, which contains a large number of finger-like projections called villi, which are essential for nutrient absorption. After that, the anatomy of a single villus was considered and the students learned that only small molecules such as monosaccharides, amino acids and fatty acids can be absorbed from the surface of a villus into blood or lymph. Then their previously acquired knowledge about membrane transport processes was called upon, as it was elaborated that the absorption of monosaccharides and amino acids is based on the mechanism of active transport, whilst the absorption of fatty acids is based on the process of facilitated diffusion. The students were also explained that a portion of the ingested water is absorbed in the small intestine, whilst the rest is absorbed in the large intestine, according to the mechanism of osmosis. As alcohol use and overuse represent one of the major problems linked with the adolescence period, alcohol absorption in the stomach, as well as types of food that can slow down or accelerate this process, were also considered.

Instruments of Research

The quantitative data in the experiment were gathered by means of a pre-test and a post-test, both of which were developed by the researchers. It has been shown that taking a pre-test may influence the outcome of a subsequent identical post-test, for the students in both groups. Furthermore, the very concept of the pre-test can sensitize the students in the experimental group to the intervention (Martella, Nelson, Morgan, & Marchand-Martella, 2013). Therefore, devising of the two tests was based on a guideline which states that the pre-test and the post-test may differ in form and wording, as long as they refer to the same topic of interest (Cohen, Manion & Morrison, 2007).

The pre-test was used as an instrument for checking how balanced the previously acquired chemistry, biology and physics knowledge prerequisite for successful learning about the process of digestion of the students in the two groups was. It is important to note that the items on the pre-test were devised so as to resemble regular textbook items that do not require linking of knowledge from several different disciplines in order to solve real-life problems, but a simple reproduction of knowledge from only one discipline per item, in order to respond to purely academic requests (e.g. within I7 the students had to select the correct definition of the intestinal flora). In this way, sensitizing the students in the experimental group to the interdisciplinary intervention has been avoided. An overview of the pre-test items (the content to which each item on the pre-test refers, the course within which that content was taught to the students in the two groups, as well as item type) is presented in Table 3. The full contents of the pre-test are presented in Appendix 1.

Table 3. An overview of the pre-test items.

Item number	Content to which the item refers	Course within which the content was taught	Item type
I1	Anatomy of the alimentary tract	Biology course in the third year of high school	multiple choice item
I2	The difference between physical and chemical digestion	Biology course in the third year of high school	alternative choice item
I3	Anatomy and function of the stomach	Biology course in the third year of high school	multiple choice item
I4	Proenzymes	Chemistry course in the fourth (current) year of high school	open-ended item
I5	Factors that affect enzyme activity	Chemistry course in the fourth (current) year of high school	open-ended item
I6	Vitamins	Biology course in the third year of high school; Chemistry course in the fourth (current) year of high school	open-ended item

Item number	Content to which the item refers	Course within which the content was taught	Item type
I7	Intestinal flora	Biology course in the third year of high school	multiple choice item
I8	Mechanisms of membrane transport processes diffusion, osmosis and active transport	Physics course in the second year of high school (diffusion and osmosis); Biology course in the third year of high school (active transport)	matching item

The post-test was used as an instrument for comparing the effectiveness of the interdisciplinary and disciplinary teaching approach about digestion. In order to find the answer to the second research question, items on this test required the application of knowledge concerning digestion in solving real-life problems. Additionally, in order to find the answer to the first research question, within all the items on the post-test, with the exception of I1, the students were required to provide an explanation of their solution. In this way, an insight into their understanding of the applied knowledge was provided. An overview of the post-test items (the content to which each item on the post-test refers and item type) is presented in Table 4. The full contents of the post-test are presented in Appendix 2.

Table 4. An overview of the post-test items.

Item number	Content to which the item refers	Item type
I1a	Cellulose as a substance that cannot be utilized as a nutrient by the human body	multiple choice item
I1b	Characteristics of various nutrients	matching item
I2	Energy content of food and body weight	open-ended item
I3	Factors influencing the activity of the digestive enzyme pepsin	open-ended item
I4	Types of food that influence the speed of alcohol absorption	open-ended item
I5	Pathological states of the digestive system and their consequences	open-ended item
I6	Recognizing that the absorption of diverse types of nutrients in the digestive system and various other processes in plants, humans and microorganisms are based on the identical membrane transport processes (diffusion, facilitated diffusion, osmosis and active transport)	open-ended item

It is important to note that the students in both groups had previous experience in solving all of the above-mentioned types of items, in both tests.

To confirm the content validity, the pre-test and the post-test were examined by a group of experts comprising two university educators and four high-school teachers who have been teaching for over twenty years in high schools in the cities of Belgrade and Pančevo.

In order to confirm their internal consistency, the values of Cronbach's alpha internal consistency coefficient were established for both tests. The pre-test had a Cronbach's alpha internal consistency coefficient value of 0.72, whilst the value for the post-test was 0.74. On the basis of these values, which are higher than the border-line value of 0.70 (Cronbach & Meehl, 1955) it can be concluded that both tests have a satisfactory degree of internal consistency.

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Data Analysis

By using the SPSS software program for statistical analysis, the mean score and standard deviation on the pre-test and the post-test were determined for both groups. The statistical significance of the difference of the mean score of the two groups was examined by means of a *t* test. Additionally, for each item on both of the tests, a 2 X 2 contingency table, as well as the corresponding values of the chi-square test of independence, are provided.

Results of Research

Table 5 contains the descriptive statistics of the pre-test, and the corresponding $t(257)$ value.

Table 5. Descriptive statistics and the *t*(257) value of the pre-test

Group	Mean	SD	t(257)
Experimental	10.384	3.172	+0.096a
Control	10.346	3.215	

[a]*The difference in the mean score of students in the experimental and the control group is not statistically significant at the level of p < 0.05.*

The number of correct/incorrect answers in absolute frequencies and the corresponding values of the chi-square test of independence for each item contained in the pre-test are presented in Table 6.

Table 6. The chi-square test of independence values for each item of the pre-test

Items	Number of correct answers in the experimental group	Number of correct answers in the control group	Number of incorrect answers in the experimental group	Number of incorrect answers in the control group	χ^2(1, N = 258)
I1	103	107	22	26	0.162a
I2a	102	111	23	22	0.155a
I2b	101	110	24	23	0.157a
I2v	62	74	63	59	0.943a
I2g	77	81	48	52	0.013a
I2d	116	120	9	13	0.547a
I3	56	58	69	75	0.037a
I4	61	63	64	69	0.030a
I5	69	73	56	60	0.002a
I6a	72	67	53	66	1.353a
I6b	81	74	44	59	2.255a
I7	51	63	74	70	1.127a
I8a	74	86	51	47	0.816a
I8b	100	112	25	21	0.779a
I8v	106	111	19	22	0.086a
I8g	67	66	58	67	0.407a

[a]*The value of the chi-square test of independence is not statistically significant at the level of p < 0.05.*

As can be seen in Table 5, no statistically significant difference in the mean score of the students in the two groups was determined on the pre-test. Additionally, the chi-square test of independence values presented in Table 6 indicates that there was no statistically significant difference in the number of correct answers in absolute frequencies between the students in the two groups, on any of the items on the pre-test.

Table 7 contains the descriptive statistics of the post-test and the corresponding t (257) value.

Table 7. Descriptive statistics and the *t*(257) value of the post-test

Group	Mean	SD	t(257)
Experimental	10.352	2.204	5.853a
Control	8.120	3.689	

[a]The difference in the mean score of students in the experimental and the control group is statistically significant at the level of p < 0.01.

The number of correct/incorrect answers in absolute frequencies and the corresponding values of the chi-square test of independence for each item contained in the post-test are presented in Table 8.

Table 8. The chi-square test of independence values for each item of the post-test

Items	Number of correct answers in the experimental group	Number of correct answers in the control group	Number of incorrect answers in the experimental group	Number of incorrect answers in the control group	$\chi^2(1, N = 258)$
I1a	101	96	24	37	2.652
I1b1	99	86	26	47	6.713[a]
I1b2	93	72	32	61	11.479[a]
I1b3	64	51	61	82	4.310[b]
I2a	91	87	34	46	1.643
I2b	83	63	42	70	9.501[a]
I3	97	86	28	47	5.231[b]
I4	119	108	6	25	11.942[a]
I5a1	71	42	54	91	8.716[a]
I5a2	67	42	58	91	12.807[a]
I5b	102	97	23	36	2.745
I6a	79	61	46	72	7.802[a]
I6b	78	65	47	68	4.773[b]
I6v	77	66	48	67	3.741
I6g	74	58	51	75	6.269[a]

[a]The value of the chi-square test of independence is statistically significant at the level of p < 0.01.
[b]The value of the chi-square test of independence is statistically significant at the level of p < 0.05.

As can be seen in Table 7, the students in the experimental group achieved a statistically significant higher mean score on the post-test, in comparison to the students in the control group. Additionally, the chi-square test of independence values presented in Table 8 indicates that the students in the experimental group had a statistically significant higher number of correct answers in absolute frequencies on 11 out of 15 items on the post-test, in comparison to the students in the control group.

Discussion

The results of the pre-test show that the students from the two groups possessed a relatively similar level of previously acquired biology, chemistry and physics knowledge which they needed in order to understand the process of digestion, at the beginning of the experiment. On the other hand, after the implementation of the interdisciplinary teaching approach, the students in the experimental group significantly outperformed the students in the control group on most of the items on the post-test which, as it was previously elaborated, required a deep understanding and the application of the knowledge about digestion in real-life situations.

The finding concerning the effectiveness of the interdisciplinary teaching approach when it comes to promoting the students' understanding of the process of digestion supports the claim made by several authors that this

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approach has the potential to improve conceptual understanding (Haigh & Rehfeld, 1995; Lattuca, Voight & Fath, 2004; Maurer, 1994; McGivney-Burelle, McGivney & Wilburne, 2008; Nagle, 2013; Wicklein & Schell, 1995). Low levels of conceptual understanding have previously been associated with rote memorization oriented learning, which occurs when students simply memorize new information without considering how it relates to the knowledge they already possess. In order to prevent rote memorization, it is necessary to foster meaningful learning in which the learner makes significant connections between new information and prior knowledge (Bretz, 2001; Grove & Bretz, 2012; Novak, 2002), and this is exactly what the students in the experimental group were encouraged to do within the interdisciplinary intervention described in this paper. On the other hand, the students in the control group who possessed a relatively similar level of previously acquired biology, chemistry and physics knowledge, but were taught about digestion without referring to that knowledge or being prompted to build new knowledge about this process upon it, showed a statistically significant lower level of the conceptual understanding of this topic.

The finding concerning the effectiveness of the interdisciplinary approach when it comes to promoting the students' application of the knowledge concerning digestion in real life supports the claim that this approach has the potential to adequately prepare students for tackling various challenges of life in the modern world (Rennie, Venville & Wallace, 2012). As previously discussed, the interdisciplinary teaching approach focuses on real-world concepts tied to the personal interests and experiences of the students (Czerniak & Johnson, 2014; McComas, 2009). Therefore, instead of looking at digestion as a series of reactions and processes that occur in various parts of the digestive system, the students in the experimental group were encouraged to look upon them in the light of real-life issues such as alcohol use and food intolerance, elaborations on why certain types of food are more easy to digest than others, why certain types of food have a particular taste, etc. As the results obtained in this experiment indicate, linking new knowledge to authentic situations and problems in this way represents a very effective tool for promoting the functionalization of that knowledge.

As can be seen in Table 8, no statistically significant difference in the achievement of the students in the two groups was found for items I1a, I2a, I5b and I6v on the post-test.

Items I1a and I5b represent the simplest items on the post-test. These items did not require dealing with real-life problems, but a simple reproduction of factual academic knowledge. Specifically, within I1a the students had to choose cellulose as a substance that cannot be utilized as a nutrient by the human body (other possible options were iodine, bovine serum albumin, folic acid and cholesterol). Within I5b, the students had to produce the name of the pathological state in which digestion of lactose is impaired. Given the results obtained in this study, it can be concluded that the interdisciplinary approach is not more effective than the disciplinary approach in promoting memorization and reproduction of factual academic knowledge.

The lack of a statistically significant difference on I2a in favour of the students in the experimental group is very likely caused by their inattentive reading of the item's text. More specifically, whilst the majority of the students in the control group whose answers were coded as incorrect failed to produce any answer to this item, almost half of the students in the experimental group whose answers were coded as incorrect managed to determine the correct energy value of the diet soda, based on the information that this drink contained no carbohydrates, fats or proteins. However, they failed to use this information in order to fully address the further requirements of this item, i. e. to calculate the full energy value of a meal that, besides diet soda, included one hamburger and one milk shake, whose energy values were provided within the text of the item. After the experiment was completed, several of these students actually confirmed that they were completely unaware of this requirement.

I6v referred to the process of facilitated diffusion. After the experiment was completed, the students in both groups revealed that within their second year physics course, as well as their third year biology course, they had dealt with the mechanisms of diffusion, osmosis and active transport in great detail, but were not properly explained the mechanism of facilitated diffusion. Most unfortunately, within the pre-test only their knowledge of the mechanisms of diffusion, active transport and osmosis was checked, so that their lack of knowledge of the process of facilitated diffusion passed unnoticed. Consequently, the majority of the students in both groups whose answers were coded as incorrect mistook this process for the process of active transport, probably because both processes require the participation of membrane transport proteins. This finding confirms the claim that effective teaching about a physiological process must consider all chemistry, physics, and biology misconceptions related to that process, as any of these misconceptions have a negative impact on further learning (Michael, 2006).

Conclusions

On the basis of the results of research, it can be concluded that both research questions that have been posed can be answered in the affirmative, i.e. the interdisciplinary teaching approach is significantly more effective in promoting high-school students' conceptual understanding and functionalization of knowledge concerning the process of digestion, in comparison to the disciplinary approach. In this way, the benefits of the implementation of the interdisciplinary approach in teaching about digestion in high school have been experimentally confirmed for the first time. Consequently, high-school teachers can be advised to apply this approach in order to improve their students' understanding and functionalization of knowledge about this process. Given that nutrition is strongly influenced by knowledge about digestion, this should also help the students to develop healthier alimentary habits.

The results of research further indicate that, whilst the interdisciplinary approach is more effective than the disciplinary approach when it comes to fulfilling the relatively complex requirements for a deep understanding and transfer of knowledge about digestion to real life, the same cannot be said of a relatively simple requirement for promoting the reproduction of factual academic knowledge concerning this process.

It is important to note that a successful implementation of an interdisciplinary intervention which is based on linking chemistry, biology and physics content in teaching about digestion, requires the students' thorough knowledge of all of the concepts from the three disciplines which are prerequisite for successful learning about this physiological process. Any misconceptions concerning concepts from any of these disciplines, as the results of this study confirm, cause further misconceptions and problems with learning of this topic.

In view of the fact that they confirm the great potential of interdisciplinary interventions based on linking chemistry, biology and physics knowledge when it comes to improving teaching about the process of digestion in high school, the results of research could have important implications for teaching practices. However, as it was previously stated, further research that confirms these findings is necessary in order to make them more readily generalizable. Additionally, it should be noted that the Hawthorne effect, which presupposes that being exposed to new factors in a working environment, such as an experimental intervention for the students in the experimental group, may prompt these students to temporarily improve their working performance, which in turn could be responsible for a part of the gains observed.

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Appendix 1

The pre-test

Item 1	Item 2
Encircle the letter next to the intestinal tract component inside whose lumen the pH value exceeds 7: A) the stomach B) the large intestine V) the gallbladder G) the duodenum	The digestion process in the human organism can be physical and chemical. State which form of digestion each of the processes listed below represents, writing in the adjacent box P for physical and C for chemical digestion: A) ☐ decomposition of polypeptide protein chains into shorter peptide fragments, catalysed by proteolytic enzymes B) ☐ crushing and grinding food through mastication V) ☐ emulsification of fats in the presence of bile acids G) ☐ turning chewed solid food into pulp by mixing it with saliva D) ☐ decomposition of cholesterol-palmitate into cholesterol and palmitic acid, catalysed by the enzyme lipase

Item 3	Item 4
Encircle the letter next to the correct statement referring to the digestion in the stomach: A) enzyme lipase, produced by cells of the stomach mucosa, breaks down food lipids in the stomach B) cells of the stomach mucosa secrete bicarbonate ions, which help protein digestion in the stomach V) enzyme pepsin, produced by cells of the stomach mucosa, breaks down food proteins in the stomach G) cells of the stomach mucosa secrete bile, which helps lipid digestion in the stomach	In the pathological state known as pancreatitis, proteolytic enzymes that must be present in the pancreatic juice so that the digestion of proteins could unfold without any problems, attack and destroy the proteins of the pancreas itself. Explain how the destruction of pancreatic proteins by proteolytic enzymes is prevented in a healthy human organism.

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Item 5	Item 6
In test tubes marked 1 and 2, 2ml of 1% starch solution and 2ml of water is poured. The test tube 1 is heated to the 100 C, after which saliva is added to both test tubes. Twenty minutes after adding saliva, iodine is added to both test tubes. State what you expect will happen in test tubes 1 and 2 following the addition of iodine, and provide a justification for your answer.	Enlist lipid-solubile vitamins:

Item 7	Item 8
Encircle the letter next to the correct definition of the intestinal flora: A) small cultures of pathogenic bacteria, in the presence of which antibodies are produced in order to destroy the pathogenic microorganisms that can cause the infection of the digestive tract B) undigested pieces of food of plant origin that coat the lumen of the large intestine V) cultures of lactobacteria; these bacteria produce lactic acid, which, inside the lumen of the intestinal tract, provides the acid surroundings wherein pathogenic microorganisms cannot survive G) cultures of lactobacteria; these bacteria produce substances of alkaloid origin that, inside the lumen of the intestinal tract, kill pathogenic microorganisms	Some of the processes described below are examples of physical-chemical transport mechanisms for substances passing through a cell membrane. For each example listed below, state whether it is a transport mechanism and which specific mechanism it is by entering the corresponding transport mechanism number in the box above each description; if such a form of transport does not exist, enter number 4: 1. diffusion, 2. osmosis, 3. active transport, 4. such a form of transport does not exist. A) ☐ Transport of substance X, in opposition to the concentration gradient (from the area of lower concentration of this substance to the area of its higher concentration), without any expenditure of energy. B) ☐ Transport of substance X down the concentration gradient (from the area of higher concentration of this substance to the area of its lower concentration), without any expenditure of energy and without any help of the membrane transport proteins. V) ☐ Transport of substance X in opposition to the concentration gradient, with the help of the membrane transport proteins and with expenditure of energy. G) ☐ Transport of water through a membrane that is non-permeable to particles of dissolved substances X and Y, from the direction of the solution with a lower concentration of these substances towards the solution with a higher concentration of X and Y, with no expenditure of energy.

Appendix 2

The post-test

Item 1

a) Encircle the number in front of the substance that is not nutritive to the human organism. Provide a justification for your choice:

1) cholesterol
2) bovine serum albumin
3) iodine
4) cellulose
5) folic acid

b) In the table below, enter the number of the foodstuff among those listed underneath that corresponds to each of the characteristics contained in it (none of the said characteristics correspond to one of the given foodstuffs) in the appropriate box:

Foodstuff characteristics	Number of foodstuff
A good source of B group vitamins	
A good source of oleic acid	
A good source of phosphorus	

1) olive oil 2) beans 3) onion 4) yeast

Item 2

The body mass index of the human organism is calculated by multiplying the body weight in kilograms by 24 for men, whereas for women, it is arrived at by further multiplying this number by 0.9. The result thus obtained represents the energy value of food, expressed in kcal, which the organism must ingest in order to maintain the same body weight. If, in the course of the day, the energy value of the food ingested is lower than the above-mentioned value, the person in question loses weight, and if the energy value of the food ingested is higher, the person gains weight.

a) Sanja (body weight 55 kg) ate a hamburger and drank a milkshake for lunch. The energy value of the food she ingested is 1350 kcal.What would have been the energy value of Sanja's lunch if, instead of milkshake, she had drunk diet soda, knowing the following:

b) Let us assume that Sanja, in addition to the hamburger and diet soda, also ate for lunch a mini chocolate bar whose overall energy value is 338 kcal. How long should Sanja ride a bicycle at the speed of 25 km/h (one hour of this activity burns 300 kcals) after this meal in order to "burn"as many kcalas necessary to keep the same body weight that she had before this meal?

Beverage	Energy value (kcal)	Hydrocarbons content of the beverage (mg)	Lipids content of the beverage (mg)	Proteins content of the beverage (mg)
Milkshake	350	45	35	5
Diet soda	?	0	0	0

Item 3

Four test tubes marked 1 to 4 contain 2ml of the standard protein albumin solution. To test tubes 1 and 2, 2ml of water is added, to test tube 3 2ml of 0.2M hydrochloric acid, and to test tube 4 2ml of 0.002M sodium hydroxide solution. The content of test tube 2 is heated to the temperature of 80 ºC, following which 2 mg of enzyme pepsin is added to all four test tubes. Twenty minutes after adding the enzyme, a ninhydrin reagent is added to all four test tubes. In which of the test tubes does the colour violet appear? Provide a justification for your answer.

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Item 4

Four persons have consumed one of the four combinations of food and drink listed below, at the same time. One hour later, each of them voluntarily underwent testing for alcohol. Arrange the combinations listed below, starting from the one that you expect to have produced the highest concentration of alcohol in the blood, working your way towards the one you assume to have produced the lowest concentration of alcohol in the blood. Provide a justification for your answer:

1) 20 ml of beer + 20 g of cheese,
2) 20 ml of whiskey + 20 gof bread,
3) 20 ml of whiskey + 20 g of cheese,
4) 20 ml of whiskey + 20 ml of soda.

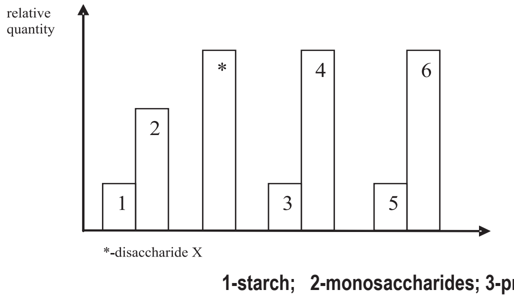
Item 5

Four persons (A, B, C and D) have consumed an identical meal, consisting of beefcutlets, mashed potatoes and a glass of milk. Two hours after the meal, a chemical analysis of the content found in the lumen of their small intestine was carried out.

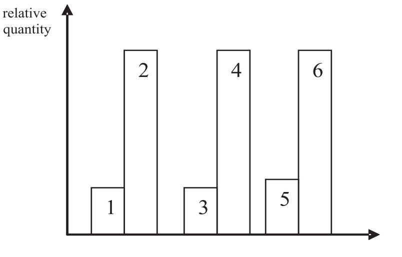
a) In the rectangle under each of the graphs showing the results of the said analysis, write a letter designating a person to which those analysis results correspond to. Provide a justification for your choice, knowing the following:

Person A is completely healthy, whereas person B suffers from pancreatitis. Person C suffers from jaundice. In the case of this illness the yellow colour of the skin occurs as a result of the high bilirubin content in the blood. There are a number of different causes of jaundice, but in the case of this patient, the illness was the result of bile duct blockage, which prevented a normal release of bile into the lumen of the small intestine. In such a case, bile is retained in the gallbladder, and the amassed bilirubin, one of its standard ingredients, "drains" into the bloodstream. The analysis results of person D would have been similar to those of person A, had person D, instead of a glass of milk, taken a spoonful or two of fat. As a result of having consumed milk, however, an uncommonly high quantity of disaccharide X can be observed in the lumen of person D's small intestine.

1)



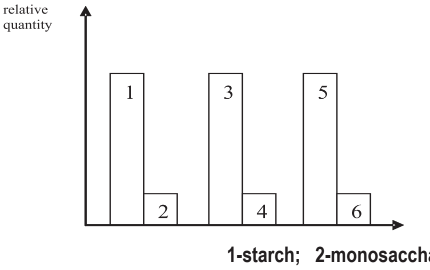
2)



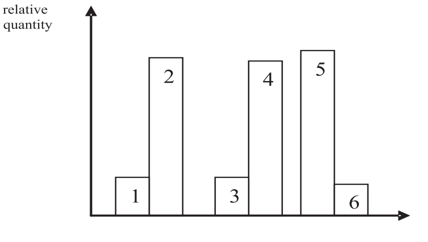
1-starch; 2-monosaccharides; 3-proteins; 4-aminoacids; 5-triacylglycerols; 6-fattyacids

Person: D	Person: Justification:

3)



4)



1-starch; 2-monosaccharides; 3-proteins; 4-aminoacids; 5-triacylglycerols; 6-fattyacids

Person: Justification:	Person: Justification:

b) Complete the following sentence:

The illness person D suffers from is called ____

____

Item 6

Various processes in the human organism, plants, bacterial cells, as well as various laboratory techniques used in scientific research, are based on identical physical-chemical transport mechanisms. Under the text of each of the processes described in this item, state one example of a process unfolding at the level of the small intestine or the large intestine in the human organism, based on an identical physical-chemical transport mechanism.

a) The opening of stomata in plants

When plant stomata open, potassium ions are amassed in auxiliary cells, whereas their concentration in the adjacent opener cells is very low. This causes water transfer from opener cells to auxiliary cells, on account of which a stoma opens.

b) The "desalting"of a protein specimen

Isolating albumin from egg white is based on the precipitation of this protein by means of ammonium sulphate. When the protein precipitates dissolved in an appropriate buffer solution, we have a ready sample of this protein, but it also contains a great quantity of ammonium sulphate. In order to remove salt from the protein sample, dialysis is applied. The sample is placed inside a dialysis tube, through the walls of which salt ions can pass freely, but not protein molecules. The dialysis tube is then placed inside a large glass full of cold distilled water, and is left in such surroundings overnight.The following morning, the concentration of ammonium sulphate in the dialysis tube will be reduced to half the initial value, that is, it will equal the concentration of this salt in the surrounding liquid.

v) Transport of fatty acids at the level of the inner mitochondrial membrane

Fatty acids in human cells undergo a process of β-oxidation inside the mitochondria, that is, in the mitochondrial matrix. For fatty acids to be transferred from the cell cytoplasm inside the mitochondria, they must pass through the outer and then through the inner mitochondrial membrane. The outer mitochondrial membrane does not differ from the cell membrane in terms of structure. When fatty acids are amassed in the cell cytoplasm, they pass through this membrane without any problems and enter the space between two mitochondrial membranes. However, the amassed fatty acids cannot pass freely from the intramembrane space to the mitochondrial matrix at any part of the inner mitochondrial membrane. That is possible only in those places where the transport protein L-carnitine is located.

g) Nutrition of bacteria from the genus Bacillus subtilis

The basic nutritive substance for bacteria from the genus Bacillus subtilis is disaccharide lactose. Consequently, the cytoplasm of the cells of bacteria from this genus contains a relatively high concentration of this disaccharide. If the cell of a bacterium from the genus Bacillus subtilis comes across a lactose molecule while moving on a nutrient ground, it will insert it into its cytoplasm by means of a lac transport protein on the cell membrane, along with the expenditure of one ATP molecule.

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