Digestion as an example of integrated teaching of chemistry and biology

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Abstract

Most people are uncertain about how nutrients enter and are distributed in the body. They may be capable of naming the different parts of the digestive system on a torso but have vague ideas of the relation between these organs and the chemical processes they govern. Reasons for this are poor understanding of gas exchange, the role of the circulatory system, and that most processes are intracellular. In order to create a more holistic view of the biology and chemistry of digestion these subjects may be taught simultaneously and integrated. Here practical exercises and lectures about digestion and nutrients for pre-service primary school teachers are presented. The practical work included food preparation in order to investigate the change of the properties of the macromolecules of nutrients. A simple drawing of a body was used in order to visualize the routes of nutrients and the role of gas exchange in digestion. An evolutionary perspective on digestion was used in order to explain the ancient origin of most chemical processes in the digestive system and in the whole body. The material produced by the students at their final examinations was used for assessing their use and understanding of concepts, the quality based on Doll's 4R's and the degree of holistic understanding of the digestive system. The findings show that the pedagogic design used gives a general picture of digestion and energy transfer usable for teaching in primary school.

Keywords: Nutrition; digestion system; evolution teacher training; concepts biology education, chemistry education

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Introduction

The curriculum for compulsory school is of importance not only for teaching in school but also in teacher education. In the Swedish curriculum the syllabuses for the science subject biology, chemistry and physics have a similar structure of aims, contents and knowledge requirements (Skolverket, 2011) which may inspire teachers to teach science as an integrated subject.

Teaching in biology should essentially give pupils the opportunities to develop their ability to:

• use concepts of biology, its models and theories to describe and explain biological relationships in the human body, nature and society (Skolverket, 2011, p. 105–106).

Teaching in chemistry should essentially give pupils the opportunities to develop their ability to:

• use knowledge of chemistry to examine information, communicate and take a view on questions concerning energy, the environment, health and society, […]

• use concepts of chemistry, its models and theories to describe and explain chemical relationships in society, nature and in people (Skolverket, 2011, p, 135).

The similarities between the aims of biology and chemistry is clearly visible. The core contents (year 4–6) of the subjects invites the teacher to use an integrated approach.

Biology

• Organ system of the human body. Names of organs, appearance, location, function and interaction (Skolverket, 2011, p. 107).

Chemistry

• Contents of food and the importance of nutrients for health […] (Skolverket, 2011, p.137).

Thus, one of the main areas in biology and chemistry in the Swedish curriculum in compulsory school is to understand the importance of health through the understanding of the function of the human body in biology (Skolverket 2011, p. 107) and chemical relationships within the human body in chemistry (Skolverket 2011, p. 137). The Swedish curriculum emphasizes the importance of personal health as a lifelong responsibility (Skolverket, 2016, pp. 23–24).

In addition, biology education should give insight into science with the theory of evolution as a foundation (Skolverket 2011, p. 105). Even though the body functions and nutrition have been important areas in chemistry and biology education, few students have persistent knowledge of how the degradation of food during digestion works and how energy is transformed to make it accessible for the body. This is not only our experience during more than ten years of education of pre-service teacher students about body functions both in a biological and chemical perspective. Especially Banet and Nuñez (1997) and Nuñez and Banet (1997) have discussed this but it is also demonstrated in children by others (c.f. Teixeira, 2000, Reiss and Tunnicliffe, 2000, Reiss, et al., 2002, Rowlands, 2004). The courses in biology and chemistry, here presented, have had the goal to give a general view of the body based on an evolutionary perspective showing the similar body construction of many different organism and similarities in their degradation of food and extraction of energy.

Further, syllabus of the compulsory school subject *Home and consumer studies* aims at developing the students' ability to “plan and prepare food and meals for different situations and contexts” (Skolverket, 2011, p. 43).

All these curricular directions concerning the aims and goals of the teaching of digestion have to be regarded. Further, we have observed an almost traumatic reaction among teacher students when they were studying the human digestive system. They rarely were able to describe the structures or the functions of the system and its relation to other parts of the body and were very concerned and distressed. The basic chemistry, biochemistry, cell biology, organs, and organ systems are taught separately and at different occasions at school and the textbooks are often focussed on names, concepts, and detailed processes instead of general functions. This design promotes the creation of a panic zone where learning is impossible, something that has to be considered when designing learning situations about the body and its functions (Brown, 2008).

The focuses on the human body and personal guidelines, e.g., regarding the importance of specific nutritious breakfasts or avoidance of carbohydrates, are also problematic. Although not directly related to the digestive system this underpins a teleological idea of a system created in order to digest a specific menu. From the evolutionary point of view humans are not created to eat a specific type of food but have achieved the possibility to digest almost anything of our choice, sometimes after proper preparation. An evolutionary view also may promote general ideas of how digestion works in most animals which also makes this area less personal. The evolutionary perspective gives the opportunity for students to understand the basic processes of the cell's uptake of nutrients without using the complex organs or organ systems appearing in more diversified animals.

Theoretical Framework

In previous studies (Mattsson and Mutvei, 2016, Mutvei and Mattsson, 2016, Mattsson, Mutvei and Lönn, 2015) the theory of conceptual profiles (Mortimer and El-Hani, 2014) has been useful for understanding the conceptual development among students. For assessment of the quality of different types of student presentations the 4 R's of Doll´s

(1993) has been used at different occasions (c.f.Mattsson and Mutvei, 2016, Mutvei and Mattsson 2015). Nuñez and Banet (1997) have investigated students' conceptual patterns regarding human nutrition. They showed that student in compulsory school show a variety of conceptual understanding of human nutrition. The conceptual patterns goes from low to high complexity where low complexity indicates low level of integrated understanding of the different systems as the circulatory system, breathing, and the role of the cell in energy production. The reason for this may be that micro- and macro-level of nutrition is taught separately with a high amount of details.

Here the theory of conceptual profiles and the integrated approach of Nuñez and Banet are combined when designing a course about nutrition and the assessment is made using the 4 R's of Doll's.

Objectives

As an integrated approach including evolutionary perspectives seems to be useful in the teaching of digestion and the main objective is to assess the learning outcome of teaching designed out of this approach among pre-service teacher students.

The study is a part of a process of development of science courses at Södertörn University and is based on results previously presented (Mattsson and Mutvei, 2015, Mutvei and Mattsson, 2015).

Methodology of research

Sample selection

This study was made within a pre-service teacher training program in a course of 10 weeks duration in biology and chemistry with 25 students. The design of the learning situations and the implementation of the course were made by a team of two academic teachers, mostly working in pair when teaching. The theoretical content was based on the aims, core content, and knowledge requirements from the syllabi of biology and chemistry in the curriculum for the compulsory school in Sweden (Skolverket, 2011).

Course design

Eight lectures with discussions and practical works in the education of pre-service primary school teachers were included. Usually the students worked full day with short introductory lectures followed by discussions, exercises, or practical work.

The exercises and the lectures were designed in an integrated way. In order to identify the initial knowledge of the students of the human digestive system and the organs involved the students individually made drawings of routes of carbohydrate, fat, protein, oxygen, carbon dioxide and water in a simple body consisting of a digestive and circulatory systems (Figure 1).

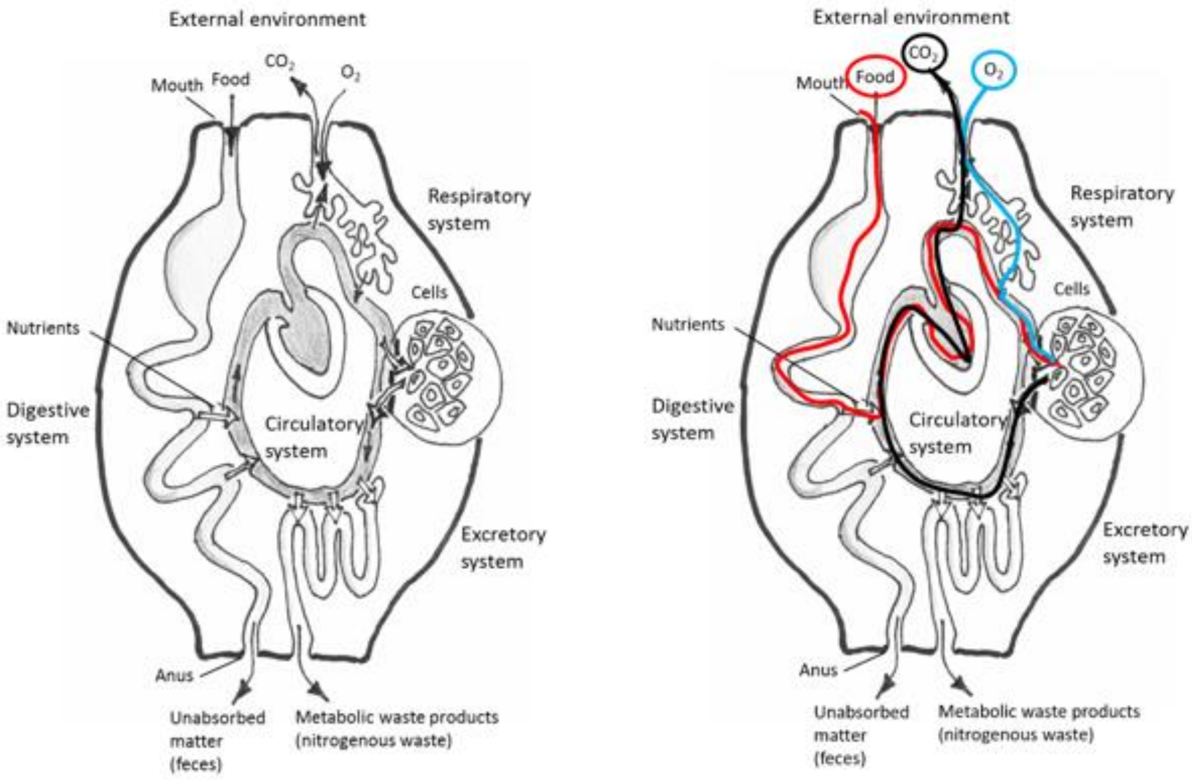

Figure 1. A general body drawing used to show different pathways in the digestive and circulatory systems (left) and with examples of marked routes (right).

The only lecture on the evolutionary development of land-living organisms were presented in order to give an understanding of the differences between being an organism living in water compared to one living on land. The digestive properties are similar among animals living under both conditions but the systems for gas and nitrogen exchange differ. Starting with simple organisms like fungi and jellyfish makes it possible to understand basic digestive principles without dealing with organs or complex organ systems. Most nutrients have to be degraded into small molecules, thus cooking and preparing food during discussions of the properties of nutrient and how they are used for energy extraction were included. Molecule models were used to visualize photosynthesis and respiration in order to show similarities in reactions on molecular level in digestion.

The course had a formative approach and the students were given different individual tasks in the final examinations, both in chemistry and biology. Here are some examples of instructions before the final examination based on assessments of previous texts and the interpretations of the students' in biology.

Example 1

Teacher: In the final examination we want you to show your knowledge of the theory of evolution, including natural selection and random variation, and use it as an explanation for the development of the human digestive system.

Student: I will use lactose intolerance as an example to discuss digestion and what consequences there are for the body when lactose cannot be digested.

Example 2

Teacher: In the final examination we want you to show how you design teaching of evolution within a sub-discipline of biology?

Student: Cooking of food is my example of an important factor for the development of the human brain.

Example 3

Teacher: In the final examination we want you to show how you will mediate the theory of evolution as this is a part of the core content in biology.

Student: Differences and similarities of digestive system in carnivores and herbivores will be used as my example of the theory of evolution.

Although all students got different instructions they were allowed to make their own interpretations of which examples they preferred to use. Thus, in total six students used lactose intolerance as example, five used cooking, two compared carnivores and herbivores. Others chose to make comparisons with teaching in other subjects in school, as religion, or how to force the students to focus on the basic principles of evolution instead of learning examples by heart.

The final examination in biology was both oral and written and the students presented their ideas about how to teach digestion presented to a fictive teacher group. It should have an evolutionary perspective and present how the animal body has developed in order to use different nutrients for building material or energy. Two teachers assessed the students' written and oral presentations using rubrics known to the students in advance evaluating their ability to connect to theory, the ability to make reflections and their connections to evolutionary processes.

The final examination in chemistry was oral where the students had to make presentations of different chemical perspectives on digestion and metabolism. The tasks were randomly distributed and the students had 30 minutes for preparations. Two teachers assessed the students' oral presentations using rubrics known to the students in advance. The assessment was evaluating the student's ability in a similar way as in the biology examination.

Research design

Written exams and notes from oral exams were analysed in order to see the development of the students. The number of words in total and the number of biological and chemical concepts in the texts written by the students were counted and the frequency of the concepts were calculated (Mattsson and Mutvei, 2016).

As quality markers biological, chemical, evolutionary concepts and the 4 R's of Doll's (1993), *recursion*, *relations*, *richness* and *rigor* were used. *Recursion* is understanding in depth by the connection of the past with the present through feedback. *Relations is* understanding through network of connections to other things and people. *Richness is* understanding at many levels, to give different interpretations, perspectives and possibilities. *Rigor* is consistently using knowledge in new ways and in new unexpected situations. The use of the R's was assessed using a scale 0−3 where 0 refers to the absence of the specific concept and 3 to regular and active use of the processes referred to by the concept.

The marks in biology and chemistry were also used in the analyses as these partly were based on the students' ability to combine knowledge from the two subjects.

Associations between concepts, understanding, quality, and marks in biology and chemistry were analysed and visualized by clustering and ordination techniques using the R statistical program (R Core Team, 2016) . The effect of using the 4 R's or scientific concepts on the marks of the final assessments, based on a generalized linear model was also calculated.

Results

Initially only a low number of the students managed to use a simplified body (Figure 1). Most were not able to follow the route of protein/carbohydrates/fat from their absorption in the intestine, transfer to the circulatory system and transport to the cells in order to be used in energy generation or in metabolism. They could not describe the effects of gas exchange in the lungs and the uptake of water. The teacher had to discuss the drawings together with the students until all the students understood the general model of how a body digests food in order to achieve building material and energy.

In the written examination texts used for assessment in biology, the students used a fairly low number of concepts (Table 1). Although these texts primarily were written for the examination in biology the frequencies of chemical concepts is fairly high. In spite of the evolutionary perspective in the student tasks they used chemical concepts in a larger degree compared to evolutionary concepts.

Table 1.Students' use of biological and chemical concepts in the examination texts in biology.

	Texts used for assessment in biology
Words	32 868
Biological concepts	416
Evolutionary concepts	119
Chemical concepts	238
Frequency of biological concepts	1.26 %
Frequency of evolutionary concepts	0.36 %
Frequency of chemical concepts	0.72 %

The quality markers showed an increase in richness in the texts during one week of the course (Table 2). This may be interpreted as an increase in the understanding of the theories and the use of their concepts. The other markers were on about the same level.

Table 2. Number of students at each quality level of the 4 R's in a museum report and in the examination texts in biology one week later.

	Museum					Examination I biology				
Quality level	0	1	2	3	Total points	0	1	2	3	Total points
Recursion	9	4	10	2	30	7	7	9	2	31
Relation	7	12	4	2	25	6	10	8	1	29
Richness	9	7	5	4	29	6	4	8	7	41
Rigor	13	7	2	3	20	12	10	1	2	18

The statistical analyses showed a significant correlation only between the quality marker (*rigor*) of the examination texts and the marks in chemistry and a weak correlation with the marks in biology. (Figure 2). *Rigor* is the quality of using knowledge in new ways and in new unexpected situations promoting an integrated view which was one of the knowledge requirements in the examination.

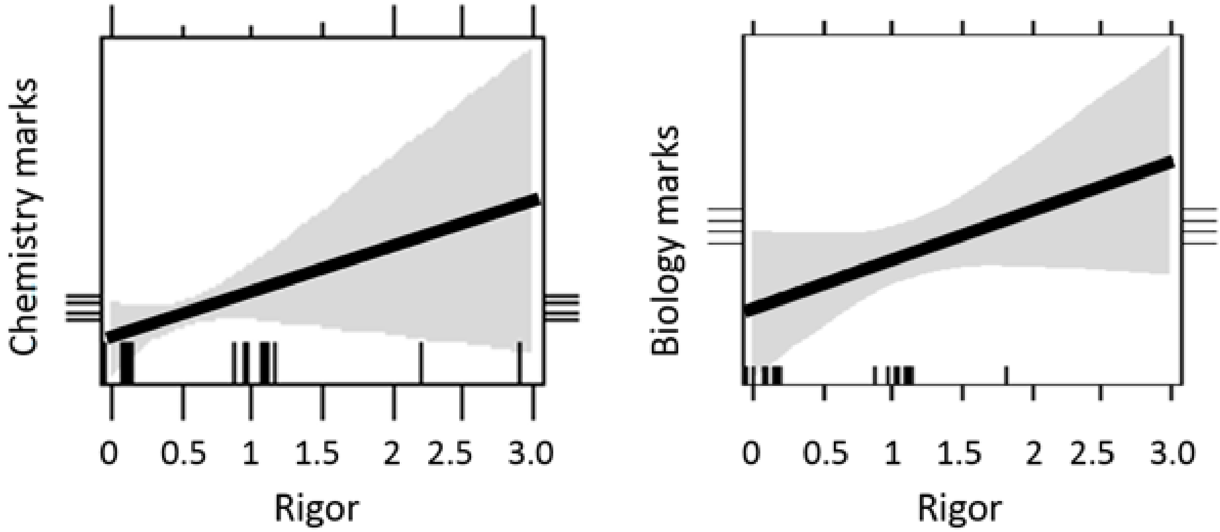

Figure 2. The effect of using *Rigor* in written examination in biology on the marks in chemistry (p=0.00498 **) and biology (p=0.06496).

Discussion

Our results show that the integrated approach of the designed activities gave good results. In general, all activities during the course and the written and oral exams showed that most students had achieved significant better view of the digestion system and the role of oxygen. This was promoted by the large variation of the structure and content of the activities during the course. The familiar everyday processes, such as cooking, helped the students to understand the body functions as previously reported by Rowlands (2004). The students become able to discuss both the biological and chemical connections and the transport of different nutrients in the body and how this could be taught to students in year 4–6 in school. This is in concordance with earlier findings (Banet and Nuñez, 1997 and Nuñez and Banet, 1997). With this holistic design we succeeded in creating a learning zone and avoided the panic zone usually occurring when teaching about human body functions (Brown, 2008).

Further, during the course the students also showed the ability to give a possible evolutionary explanation to questions around the digestion and other body functions. One important reason for this may be the general view of the body which wasn't restricted to humans. The focus on evolutionary processes like natural selection and random variation also promoted a more general view of different phenomena occurring in nature. To use the holistic view as a starting point and later focus on details seems to be a better strategy compared starting with concepts and details (Alters and Nelson, 2002).

As discussed earlier (Mattsson and Mutvei, 2015), the use of concepts cannot be used as the only indicators for assessing conceptual understanding. It is better to use quality markers like the four R's of Doll's (1993). This type of indicators give the possibility to assess deeper levels of the learning outcome. Here *richness* increased over time in the students' presentations indicating development of a deeper understanding. The other quality markers refer to general skills that should not be expected to develop during this type of course.

Conclusion

Almost from the beginning the students had an integrated view on the content of the course but they needed help to realize this. Processes and concepts from the macro-world of the theory of evolution to the micro-world of basic chemistry were used and connected to each other with the aid of the teacher using cell biology, physiology and organism biology. After this procedure, the students were able to discuss biological and chemical connections by describing the nutrients transport in the body. Thus, they showed how to teach students in year 4–6 in school.

When teaching molecular and biological processes we suggest that in order to create understanding of the processes within the human body one should

- have a generalized view of the body in based on an evolutionary perspective and
- always integrate chemical and biological perspectives.

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