Collaborative modelling of the vascular system – designing and evaluating a new learning method for secondary students

Marion Haugwitz and Angela Sandmann
Biology Education, University of Duisburg-Essen, Germany

Understanding biological structures and functions is often difficult because of their complexity and micro-structure. For example, the vascular system is a complex and only partly visible system. Constructing models to better understand biological functions is seen as a suitable learning method. Models function as simplified versions of real objects and concentrate on special features of those to facilitate learning. Because of the complexity of the vascular system, models can be implemented as beneficial teaching aids. Learning with models is also an effective form in combination with collaborative learning.

This paper introduces three simplified heart and blood vessel models. They were designed for collaborative learning. The models were implemented in a study with 7th grade students (13 years old). Results of a paper-pencil evaluation show that collaboratively learning with models of the heart and the blood vessels was interesting for students. Furthermore, students gained better understanding and achieved higher test scores.

Keywords: heart, model, collaborative learning

Models in Biology
Models are seen as a key tool in thinking and working scientifically as they enhance investigation, understanding and communication (Harrison and Treagust, 2000).

In teaching biology, models are used to realistically demonstrate biological processes, systems or objects as those are often too complex, large or small to be directly observed (Rotbain, 2006). As such, they are simplified representations of originals (Gilbert and Osborne, 1980). In contrast to real objects, models have the potential to display only relevant details and thereby help explain complicated functions. They are considered important learning and teaching aids (Harrison and Treagust, 2000), and are implemented specifically when complex mechanisms need to be clarified.

The circulatory system with its complex and multiple levels of organization is difficult to represent without simplification and therefore hard to understand for students (Buckley, 2000; see also Tunnicliffe and Reiss, 2000). As human circulatory processes are very complex, learning with models – which do not include every detail of the original – may foster interest and greater understanding. Lee (2004), for example, used a model in addition to working with a pig’s heart to further enhance students’ understanding of a coronary heart disease.

Collaborative Learning
Working in groups promotes collaborative learning (Chin, 2004) and offers several advantages over individual learning. Through discussing newly introduced concepts, students can integrate individual knowledge with collective knowledge. Empirical evidence shows that students understand concepts better if they communicate them while learning (Duit and Treagust, 1998; Lemke, 1990; Palincsar, Anderson and David, 1993). Seymour and Padberg (1975) showed that this approach does not only foster improved communication and problem solving skills, but also achievement.

Clearly, the combination of collaborative learning and learning with models provides many advantages. From a practical view, building complex models is easier in groups. Furthermore, a collaborative learning environment offers the advantages to obtain different points of views and to discuss different aspects of the models. Regarding classroom management, collaborative work reduces the amount of materials required for each student.

Learning Kits
Three learning kits on the function of the heart and blood vessels are introduced below. The kits can be used alone or in sequential combination. The tasks are about how the heart works, about the pulse and the veins.
The kits contain all learning materials necessary for the models' construction. They include two types of cards: those introducing the assignments (Problem Cards), and those covering content and structural assistance (Information Cards). The materials utilized are common laboratory or household items.

While learning with the kits, students are asked to verify a hypothesis, plan and construct the model, and discuss the result. Education through learning kits differs from a simple execution of an assignment. The students must become actively engaged in the matter, discuss and reflect upon their ideas, and cooperatively problem-solve by building the model. The assignments in the learning kits are contextualized with realistic situations (such as physical function during sports, or after an accident) in order to enhance interest and participation in the task.

The learning kits can be implemented in regular classroom instruction. Teachers may assist students with content or technical and practical information. To assess progress, students can be asked to protocol their hypotheses and learning steps. Finally, results should be reviewed in a classroom discussion.

**Kit 1: How the Heart Works**

The Problem Card in this learning kit is shown in Figure 1. Students are asked to build a model that illustrates the heart function. They are introduced to the topic by a story about a girl and her grandfather, who is no longer able to race with her. The learning goal of the kit is to discover how the heart works and learn that age decreases the heart’s ability.

The Information Card (Figure 2) provides background on the anatomy of the human heart. It explains the individual functions of the different heart valves. To complete the assignment, students must use the material listed below, which is provided in the kit:

- a) 500 ml red-coloured water,
- b) 1 laboratory beaker,
- c) 1 marble,
- d) 1 funnel with a hole in the side,
- e) 1 balloon,
- f) 1 rubber hose,
- g) 1 piece of tape,
- h) 1 piece of film, and
- i) 1 laboratory beaker.

The completed model for self-directed learning through learning kits is shown in Figure 3. It is a modified version of the one designed by the Department of Didactics of Physics at the Karl Franzens University of Graz (Anderwald, 1998) which was designed to better understand the pressure created through the heart’s function.

To build the model shown in Figure 3, students must insert the marble into the funnel, put the rubber hose into the hole in its side, and place the balloon over the funnels top. The film must be taped on the other end of the rubber hose.

After completing these preparations, students have to push down on the balloon that will cause the liquid to rise into the funnel, whereas the marble prevents the water from streaming back into the glass. By continuing pressing on the balloon, the fluid will finally flow from the funnel through the rubber hose into the other glass where the film at the end of the rubber hose keeps it from flowing back in.

To build the model, students have to discuss the different possibilities of putting the materials together. For example, without the marble in the funnel, the model does not work because the fluid always runs back.
down. Finally, students must think about the model and what the materials represent in their bodies. The following list gives insight into what the materials represent.

a) Blood,
b) Atrium
c) Mitral valve,
d) Heart chamber,
e) Heart muscle,
f) Semilunar valve,
g) Semilunar valve,
h) Semilunar valve,
i) Human body.

Kit 2: The Pulse (Arteries and Capillaries)
The assignment in the learning kit about blood vessels is provided on the Problem Card below (Figure 4). Students are asked to find out in which blood vessels one might find a pulse. They are introduced to the topic by a story about a bicycle accident, as a result of which blood pulses out of an injury.

Using the materials provided, construct a model showing in which blood vessels the blood flows in pulses and in which continuously.

1. Observe what you feel with the big hose if you press the pump bulb under water.
   You can build three different models with the given materials. Experiment and rationalise which works best, paying close attention to how the water flows.

2. What do the materials of your model represent in your body?

The learning goal of this kit is to understand the different anatomy and functions between arteries and capillaries. Furthermore, students should understand that injuries of arteries versus capillaries may result in varying, potentially serious consequences (Figure 5).

The model in the learning kit on blood vessels is a combination and modification of two models by Baer (1985) and Falkenhahn et al. (1981). In both models, a rubber hose is connected to a water tap. The tap is manipulated so that the water flows out in pulses. Students will discover that the water flows regularly as the rubber tube gets thinner. In the Falkenhahn et al. (1981) model, students install different types of hose ends to compare them with each other. The actual model provided here is modified so that the water tap is replaced by a squeezable pump bulb. This variation is more suitable for students and causes less flooding. The model is shown in Figure 6. The kit contains:

a) 1 squeezable pump bulb,
b) 1 large rubber hose,
c) 1 small rubber hose,
d) 1 glass tube,
e) 1 small rubber hose in combination with
f) 1 thin glass tube.

The blood pressure caused by the heart beat cannot be felt as a pulse in capillaries or veins. The blood flows through them at a constant pace.

Capillaries widen to become veins, which return blood to the heart. Most veins have one-way flaps called venous valves that prevent blood from flowing back and pooling in the lower extremities as a result of gravity. Muscles wrapped around veins help maintain blood flow to the heart.
The kit also contains connectors to combine the materials with each other, as well as red-coloured water.

Students must combine the pump bulb with the big hose. The pump simulates the heart and the big hose corresponds to an artery. If the students compress the pump bulb, they can feel a pulse in the big rubber hose. Three possible adapters (c, d, and e / f) can be tested sequentially to see which best simulates a capillary. If adapter c and d are installed, the water flows through the “capillary” with a pulse. The solution for the capillary is the adapter that is both very elastic and very thin (e / f).

**Kit 3: Veins**

How does the blood return to your heart from your legs? This is the question students must answer with the third model. The *Problem Card* is shown in Figure 6, while the respective content information follows in Figure 7.

The model the students have to construct is based on Thiessen’s heart model (1979). Because of its configuration, it is more suitable to demonstrate the veins with two vein valves than the heart function so that it was modified and chosen as a model for the anatomy and function of the veins.

The kit model is shown in Figure 9 and is built using the materials listed below:

- a) 500 ml red-coloured water,
- b) 1 laboratory beaker,
- c) 1 small plastic tube,
- d) 4 adapters,
- e) 2 plastic tubes,
- f) 1 silicon tube,
- g) 1 laboratory beaker,
- h) 2 needles,
- i) 2 pieces film.

Furthermore, the kit contains connectors to combine the materials with each other.

To bring the red fluid from one glass to the other, students must squeeze the plastic tubes. This causes the water to rise, while the pieces of film (affixed with needles) prevent it from flowing back.

Once finished, the students should consider the model and think about what the materials are equivalent to in their bodies. The solution is provided below:

- a) Blood,
- b) Body,
- c) Capillary,
- d) No special function,
- e) Veins,
- f) No special function,
- g) Heart,
- h) Vein valve,
- i) Vein valve.

**Implementation and Evaluation**

The described learning kits have been assessed in a study with a pre- and post-test evaluation. The goal was to investigate whether students were interested in learning with the kits and in the provided scenarios on the problem cards. Furthermore, the achievement level and the level of cooperation were measured.

The study took place in grade seven in a secondary school in Essen, Germany. The study was realized as an out-of-school activity. The forty students who participated had an average age of 12.4 years (SD = 0.55). The proportion of male/female participants was at exactly 50 %. Participation was unsolicited and with parental agreement, and the students were allowed to form their own groups which resulted in eleven groups of three to five students. Students who participated in the study attended five sessions: a pre-test session, a post-test session and three learning sessions in which the groups were engaged with the three learning kits, one after the other.

Before learning with the kits, students had to complete a prior knowledge test consisting of several multiple choice questions concerning the content knowledge of the learning kits (example item: “Which characteristic distinguishes veins? a) veins are very thin blood vessels b) veins contain valves c) veins transport blood away from the heart d) veins are muscles”). Each of the three learning sessions took place on a different day. Students had 25 minutes to solve the given problems, i.e. with reference to the problem card they were asked to build the required model and answer the question what the materials in the model represent in their body. Directly after each learning session, students had to fill out a questionnaire about situational interest as well as an achievement test with items referring to the learning task of the respective session. In addition, one week after the collaborative learning, each student had to fill out an achievement test consisting of the same items as the prior knowledge test, as well as a questionnaire about their interest in the project (post-test). All achievement tests were multiple choice tests, and the questionnaires about situational interest consisted of two scales: interest in building the model (6 items, example item: “I enjoyed learning with the kit today”) and the interest in the
provided real-life scenarios (5 items, example item: “I was interested in the topic on the problem card”). Furthermore, students had to answer four items about how well the collaboration within the group worked (example item: “We supported each other in our group”). All items were formulated using a 4-point Likert scale with higher values indicating higher interest or better cooperation.

Table 1 shows the descriptive results of the interest in the learning kits and the achievement scores. The results of the evaluation study show that student interest scores are all above average, at 2.5. This supports the idea that students were interested in learning with the kits. Students reported a high value for the scale of the interest in the project. This shows that students are highly interested in the out-of-school activity with a collaborative biological learning environment. In all three cases, the interest in the model itself was higher than the interest in the problem. This might result because the modelling activity was a hands-on activity while the realistic scenario was only described by text and pictures. Kit 1 had the greatest appeal, and students achieved higher knowledge gain. Students felt collaboration was best with kit 2. This may be because building model 2 required greater student participation through clamping the materials.

For the pre- and post-test comparison, a paired sample t-test was conducted with the prior knowledge and the post-test achievement (t(39) = 7.49, p < .001). The result shows that students profited significantly from learning with the kits. This means that students acquired biological knowledge of the human heart and the vascular system while collaboratively learning with the kits.

Conclusion
The learning kits were designed to provide an opportunity to collaboratively learn the function of the heart, the cause of the pulse and the function of the veins through the construction of simplified models. Building models is one way to easily learn about complex processes by reducing the amount of information. Results of the evaluation show that this is true for the given content (function of the heart and the blood vessels). Furthermore, findings indicate that learning with the presented learning kits is interesting for students.

Building these models in small learning groups creates several advantages, such as the amount of material needed for the classroom can be reduced. Moreover, students can assist each other, while still benefiting from teacher support. The teacher can also point out the limitations of models and expand on the topic through further textbook-specific instruction. The finding that students engage in learning activities besides regular class, report high interest, and gain knowledge should encourage biology educators to implement collaborative hands-on activities in education.

<table>
<thead>
<tr>
<th>Interest in</th>
<th>Interest in</th>
<th>Achievement</th>
<th>Interest in</th>
</tr>
</thead>
<tbody>
<tr>
<td>the Model</td>
<td>the Problem</td>
<td>Collaboration</td>
<td>Score [%]</td>
</tr>
<tr>
<td>Pre-test</td>
<td>3.31 (0.53)</td>
<td>2.98 (0.62)</td>
<td>3.04 (0.86)</td>
</tr>
<tr>
<td>Kit 1</td>
<td>3.30 (0.52)</td>
<td>2.93 (0.57)</td>
<td>3.07 (0.71)</td>
</tr>
<tr>
<td>Kit 2</td>
<td>3.17 (0.65)</td>
<td>2.82 (0.61)</td>
<td>2.96 (0.78)</td>
</tr>
<tr>
<td>Kit 3</td>
<td>3.17 (0.65)</td>
<td>2.82 (0.61)</td>
<td>2.96 (0.78)</td>
</tr>
<tr>
<td>Post-test</td>
<td>64 (11)</td>
<td>3.10 (0.60)</td>
<td></td>
</tr>
</tbody>
</table>

Acknowledgements
This research was supported by the German Research Foundation (DFG) within the research project on context-oriented learning in biology and chemistry (SA 1712/1-2 und SU 187/7-1) in the Research Training Group Teaching and Learning of Science (nwu-essen).

References


Lee Y C (2004) There is more to the dissection of a pig’s heart. Journal of Biological Education. 38 (4) 172-177.


Marion Haugwitz (corresponding author) is a post-doctoral Researcher, National Educational Panel Study (NEPS) at the University of Bamberg, Germany. Email: marion.haugwitz@uni-bamberg.de.

Angela Sandmann is Professor of Biology Education at the University of Duisburg-Essen, Germany.
Copyright of Journal of Biological Education is the property of Institute of Biology and its content may not be copied or emailed to multiple sites or posted to a listserv without the copyright holder's express written permission. However, users may print, download, or email articles for individual use.