The journey of a sandwich: computer-based laboratory experiments about the human digestive system in high school biology teaching

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Šorgo A, Hajdinjak Z, Briški D. The journey of a sandwich: computer-based laboratory experiments about the human digestive system in high school biology teaching. Adv Physiol Educ 32: 92–99, 2008; doi:10.1152/advan.00035.2007.—Teaching high school students about the digestive system can be a challenge for a teacher when s/he wants to overcome rote learning of facts without a deeper understanding of the physiological processes inside the alimentary tract. A series of model experiments illustrating the journey of a sandwich was introduced into teaching high school biology. Using a computer equipped with a commercially available data-acquisition system and a couple of sensors, it was possible to illustrate the basic underlying physical and chemical principles of digestion to the students. Students were able to investigate, through hands-on activities, the chewing force of the jaws, importance of the mechanical breakdown of food, enzymatic activity of pepsin and amylase, antibacterial activity of hydrochloric acid, and importance of the villi for absorption. Students found the experiments interesting and helpful for understanding the digestive process. Furthermore, the results from testing indicated that the students had a deeper understanding of the physiological processes.

education; data logging

IF A HIGH SCHOOL BIOLOGY TEACHER in a human anatomy course wants to overcome the rote learning of lists of Greek and Latin names, s/he must overcome several obstacles. The first one is that, even before entering a course, every high school student has a solid block of knowledge about his/her body that can be described as a mixture of common knowledge, facts learned in their previous schooling, and misconceptions (20), with little understanding concerning the anatomy and physiology of their organ systems (13, 14, 17, 18). Therefore, a teacher’s work cannot start simply by adding new facts to existing knowledge. Identification and dispelling of preexisting misconceptions that have their roots partly in the students’ previous schooling must occur first or in conjunction with the acquisition of new facts (1, 21). The second obstacle is the students’ limited knowledge of chemistry and physics, which are prerequisites for understanding most physiological processes. The third obstacle is that many activities concerning teaching about human physiology are unsuitable for classroom use, at least at the preuniversity level, because of health issues, ethical concerns, and the possibility of exposing private or intimate data. Last, but not least, there is the availability of appropriate equipment. Only the second obstacle will be addressed in the present study.

The physiological processes within the digestive tract are rather complex, requiring the understanding of many biological, chemical, and physical processes. Fortunately, a sufficient number of these processes have more general underlying principles in common. Because such principles are not unique to the digestive system, students can transfer such knowledge to other situations, both inside the body or in nature and technology. The most important processes that take place inside the digestive tract are the mechanical crushing of food, chemical breakdown of molecular bonds, dissolving of molecules, absorption, disinfection of microorganisms, transportation, and bacterial decomposition. In the laboratory exercises presented in the present study, these processes did not receive equal attention. The first five processes were directly addressed through the laboratory exercises presented, but transportation and bacterial decomposition were only mentioned. The reason is that we omitted computerized laboratory work concerning these two processes from our teaching practice, owing to possible health risk to the students.

Based on our previous teaching experience showing that active methods lead to a higher order of knowledge (20), we began to think about how to actively engage the students during these human anatomy and physiology lessons. The importance of active learning for physiology teaching can be summarized in the work of Michael (10). Our intention was to develop or adapt a set of simple experiments combining computerized measurements with a data-acquisition system to be used in the teaching of physiology of the human digestive system. As an appropriate framework, we referred to a textbook idea (15) where digestion is described as the journey of an egg sandwich. To avoid dissection and work with fresh animal tissues, we began to consider about model experiments that would clarify basic principles in the physiology of digestion. Computerized experimentation was used because such laboratory work has many advantages for teaching physiological processes (9, 26) and had been successfully tested, in practice, in other biological fields during our previous teaching (22, 23). The most important reported benefits of computerized laboratory activities are the possibility of tracking very slow, very rapid, and unpredictable processes. Data are presented to the students in real time in graphic and/or tabular form, and sensors can be combined in almost limitless combinations (8, 11, 12, 16). Furthermore, a computer-based laboratory offers several possibilities for the introduction of physiological topics into regular high school biology lessons, yet all such possibilities are far from fully explored. One of the important underlying problems is how to place such activities into an appropriate context and incorporate such activities into the syllabus.

The final but perhaps even most important reason was our aim to improve our teaching not only toward achieving higher order knowledge but in such way as to raise students’ interest in science and technology. Science in Slovenia is unpopular among students as early as in upper primary school, and attitudes concerning science subjects are even more negative than in other parts of the world (5). Because of a constant fall

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in students’ interest in science from year to year, as recognized in the number of students who choose science subjects in their maturity examinations as the final stage of general secondary education (19), stopping this trend may become the most important issue in science education.

**Materials and Methods**

The Prva gimnazija Maribor (First Grammar School of Maribor, Slovenia) is a four-year urban general secondary school, with ~800 students, in the city of Maribor, Slovenia. The students are recruited from upper-ability pupils finishing 9 yr of compulsory primary schooling. When entering the gimnazija program, students are between 14 and 15 yr old. The main goal of the program is to prepare students for the maturity exam as a prerequisite for entry into university studies. Biology, chemistry, and physics are taught over the first 3 yr as compulsory subjects (210 academic hours over 3 yr) and as optional courses in the fourth year (140 academic hours). Topics covered in compulsory biology include biology of living kingdoms, human anatomy, human physiology, evolution of humans, human genetics, chemistry and physiology of a cell, and ecology. Students learn in school about computers through a compulsory subject, informatics, and through a number of activities connected with other subjects. Informatics is taught over the first 2 yr in a 140-hour course. In the first year, students learned about computer basics: e-mail, the internet as a source of information, and how to prepare a document. In their second year, they learn how to prepare a presentation and webpage. Computer programming and work with data loggers is not part of this course. More information about the school system of Slovenia is available online (3).

Data-acquisition systems were introduced into Slovene schools as early as the 1980s but were restricted to a small number of science teachers. Between the years of 2001 and 2003, about two-thirds of Slovene secondary schools received from the Ministry of Education and Sport computers equipped with data loggers and sensors to be used in teaching biology, chemistry, and physics. The use of the donated equipment was not compulsory for teachers and was left to their discretion. Four years later, we were able to recognize great differences in the usage of the donated equipment among science teachers. We did not find differences in usage among teachers of the same subject coming from general high schools and teachers from technical and vocational schools, but among the teachers of different subjects (25). The usage of data-acquisition systems was recognized as beneficial to both high- and low-achieving students from general and vocational schools (24).

Computerized laboratory activities were introduced into the teaching of biology, chemistry and physics at the Prva gimnazija Maribor in the late 1990s. The school’s biology laboratory is equipped with one teacher set and four student sets of the e-ProLab data-acquisition system and software (4), four Vernier LabPro systems, and a range of Vernier sensors (27). A portable computer is used for demonstrating experiments outside the science laboratory. Other laboratory equipment is standard and commonly available.

The introduction of computerized laboratory exercises into biology teaching did not happen instantly but in many successive steps over the years. After each of the experiments was tested by the teachers, experiments were performed and tested by a group of students as a voluntary extracurricular activity. Based on students’ remarks and on obstacles observed during their work, experiments were fine tuned. Only then did we introduce the experiments into our classes. In such a way over the years, >30 different experiments were prepared to be used in school (19). In previous years, single experiments concerning human physiology had been introduced into teaching, among them experiments concerning the digestive system. As a defined set of experiments about human digestion, the experiments were performed for the first time in 2006, with a class of 32 students in their second school year (age: 15–16 yr old). At the time of experimentation concerning the human digestive system, they were already familiar with a data-acquisition system. Following the basic training, they had performed a couple of exercises during their chemistry course, measuring pH, temperature, and gas pressure. During their biology course, they measured the temperature on different parts of the body, examined the insulation properties of hair and feathers, compared differences in oxygen concentration between inhaled and exhaled air, and measured hear rate.

Because of the differences in time needed to execute a single experiment, potential risks to the students, availability of the equipment, and students’ fixed schedule with a 45-min academic hour, we used a different approach for incorporating experiments into a teaching unit about the digestive system. Owing to the economics of organization and equipment availability, we have not performed all the experiments in strict linear order following the journey of the sandwich, but we tried to stay as close as possible to the original plan.

The first lesson (1 academic hour) was an introduction to the digestive system and the composition of the food and was given to the students as direct instruction. In the second hour, the experiment called “Speed of Dissolution” was performed as a starter in a problem-based lesson about the mouth. After a short explanation of the experimental setup, students were asked to predict the results and draw the proposed curves. The experiment was used to verify the students’ hypotheses and was performed as a demonstration by the teacher on a single computer with an overhead projector. The experiment was performed in the first part of the lesson, and discussions followed. For such an experiment and discussion about the process, we spent 20 min. The rest of the hour was spent on the other processes and anatomy of the digestive tract. Part of this lesson was a demonstration of the importance of the mucous glands, which make food slippery, using dry biscuits (not described in the present study).

The third lesson (2 academic hours) was dedicated to experiments concerning enzymatic activities. Experiments were performed as student hands-on activities. Owing to the lack of equipment, and given that basically the same principle was being addressed by each experiment, we arranged the experiments in stations, with students working in groups of four. Each group performed a single experiment, and the results were later shared between groups and discussed in a session after the laboratory work. The experiment called “Chewing Force of the Jaws” was left to the students to perform because of its simplicity. This activity was voluntary while students were waiting in the enzyme laboratory for color changes.

The experiment called “Bacteriocidal Activity of Hydrochloric Acid” was, for safety reasons, performed by the teaching staff as an illustration of the principle on a single computer in the laboratory preparatory room. Students had an opportu-
nity to examine the experimental setup and to download the results.

The experiment called “The Importance of the Lining’s Surface” was performed in a problem-based unit as a demonstration by the teachers, followed by microscopy of the slides of the small intestine. For the experimental part of the lesson, ~20 min was assigned.

In the final lessons, the experimental work was summarized, and any topics that had not been covered with the exercises were presented to the students. The knowledge gained was later used as a basis in discussion of topics concerning health. During this part of the course, homework was given to the students. They had to write an essay titled “The Journey of a Sandwich” to organize their knowledge. Altogether, 10 academic hours were spent on lessons about the digestive system.

The method for the assessment and evaluation of our work can best be described using the term “action research” (7). In action research, teachers are not only external observers and evaluators of the processes initialized in a classroom but are an integrated part of such processes. Teaching in such a case does not follow a strict preprogrammed line but is fine tuned at every step in favor of the preferred outcomes.

In our first attempt at introduction of experiments concerning digestion, we were more interested in student perspectives on and personal feelings about such work, and the possible technical and organizational obstacles, than in their learning outcomes measured as test scores. Because of the small number of students involved (32 students), we are well aware that our results cannot be generalized to the whole population, but they can be taken as a preliminary study. Because of our position in education (secondary school teachers), we cannot plan large-scale experiments involving different teachers and types of schools, but we can offer our ideas for others to use or adapt to best fit their teaching.

Evaluation of the experimental work was carried out through interviews with students, whether in groups after a lesson or in individual talks during a break (19) as well as personal observations after a lesson. Short questionnaires were distributed to the students after the completion of the experimental work, as tested in our previous study (22).

The questionnaire was divided into two parts and was completed anonymously. We received responses from 27 of 32 students, owing to some absences on the day when the questionnaire was delivered.

The first part was a closed questionnaire with 12 items, using a 5-point Likert scale (where 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, and 1 = strongly disagree). One of the questions (question 12 in Table 1) was posted in such a way that disagreement with it meant a positive attitude. The results of this question were later recoded in the opposite direction to allow further statistical analysis. The SPSS 12.0 statistical package was used for data analysis. Frequency means and SD are reported. The reliability of the questionnaire was expressed as Cronbach’s-α-coefficient and had a value 0.898, which can be recognized as good (6). Factorial analysis was performed utilizing principal component analysis as the extraction method and varimax with Kaiser normalization as the rotation method (6).

The second part, concerning laboratory work with computers, allowed for open-ended answers:

1. Where did you have the greatest difficulty during the laboratory work?
2. What was the best during the laboratory work?
3. How would you improve the laboratory work?

The work was incorporated into the European Commission Leonardo da Vinci program, Computerized Laboratory in Science and Technology teaching Comlab-2 project (2).

Experiments

Our experiments are presented in a successive way leading through the journey of an egg sandwich starting with the mouth.

Chewing force of the jaws. The mechanical breakdown of food into pieces before swallowing is the first step in digestion. The force for this process is generated by muscles. The experiment was “developed” by the students during the laboratory activity using Vernier’s Hand Dynamometer, exploring the differences between forces produced by both left and right hands as well as differences between the force produced by fingers in boys and girls. During the laboratory work, we heard giggling and recognized that students in one of the groups were testing the force produced by their jaws. We intervened to suggest that they should use paper towels to cover the hand grip, for hygiene reasons (Fig. 1). Afterward, answers to

Table 1. Statistics from the questionnaire concerning computer-based experiments about human digestion

<table>
<thead>
<tr>
<th>Statement</th>
<th>Frequencies</th>
<th>Mean</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I knew the goals of the experiment.</td>
<td>5 17 5 0</td>
<td>4.00</td>
<td>0.62</td>
</tr>
<tr>
<td>2. I could arrange the experiments by myself.</td>
<td>3 15 5 4</td>
<td>3.63</td>
<td>0.88</td>
</tr>
<tr>
<td>3. I did not need much help from the teacher.</td>
<td>4 10 5 6</td>
<td>3.30</td>
<td>1.20</td>
</tr>
<tr>
<td>4. I did not have trouble with the software.</td>
<td>6 6 7 6</td>
<td>3.37</td>
<td>1.18</td>
</tr>
<tr>
<td>5. The experiments were interesting.</td>
<td>10 11 1 3</td>
<td>3.89</td>
<td>1.25</td>
</tr>
<tr>
<td>6. I understood the graphs.</td>
<td>8 10 7 1</td>
<td>3.85</td>
<td>1.03</td>
</tr>
<tr>
<td>7. The laboratory work proceeded in a pleasant working atmosphere.</td>
<td>6 13 6 2</td>
<td>3.85</td>
<td>0.86</td>
</tr>
<tr>
<td>8. After the laboratory, I better understood the underlying theory.</td>
<td>7 6 9 3</td>
<td>3.48</td>
<td>1.22</td>
</tr>
<tr>
<td>9. I prefer laboratories using computers.</td>
<td>10 4 6 6</td>
<td>3.59</td>
<td>1.31</td>
</tr>
<tr>
<td>10. There should be more laboratories with computers.</td>
<td>12 4 2 5</td>
<td>3.56</td>
<td>1.58</td>
</tr>
<tr>
<td>11. I like it when I am involved in the planning of laboratories.</td>
<td>8 8 9 1</td>
<td>3.78</td>
<td>1.05</td>
</tr>
<tr>
<td>12. Laboratories are a waste of time that could be better spent in lectures.</td>
<td>1 0 3 5</td>
<td>1.56</td>
<td>0.97</td>
</tr>
</tbody>
</table>

Statements were evaluated using a 5-point Likert scale, where 5 = strongly agree, 4 = agree, 3 = neutral, 2 = disagree, and 1 = strongly disagree. Means and SDs are also shown. *Recoded value.
It was easy to demonstrate to the students the breakdown of starch by amylase or proteins by pepsin. In the experiment shown in Fig. 4, an egg was hardboiled, and the white was separated from the yolk. The egg white was whisked using a kitchen mixer. We scaled 10 g of whisked white and put it into a 500-ml beaker; 200 ml of distilled water were then added, and the beaker was placed for 15 min on a magnetic stirrer. The solution was filtered through cotton, and the filtrate was divided into two halves and then poured into two 250-ml beakers. We added a solution of previously prepared pepsin to the first beaker. The solution consisted of 2 g pepsin suspended in 100 ml of distilled water and 1.2 ml of concentrated hydrochloric acid. Distilled water (100 ml) was added to the second beaker as a control. Both beakers were put onto the magnetic stirrers, and the transparency was measured as a rise in illumination (Fig. 5).

Additionally, it was possible to investigate the effect of pH or temperature on pepsin activity in a similar fashion. We did not perform these experiments because of the lack of class time.

In a similar fashion (not presented here), a suspension of starch was prepared, and a drop of iodine was added, which turned the color to violet. The suspension was divided into two...
halves, put into two beakers, and placed on the home-made colorimeters. Diastase was added to one of the beakers. After some time, depending on factors such as temperature and the quantity of the enzyme, the color in the beaker changed, as detected by the light sensor.

Capsules with 10,000 IU of an enzyme, commercially sold in a local pharmacy, were used to present the activity of lipase. We started with the idea that lipase would hydrolyze lipids from oil floating on the water in fatty acids and glycerol. Fatty acids will diffuse in water, so the pH would drop. Phenol red was used as an indicator.

Bacteriocidal activity of hydrochloric acid. The same experimental setup as in the pepsin experiment (Fig. 4) was used to demonstrate the bacteriocidal activity of hydrochloric acid. We divided a piece of white chicken meat (~3 g) into halves. Each half was then placed in a separate petri dish and left for a day at room temperature. Rich microbial cultures were obtained in this way. Tap water (200 ml) was put into the first 250-ml beaker, and 200 ml of 1 M hydrochloric acid were added to the second beaker. A cube of meat was then added to each beaker. The beakers, with magnets inside, were placed on magnetic stirrers at a temperature of ~35°C. Temperatures were kept constant during the experiment. Additional temperature sensors and pH sensors placed in each beaker were optional. The difference due to bacterial growth is recognized as a drop in illumination (Fig. 6). Bacteriocidal activity is not the only or the even main purpose of hydrochloric acid secretion into the digestive tract, so its other roles, which have not been highlighted by this experiment, should be discussed in sessions after the experiment.

Importance of the lining’s surface. The surface of the small intestine is covered with finger-like projections called “villi.” In this fashion, the inner surface is greatly enlarged, so absorption into the transport system is faster. The idea of the experiment was imported from chemistry, where filter paper is folded to increase the speed of precipitation. We used this idea and prepared two tubes from cardboard with equal diameters and different surface areas (Fig. 7). These tubes were fixed inside the beakers using gelatin. Afterward, both beakers were half-filled with distilled water, and conductivity sensors were placed in the spaces between the tubes and beaker walls. We performed this experiment in two ways, with table salt and...
Evaluation and Conclusions

Because of the small number of students involved (32 students) and the 27 responses to the questionnaire, we are well aware that our results cannot be generalized and can be taken only as a preliminary study and as guidance for further improvement of this particular teaching unit. However, from the responses summarized in Table 1, we can conclude that students mostly agreed with the statements offered. The highest value [mean = 4.44 (0.97 SD)] related to the statement that the laboratories are not a waste of time that could be better spent in lectures. Only 1 student in the group strongly agreed that laboratory work was waste of time, while 18 students strongly opposed him/her. Similar results were obtained for the statement that experiments were interesting [mean = 3.89 (1.25 SD)], where 21 students agreed or strongly agreed with this statement and 5 students opposed it. Best of all, knowing that most students find such exercises a pleasant experience encourages us to prepare new experiments and laboratory activities as often as possible. From the perspective of gaining knowledge through laboratory activity, it is encouraging to note the results from the statements showing that students know the goals of the experiments [mean = 4.0 (0.62 SD)] and that they understand the graphs [mean = 3.85 (1.03 SD)]. Less satisfactory is the finding that after the laboratory, nine students remained neutral and five students disagreed with the statement that they better understood the underlying theory [mean = 3.48 (1.22 SD)], but, on the bright side, seven students strongly agreed and six students agreed with this statement. From a teaching perspective, this should mean that, in a session after the laboratory, the teacher should help students to make connections between what was seen and what it all means. The lowest values related to the statements that students did not need much help from the teachers [mean = 3.3 (1.2 SD)] and that they had no trouble with the software [mean = 3.37 (1.18 SD)]. From these results, we can conclude that working with computers can be the weakest link in the chain. We think that this problem has its roots in the fact that computers equipped with data loggers are not often used during the science courses. With the introduction of new exercises, we believe that student proficiency in using information and communication technology in the laboratory would increase.

In the support of our findings from the first part of the questionnaire, the following are the answers from the open-ended questions.

1. To the question “Where did you have the greatest difficulty?,” the most common answer was a variation on the theme that they had trouble with the computer settings.

2. To the question “What was the best?,” we emphasize these statements: “The results I hadn’t expected,” “The work was much more interesting than lectures,” “Seeing graphs immediately,” “We got the results based on our own work,” and “You do not just sit and listen.”

3. To the question “How would you improve the work?,” the most common answer was that the laboratory work did not need further improvement, and about a quarter of the students asked for more experiments.

Miscellaneous.

We were able to imagine experiments using computer equipment to demonstrate the importance of lubrication to the food or bacterial activity inside the large intestine, but these experiments were never performed inside the classroom for reasons of hygiene. In the first case, the classical physical experiment of pulling a weight along a rough surface and measuring force using a dynamometer would work. In the second case, the surface can be moistened with mucous saliva. The needed force in the second case would be smaller, owing the reduced friction. In practice, it was easier to demonstrate the importance of the literally billions of mucous glands, which make food slippery, using dry biscuits.

As in the case of food lubrication, we were able to imagine an experiment using fecal bacteria for the breakdown of different molecules but never performed it for of hygiene reasons. It would be possible to use the same equipment as in the bacteriostatic activity of the hydrochloric acid experiment using coliform bacteria instead, but we left this experiment in the domain of mental activity.

Fig. 7. Experimental design of the experiment where the importance of folding the lining to the speed of diffusion was demonstrated.

Fig. 8. Screen capture of the experiment where the importance of folding the lining to the speed of diffusion was demonstrated. The x-axis shows time (in min and s). The y-axis shows conductivity (in μS/cm). The top curve (black line) shows folded paper; the bottom curve (gray line) shows unfolded paper.
Using factorial analysis, three components were extracted, explaining 69.6% of the variance. The first component (48.1%) summarized variables 4, 10, and 6 (Table 1) and reflects feelings and confidence in working with computers; the second component (11.9%) summarized variables 8, 5, 2, and 1 and reflects student opinions in that they knew what they were doing and found it interesting. The third component (8.1%) summarized variable 14 in the positive direction and variable 3 in the negative direction: it can be summarized that students like laboratories but that the teacher has to be close to help when needed.

Interviews with the students were done by all three authors of the study. As part of the action research with the primary goal of improving a particular teaching unit about the digestive system, these were used primarily as feedback and as a guide for the teachers during the course. The expressed opinions of the students were, in the most part, similar to the answers given on the questionnaire. We can summarize that students like such work and value it more highly than lectures, where they just sit and listen. Using the computer is an incentive to work harder in the laboratory, especially for boys.

From the teacher’s point of view, the most important issue was bringing new life into our teaching and, hopefully, raising the level of interest in biology among our students. Teaching biology in Slovenia follows a syllabus prescribed by authorities at the state level. A teacher must fulfill prescribed goals but is free to choose which method to employ. In the prescribed syllabus, suggested laboratory practices about the human body can be regarded as highly biased toward anatomy, with observations of models, sections of animal organs like kidneys or the heart, and the microscopy of slides. Experimentation in human physiology suggests only 4 experiments in 60 academic hours: counting heartbeats, observation of the knee reflex, the location of different tastebuds on a tongue, and measurement of the quantity of carbon dioxide in exhaled air. In the teaching of the human digestive system, only the microscopy of slides is suggested. The introduction of new laboratory exercises can be seen as a switch from teacher-centered lectures toward student-centered practices, where students gain new knowledge through firsthand experience. In such a fashion, we were able to stimulate discussion about the physiology of the digestive system based on students’ personal experience with some of the underlying phenomena after the experiments. This was an improvement over previous practice, where teachers’ questions posed to the students were largely based on the facts and explanations already presented in the classroom by him/her. As an example, we presented a situation where students were asked if they could imagine other ways of performing an experiment based on the principle learned in the Speed of Dissolution experiment. After posing the question, we divided the students into groups of four and received innovative answers within a couple of minutes. They proposed ideas such as putting a whole fizzy tablet into one beaker and a second tablet, broken into pieces, into another beaker. After an equal quantity of water was added, they would seal both beakers with gas pressure sensors. The other group wouldn’t use gas pressure sensors but pH sensors instead, and so on. Best of all was that they were able to transfer knowledge gained during one session of laboratory work to a family of new experiments.

The evaluation of differences in learning outcomes based on experimental design with a test and control group has not yet been done. However, as experienced teachers with >20 yr of teaching experience, we were able to recognize improvement, in addition to the expressed positive attitudes toward such work, in upgraded laboratory skills, better understanding of graphs, use of knowledge in new contexts, and transfer of principles learned in one context to another. An added value for the students can be the recognition that computers can be used as sophisticated instruments as well as their own new skills at handling data. At least part of the success achieved in this particular class, expressed as final grades, can be assigned to active work during the course. Of the 32 students, 9 students achieved grades of excellent (90% or more on test scores), 17 students achieved grades of very good (between 75% and 84%), and 7 students achieved grades of good (between 62% and 74%). Nobody in the class failed (<49%) or achieved a grade of poor (between 50% and 61%).

Encouraged with such work, we are, at the moment, planning to upgrade our experiments with the incorporation of fresh student ideas and to design, in a similar fashion, computer-based units about other organic systems.

REFERENCES