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Project laboratory for first-year students

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Abstract

This paper reports the modification of an existing experimental subject into a project laboratory for first-year physics students studying in the first cycle of university level and at a higher professional level. The subject is aimed at developing important science-related competences and skills through concrete steps under circumstances that are similar to those met in real-life situations. A selection of suitable project tasks is discussed in detail and examples are given. In addition, the integration of the project laboratory into the training process of the physics education students in the second cycle is presented.

(Some figures in this article are in colour only in the electronic version)

1. Introduction

Experimental work is an integral part of undergraduate physics education. The prevalent form is a physics laboratory (in some countries called physics practicum) where students work alone or in pairs on pre-defined problems, following instructions from the lab manuals. These types of labs are essential for acquiring basic skills in handling different measuring devices and data analysis, but are in constant danger of becoming routine, unstimulating and remote from students' interest.

A different approach, which can avoid these problems, is to make laboratory work less structured, more explorative and to work in groups. Reports on similar approaches from decades ago read as if they were written today [1–3]. Two ways of making laboratory work more explorative are open-ended experiments and project laboratories. As described by Shonle [2], in open-ended experiments a specific beginning is established by the instructor, but the students are allowed to pursue a given experiment in any manner they desire. In a project laboratory case, a group of students chooses their desired topic (project task) and investigates it for an extended period of time. Of course, several variations and combinations exist.

In this paper the expressions *project laboratory* and *physics laboratory* will be used, the former covering also open-ended experiments and the latter all types of physics laboratories with the characteristics mentioned above (work on pre-defined problems following the lab manuals). It should be emphasized that, in general, the goals of the project laboratories are significantly different from (and in many cases complementary to) the goals of the physics laboratories, as will also be presented in this paper. What one should aim at is to include both types of subjects in an undergraduate physics programme.

Other contexts in which project laboratories are often mentioned today are recommendations for undergraduate science and engineering education. The results of the project *Tuning Educational Structures in Europe*, carried out by over 100 Universities and sponsored by the European Commission, showed that among the first five generic competences ranked by physics graduates (three to five years after graduation) and employers are problem solving, capacity to apply knowledge in practise and teamwork[1]. In this context, the project laboratory seems to be the ideal course for acquiring these competences in the first cycle of university education. In the US the major recommendation of the national study called *Shaping the future* for all science, mathematics, engineering and technical faculties was: '... build inquiry, a sense of wonder and excitement of discovery, plus communication and teamwork, critical thinking, and life-long learning skills into learning experiences'[2]. These recommendations, issued in 1996, obviously preceded the European ones by several years.

2. Gradual modification of an existing experimental subject

The experimental subject called *laboratory skills* was part of the study programme at our department from the very beginning. Originally, the subject was aimed at acquiring some basic practical skills such as electrical soldering and wiring, glass blowing, handling some basic tools in a mechanical workshop, black and white photography, etc. Typically students spent 3 h per week in two semesters on this subject, working in groups of ten but not as a team on a common problem. The subject was graded in the same way as other subjects, with marks on the scale from 5 (fail) to 10. In most cases students got grades from 8 to 10, depending on their presence at contact hours and the level of assiduity as perceived by the teaching staff. For this reason the objectivity of grading *laboratory skills* was always questionable, and it was later replaced with grading on a pass/no pass base. In addition to *laboratory skills*, students had to complete the classical physics laboratory (called physics practicum) that spans over first three years of studies and where students work individually on separate problems.

The first changes were made in 1985, when some outdated units were replaced with computer-related skills. In 1998 a new unit, called project laboratory, was added to the list. This was a seed unit and a test field for today's structure of a new subject. Based on the experiences with the project laboratory unit, in 2002 a new structure of the subject was set. It was realized that most of the students now acquire basic computer-related skills and some experimental skills in secondary school, as a result of common trends and changes made in secondary education at that time. On the other hand, it was also realized that students have almost no opportunities for applying theoretical knowledge of physics in practice and for developing teamwork skills at least until the end of the first cycle. Therefore, the sequence of separate skill-acquiring units was completely abandoned. Instead, each group of students now spends the whole time on completing the given project task, including the preparation of a final report in the form of a web page. The subject was finally renamed project laboratory. Overall the number of contact hours remained unchanged, while the teaching load has even been reduced. This in turn allowed us to organize optional workshops at the beginning of the year

[1] The project *Tuning Educational Structures in Europe* is available at http://www.tuning.unideusto.org/tuningeu/

[2] Link to report of study *Shaping the future*: http://www.nsf.gov/pubs/stis1996/nsf96139/nsf96139.txt

Table 1. Constraints imposed on project laboratory and corresponding competences and skills.

Constraint	Competence, skill
Knowledge base (first year, first cycle)	Problem solving, applying knowledge in practise, creativity, capacity to learn
Time limit (9 h for experimental work, 9 h for web page report)	Time management, organisation and planning
Work in group (five students per group)	Interpersonal skills, specific communicational skills, teamwork, leadership
Limited help from the Departmental/ Mechanical or Electronic Workshops	Planning, specific communicational skills
Limited budget	Money and material management
Report in the form of a web page	Concern for quality, skills for using ICT

for students who feel that they did not acquire some basic skills as mentioned above, during their secondary education. The rest of the subjects, including physics laboratory, have remained unchanged.

The main goals of the new subject have been redefined to aim at acquiring important generic competences as described in the following section. Our additional goals were to give first-year students opportunity to apply in a creative way the knowledge of physics that they have acquired so far and to let them discover how exciting physics is when 'hidden' in fairly simple problems.

3. Project laboratory

The project laboratory at the Department of Physics, Faculty for Mathematics and Physics, University of Ljubljana combines characteristics of the open-ended experiment and project laboratory, as defined in the introduction. The subject is offered in the second semester of the first year and in the first semester of the second year to all students. Typically, about 100 students in the first year enrol in the project lab, out of which about 70 are studying at university level (UNI) and the rest on a higher professional level (HP) (single cycle). The required load is 3 h per week in one semester that brings 3 ECTS points[3].

The main idea of our project laboratory model can be summarized in the following lines that also represent basic steps in completing the project.

(i) Give students a well-defined, sufficiently simple and attractive project task but no initial hints for the solution. Give students time for preparation and brain storming.
(ii) Require role assignment within the group.
(iii) Confront students with the constraints of the project (time, manpower, equipment, money and help from the workshop).
(iv) Let students take their own approach. Give hints when they get lost and advice when they get too ambitious.
(v) Require a final report and give feedback on it.

The major goal of the subject is the development of science-transferable/science-related competences and skills. These are achieved by solving concrete problems with freedom to choose how to do it, but under well-defined external constraints, similar to those met in real-life situations. The main constraints in our model of the project laboratory and corresponding competences and skills are summarized in table 1.

[3] Home page of the Project laboratory described in this paper is on the following address (for now in Slovene only): http://student.fmf.uni-lj.si/fiz/projlab/

In our experience the time limit and knowledge base have the major affect on the choice of the projects. Note that the experimental part of the project should be completed during the nine contact hours, though it is not unusual that highly motivated groups decide to spend additional time outside the required time. A novelty for us and for the students was also moving to an entirely electronic way of dissemination of the material and presentation of the reports. According to the questionnaire given to the students in the period from 2003 to 2004, the vast majority of the students preferred this way of communication. Requiring the reports in the form of a web page proved to be an optimal solution regarding manpower and time requirements needed to run this type of activity for about 100 students per year.

3.1. Structure of the subject

The work of each group of students is performed in the following four steps:

(1) role assignment, brain storming, searching literature (1 week);
(2) experimental work (9 contact hours in 3 weeks);
(3) data analysis and composing web page report (9 contact hours in 3 weeks);
(4) finalization of the report (up to 2 weeks).

In the first step groups get project tasks, usually 1 week before experimental work is scheduled to begin. Each group has to choose a ‘head’ and his or her ‘right hand’ within the group. The head of the group is responsible for all members of the group being about equally active and that equipment and tools used by the group are left in the same condition as received at the beginning. The ‘right hand’ makes notes in the lab book and helps the head of the group.

The second and the third steps take place at the department at a specified time and location, but the responsibility for the completion of the first and the last steps is left to the students. In this way, the number of contact hours has been reduced compared to the old subject. This gives students more freedom, but also more responsibility. The reduction of contact hours as well as a new laboratory room that was build specifically for this subject resulted in further improvements. First, the number of students per group was reduced from 10 to 5, which we think is an optimal number. This made qualitative changes in the way groups are functioning, enabling development of interpersonal skills and increase of the personal responsibility of each individual in the group. Second, time and space have been created for optional 1 day workshops on specific skills as mentioned in section 1. Typical workshops offered now are on electronic circuit design and on handling basic measuring devices such as oscilloscopes and multimeters.

In our experience the following four factors proved to be essential for the successful management of the project lab: selection of the project tasks, laboratory room and equipment, training of teaching assistants (group mentors) and evaluation of the reports. Each of the factors is discussed in the following sections.

3.2. Selection of the project tasks

Broadly speaking, one can choose between the following two approaches: one can require students to propose project tasks by themselves [4] or give students well-defined project tasks but give them the freedom to find their own solution. We took the second approach, with an additional goal, that every group of students gets a new project task, which means that every year about 18 new project tasks have to be created.

In our case the main objectives for taking the second approach were the following. We believe that the important goal of the first-year project laboratory is to help students build confidence in their ability to solve experimental tasks by applying the theoretical knowledge that they have acquired. By a careful selection of the project task, one can assure that a particular group of students will successfully complete the task and that there will be opportunities for all members to participate about equally in the final result. Using this approach one can also create situations in which students will more effectively and more likely combine theoretical knowledge with experimental results and observations, the process so essential for the majority of first-year students who still have to build a coherent knowledge of basic physics. Finally, situations where a group of people have to solve a well-defined problem using all their knowledge and creativity are those that most of these young people will meet in practice. It should be noted, however, that students were also invited to suggest their own project ideas, which were than discussed and if necessary modified to meet the standards of other project tasks. Though the students' interest in the subject is very high and constant, only three suggestions from students were given during the last 4 years, which indicates that project tasks created by us are well accepted by the students. The results of an anonymous questionnaire and interviews with students confirmed this.

Creation of 18 project tasks per year poses a serious demand on the subject. Our primary resources for project ideas and/or sources of inspiration for creating new projects were the following.

(i) Articles from journals such as European Journal of Physics, American Journal of Physics, Physics Education and The Physics Teacher.
(ii) Books that focus on exciting physics of everyday life, such as [5, 6] and physics textbooks that include ideas for home experiment and investigations at the end of the chapters (for example, [7, 8]).

A lot of project ideas can be found on the web, but often these resources become really useful as a reference after the main idea is formulated and a number of questions appear. However, there is a web resource that we found particularly useful in creating our project tasks; the problems given each year at the International Youth Physics Tournament[4] fit extremely well into our model of project laboratory. Of course, good project ideas also appeared at coffee-break discussions with other colleagues from the department, with physics teachers and with colleagues working in industry. After reporting on the implementation of our project laboratory at the International GIREP Seminar [9], we learned about other departments that offer similar project laboratory activities[5] [10]. We are convinced that an intensive exchange of successful project laboratory ideas at an international level will appear in near future.

The short period for project completion requires the choice of relatively simple projects. On the other hand, project tasks should be rich enough to keep busy and motivate five students for 9 hours of experimental work. Ideally, the experimental part of the project should require students to work on different tasks, including planning, construction work, measuring and documenting.

We decided to limit the use of measuring equipment to a computer-driven acquisition system with a set of school sensors (in our case Vernier system), oscilloscope and classical measuring devices such as callipers and multimeters. In this way less time is spent on preparations to acquire measurements, and more time can be devoted to measuring dependences on different parameters or testing different solutions. The majority of high schools in Slovenia were equipped with the Vernier measuring systems 3 years ago, so most of our first-year students are familiar with this type of equipment. It should also be noted that

[4] Link to the home page of *International Young Physics Tournament*: http://www.iypt.org/

[5] Link to Physics Project laboratory of Friedrich-Alexander-Universität Erlangen, Nürnberg, Germany: http://pp.physik.uni-erlangen.de/index.html

Table 2. Categories of project tasks and corresponding frequencies of occurrence. See the appendix for examples of project task descriptions for each category.

Category and typical formulation	UNI[a] + HP[b]	UNI	HP
A. Design an experiment to measure/explore dependence . . .	40	26	14
B. Design a demonstration experiment that shows . . .	4	4	0
C. Design an apparatus or procedure that meets the following requirements . . .	14	9	5
Total number of projects given	58	39	19

[a] University level.
[b] Higher professional level (single cycle).

students get acquainted with commercially available electronic elements, including sensors, and work with more professional measuring equipment in the second year of study when they have to take another experimental laboratory subject called *electronic practicum*.

During the past 3 years, about 60 different projects were created and performed by the students. As explained earlier, the students attended project laboratory study at two different levels: university level and single-cycle higher professional level. A basic difference between these two groups in the first year of study is that UNI students come mainly from gymnasiums where they acquire solid knowledge of basic physics, while HP students come mainly from vocational secondary schools with typically less knowledge of physics and mathematics than the former. After launching the project laboratory in 2002, all students have been asked to complete a questionnaire after finishing the project reports. Based on their answers and interviews with individual students as well as interviews with teaching assistants that mentored groups, we gradually built criteria and 'feeling' for first-year students' project tasks that work best at each level of study.

Comparing the 58 projects, three different categories of project task descriptions have been identified (see table 2).

The most frequently met project tasks (category A) require students to design an experimental setup to measure a certain value or dependence. Often students are challenged to search for other relevant parameters, vary them and measure corresponding dependences. The projects in category C require students to design an apparatus that meets certain requirements. This type of project can be extended in competitions (such as competitions of soda-bottle rockets, rubber band cars or project number 6, described in the appendix). In this case the same project task should be given to several groups, and the winners are chosen at the final competition. Descriptions of these projects should also include rules and criteria for competition, which should be carefully thought out and clearly formulated. In our experience such competitions can significantly contribute to the positive atmosphere among the first-year students and increase their motivation for study.

Interesting project tasks can be based on the requirement to design a particular demonstration experiment (category B). The results of such projects may lead to the development of new demo experiments that may be further improved with students studying on a physics education course [11, 12] or a new exhibit for the local Science Centre [13]. No particular interest was observed among students of the HP level for this type of project, and that is why this type of project was not given to them. Of course, there are several projects that have characteristics of two or even all three categories and there are projects that do not fit well in any of them (for instance, projects that require students to explore and explain the principles of operation of a certain apparatus could be a category of its own.). Examples of different project task descriptions from each of the categories are given in the appendix.

Figure 1. Project laboratory room (180° panoramic view).

Table 3. List of basic tools provided to each group.

Set of screwdrivers and spanners
Set of pliers, tweezers and clamps
Knife, scissors and hacksaw
Hammer and files
Ruler, measuring tape and calliper
Rechargeable cordless drill with drill bits
Glue gun
Protecting goggles and gloves
Mains tester and multimeter
Stopwatch

The projects were regarded as completed if both the experimental work and web reports were satisfactory. Only in two cases out of 58, groups did not complete the projects. Both cases occurred at the HP level, and the failure to complete the projects was mainly due to the ignorance of the majority of students in these two groups. In four cases groups completed the experimental part of the work, but were not able to produce a satisfactory report even after several revisions. Three of these groups were from the HP level and one from the UNI level. The reason for failure to produce a satisfactory report was mainly weak knowledge of basic physics in these groups, in some cases combined with the more demanding project tasks (for example, projects where students have to measure and interpret different dependences).

It was expected from all groups that they try to apply their knowledge of physics (theory) wherever they can, but particularly when interpreting their observations, explaining principles of operation and when analysing the measured data. However, to what extent the basic physics can be applied varies very much from project to project. As expected, students' motivation was generally higher for the projects that offered them more opportunities for applying basic physics.

3.3. Laboratory and equipment

A dedicated laboratory room is one of the essential needs for project laboratory activities. In 2005 a new laboratory of 67 m^2 was built in which three groups can work at the same time, though in practise we try to schedule no more than two (see figure 1).

Each group has a working bench (dimensions 1.5 m $\times$ 3.4 m), white board, computer and collection of basic tools as listed in table 3. At the mentor's place there are a collection of basic electronic elements (including bulbs and batteries), a collection of screws, nuts and bolts, connecting cables, lab stands and some special tools such as a tool for making threads. As mentioned earlier, the laboratory is equipped with a Vernier computer-assisted acquisition system and a set of school sensors for measuring several quantities such as position, velocity, acceleration, angular rotation, force, temperature, pressure, relative humidity, voltage, current, magnetic field, light intensity and sound pressure. Three boxes with all kinds of junk material made from plastic, wood and metal are an integral part of the laboratory room. An essential part of the equipment is also a digital camera and a tripod.

3.4. Group mentors

In our case four group mentors (three teaching assistants and one assistant professor) have been assisting in the project laboratory for the last 4 years. Group mentors have a crucial role in achieving the goals of the subject. In a way their role can be compared with the role of a coach at football: he is not allowed to play, but he can make his team win by advising which strategy to use in a given situation. By all means, this is not an easy task. Perhaps the most important ability that group mentors should develop is to be able to answer students' questions by posing the right questions and to resist the temptation to reveal their solution of the problem. Several basic teaching techniques that promote conceptual change in students and are well known to those working in physics education research may be of a great help in training group mentors for project laboratories. In addition, mentors also give basic instructions on safety regulations to every group at the beginning of the first meeting and keep records about the presence of the students. The typical workload of a group mentor is 4 h per week, which includes a first review of the web reports. The final review is done by the course supervisor.

3.5. Evaluation of the project work

Grading group work and, in particularly, experimental work is a difficult problem which does not have a unique solution. Different approaches are described in the literature, where an instructor grades the report or result of the work and then students split the grade among them [14] or where students initially decide the grading criteria and then the instructor grades the results according to these criteria [15]. As mentioned earlier, in our case the project laboratory was graded on a pass/no pass basis. In order to pass the subject, full-time presence during the contact hours is required as well as on-time completion of the web report. An additional important requirement is that the name of a particular student is included in the web report. There were two cases where a particular student did not participate at all in the preparation of the web report and so the group did not add his/her name in the final report. In these cases, the student had to repeat the project laboratory with another group to pass the subject. We feel that in our case the pass/no pass grading system is optimal and that it is not diminishing the motivation of the students for taking the subject. It is a special pleasure to see that high motivation for this subject is mainly the result of a student's motivation for work and not the result of struggle for grades.

4. Integration of the project laboratory in physics education course

The physics education (PE) programme at the Department of Physics, University of Ljubljana is a two-cycle programme designed primarily for educating future high school physics teachers. The subject *Didactics of Physics* in the second cycle (postgraduate level) is linked with the undergraduate subject project laboratory described in the previous sections in the following way. During the lectures on Didactics of Physics, several aspects of the experimental work in school are discussed. The specifics of the first-year undergraduate project laboratory are addressed and PE students are encouraged to propose their ideas for future projects. PE students are first requested to solve the proposed projects by themselves. If the projects prove to be suitable for our purpose (in the light of the constraints presented in the previous sections), then students may take the role of mentors and work with the groups of undergraduates during the 3 weeks of their practical work. During the time when groups work on the web reports, mentors are available for consultations. Once the project is completed and the web report is accepted, the students–mentors write an analysis of the work with their groups. The analysis is later discussed and used as feedback information for future mentors. A detailed description of the integration of the project laboratory in the second cycle of the PE course will be given elsewhere.

5. Conclusions

During the past 4 years, simple project tasks that can be completed in 9 hours and often refer to phenomena or objects met in everyday life were successfully solved by about 20 groups of first-year physics students per year. The project laboratory proved to be equally useful and attractive for students studying in the first cycle of university level as well as for students studying at a higher professional level, provided some specifics of the two levels are taken into account. In general, the projects for HP students should be defined more explicitly with fewer requirements for student-driven explorations and more guidance from the mentors than the projects for UNI students. On the other hand, we observed in several cases that HP students tried to put more effort into technical perfection of their experiments, which one should keep in mind when selecting the projects for them.

The project laboratory for first-year physics students proved to be an experimental subject where students can develop several competences and skills that are today regarded as essential in scientific work, apply their knowledge of physics in a creative way and experience the excitement of discovery. In this respect, the project laboratory in our department represents a complement to the existing classical physics laboratory. In addition, assisting in the project laboratory, mentoring the groups and analysing the students' group work proved to be a great opportunity for postgraduate students on the physics education course (future physics teachers at high schools) to acquire new knowledge and competences in organizing and conducting this type of experimental work.

In order to keep project laboratories vital and encourage more departments to include this type of subject into their programmes, the exchange of successful project laboratory ideas and approaches at the international level is necessary.

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Appendix

Some typical project task descriptions, as they were presented to students, are presented below. A corresponding category of project task, as defined in table 2, is given in brackets at the end of each description.

Figure A1. Results of students' project: three modes of oscillation of soap bubble (project number 1).

(a) (b)

Figure A2. Results of students' projects: (a) measurements of friction forces in climbers' device (project number 5) and (b) 'alter record player' (project number 6).

A.1. Project tasks for students at university level

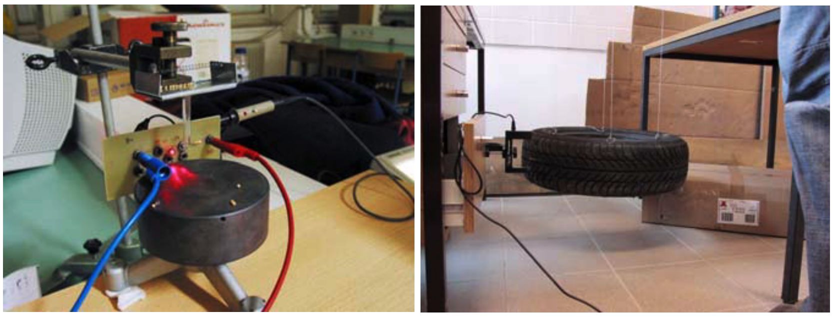
(1) Design an experiment to explore modes of oscillation of soap bubbles driven by the sound (see figure A1). [A, B]

(2) Design an experiment to measure the electric charge that forms on a container when sugar (or other granular material) is poured from it. Explore different combinations of materials. [A]

(3) Design a demonstration experiment that shows several physics phenomena in a uniformly rotating system as seen from the rotating reference frame and the laboratory reference frame (students can borrow a video camera from the department). [B]

(4) Design, test and calibrate a simple humidity meter. Try several designs and compare their performance. You may use a Vernier humidity sensor for calibration. [A]

(5) Climbers use a rope wound around a tree trunk to help slow down a descending companion. Sliding friction plays a central role in such devices. Theory shows that the ratio of the tensions of the rope on the two sides of the winding increases exponentially with the angle of winding. Design an experiment to test the predicted dependence (see figure A2(a)). [A]



(a) (b)

Figure A3. Results of students' projects: (a) measurement of coefficient of restitution of mustard seeds (project number 8) and (b) measurement of rotational inertia of a car tyre (project number 9).

(6) Design an apparatus for playing classical vinyl records. The apparatus should meet the following requirements: (a) it should not use electricity to run any part of the apparatus or to amplify the sound, (b) it should play music from a record for at least half a minute without any assistance, (c) the quality of the music should be high enough that an independent listener recognizes a well-known song, (d) try to achieve as loud a sound as possible (see figure A2(b)). [C]

A.2. Projects tasks for students at the higher professional level

(7) Granular materials such as seeds are kept in silos. Designers of silos need to know how the flow of a granular material from the silos depends on its shape. Design an experiment to measure the time dependence of a granular material flow from the silo models of different shapes. Use soda bottles of different shapes for silos and if time permits explore different granular materials. [A]

(8) Design an experiment to measure the coefficient of restitution of mustard seeds. The coefficient of restitution of a body is a fractional value representing the ratio of velocities before and after an impact (see figure A3(a)). [A]

(9) Design an experiment to measure the rotational inertia of a car tyre around each of two perpendicular geometrical axes. Try several methods and compare the results (see figure A3(b)). [A]

References

[1] King J G 1966 On physics project laboratories *Am. J. Phys.* **34** 1058–62

[2] Shonle J I 1967 Project laboratory in electricity and magnetism *Am. J. Phys.* **35** 792–6

[3] Dhaenens F and Herreman W 1980 A project laboratory experiment on digital electronics *Eur. J. Phys.* **1** 193–7

[4] Neumann K and Welzel M 2007 A new labwork course for physics students: devices, methods and research projects

[5] Walker J 1977 *The Flying Circus of Physics With Answers* (New York: Wiley)

[6] Downie N A 2001 *Vacuum Bazookas, Electric Rainbow Jelly and 27 Other Saturday Science Projects* (Princeton, NJ: Princeton University Press)

Downie N A 2003 *Ink Sandwiches, Electric Worms and 37 Other Experiments for Saturday Science* (Baltimore, MD: John Hopkins University Press)

[7] Crawford F S 1968 *Waves, Berkeley Physics Course* Vol 3 (New York: McGraw-Hill)

[8] Rees R L 2000 *University Physics* (Pacific Grove: Brooks/Cole)

[9] Planinšič G 2004 Revitalization of the laboratory activities and integration of the subject into the post-graduate physics education course *Quality Development in Teacher Education and Training: GIREP Book of Selected Contributions (Udine, Italy, 1–6 September 2003)* pp 84–9
[10] Dickison A Private Communication Seminole Community College
[11] Planinšič G 2004 You can make sweet electricity in your kitchen *Phys. Educ.* **39** 36–7
[12] Lasič S and Poljšak G 2005 Friction holding the climber: an experimental example from physics in sports *Informal Learning and Public Understanding of Physics, GIREP Book of Selected Contributions (Ljubljana, Slovenia, 5–9 September 2005)* pp 250–6
[13] Planinšič G and Kos M 2005 Collaboration between the science centre and university department—opportunities and challenges *Informal Learning and Public Understanding of Physics, GIREP Book of Selected Contributions (Ljubljana, Slovenia, 5–9 September 2005)* pp 103–7
[14] Conway R, Kember D, Sivan A and Wu M 1993 Peer assessment of an individual's contribution to a group project *Assess. Eval. Higher Educ.* **18** 45–56
[15] Erzberger A, Hiebert L, Merrill T, Weinmann L and Woosnam T 1996 A framework for physics projects *Phys. Teach.* **34** 26