The main objective of laboratory exercises is to teach students laboratory skills and to introduce new ideas that help students become familiar with basic laws and concepts (1, 2). Though the laboratory has had a distinctive role in science education over many decades, its potential has not always been realized (3). It is generally agreed that students do not come to the laboratory prepared (4). Laboratory instructions and pre-laboratory work should therefore comprise an important segment of each exercise. Results of a survey in England and Wales (5, 6) revealed a large variation in time that students spend preparing for the laboratory exercise. Time spans between zero and 2 hours were reported for different universities. The typical pre-laboratory session comprises ∼20 minutes of instruction, just prior to the exercise, and covers the aim of the work, laboratory procedures, safety regulations, and the way that data are handled at the end of the experiment. Although this is a common practice, certain problems may arise from its implementation. Students, weak in theoretical knowledge, cannot grasp the aim of the work and may not understand the underlying concepts of the laboratory exercise. As a consequence their experience is reduced to the level of a technician: they simply follow the “cookbook” recipes. The problem of the large quantity of information given to the students in a short period of time immediately before the exercise was studied by A. H. Johnstone and co-workers (7, 8). They found that the quantity of recorded information was lower than if the same topic was presented in a less exhaustive format (9).

Several methods to motivate the students to prepare in advance for the laboratory exercise have been tested. Formation of smaller groups of students who were involved in the planning of an open-ended experiment was shown to be a convenient way of raising their motivation for the laboratory exercise (10). Isom and Rowsey (11) developed an organizational plan consisting of 25-minute instruction about the experiment and another 20 minutes for communication between the instructor and the students, held two days prior to the laboratory exercise. The benefit came from the interaction between the students and the instructor and the fact that it forced the students to think about the experiment prior to the laboratory. Radical approaches, such as that of Ealy and Pickering (4) where students entered the lab with a written summary of the experiment that they used instead of the manual, have also been tried. Rollnick et al. (12) tried to motivate students by requiring them to write synopses of the experiment prior to the practical exercise.

Students usually devote more time to the post-laboratory activities, which could last up to 5 hours per exercise (6), than to the pre-laboratory preparations. These post-laboratory activities consist mainly of writing reports, usually completely or partially finished outside of the lab. The reports include the aim of the work, the experimental section, and the handling and interpretation of data. Evaluation of laboratory exercises and their contribution to the final grade of the course varies considerably. Many different items can contribute to the assessment, such as practical tests, written reports, or interviews (6). The major contribution to the final grade usually consists of the reports or worksheets written after the exercise, as well as the answers to questions or calculations, which are typically part of the reports.

One of the major problems of laboratory exercises is the fact that the students get too much information in a short time just before the exercise. The students are usually preoccupied with the technical and manipulative details, which seriously limit the time they can devote to meaningful, concept-driven inquiry (13). Gunstone and Champagne (14) suggested that meaningful learning would develop if students were given sufficient time for interaction and reflection. Information overload can thus be reduced and substituted by a substantial increase of pre-laboratory work directed towards a better understanding. This article presents an alternative organization for laboratory exercises in chemistry and biochemistry. The main objectives of our approach are: (i) to motivate students to acquire the necessary basic knowledge before the laboratory exercises, (ii) to shift the time burden from post-laboratory to pre-laboratory work, and (iii) to improve student performance at the final exam. All of these should be achieved with no extra time burden for students and teaching assistants.

Design of the Course

Chemistry courses at the University of Ljubljana are divided into two equally important parts: lectures and laboratory exercises, the latter run by teaching assistants. The student’s knowledge is evaluated independently for both parts and the students received two grades. The grade for the laboratory part was obtained in most cases solely from the results of the final exam given at the end of the course. This exam consisted of practical and theoretical questions and problems about the experiments performed. The student’s performance in the laboratory and the written reports did not usually contribute significantly to the final grade and were only used to qualify for attendance at the final exam.

To improve the student’s performance in the lab and at the final exam the pre-laboratory preparation period has been modified—two additional segments have been added.1 Students attend a 30-minute initial session, held by the teaching assistant 8 to 14 days before each laboratory session. Here the theoretical basis of the experiment, basic calculations, significance, and interpretation of results are discussed. The following week, 1 to 7 days prior to the experiment, students take a 25-minute preliminary test, which includes multiple-choice questions, short-answer questions, and mathematical calculations. Questions require the student to operate predominantly at the two lower levels of Bloom’s taxonomy, knowledge, and comprehension. Only pencils and calculators are allowed.
The short introductory session held in the laboratory just prior to the experiment has been retained and practical work has not changed greatly. However, the laboratory reports have changed considerably. Instead of an extensive report written at home, the student writes a short 25-minute report immediately after the experiment. This comprises calculations and other data handling procedures with data obtained during their practical work. Additionally, they have to answer questions where their understanding of certain steps of the experimental procedures is assessed. Writing the reports require the student to develop cognitive processes of application and analysis. Use of literature and the laboratory manual is encouraged.

At the end of the course, students take a 90-minute final exam that covers the topics of all the exercises performed. Only pencils and calculators are allowed. It comprises various types of questions—multiple-choice, short-answer, mathematical calculations, together with questions where students are asked to compare, explain, analyze, and evaluate a variety of results and procedures. Most of the questions require the student to apply lower cognitive skills such as knowledge, comprehension, and application, but certain questions demand the skills of analysis and evaluation. The final grade for the laboratory course includes the scores for the final exam—70 points, for the preliminary tests—30 points, and for the reports in the range of 10 points (bonus or deduction) to the overall sum. Students with the total above 50 points pass the exam.

Questions asked on the final exam over the years are similar with respect to the breadth of the field and different cognitive levels. Topics and knowledge requirements are well known in advance to students. Validity and, to a certain degree, reliability have been improved because the exam is taken by the teaching assistants prior to the students. Their comments on the volume and complexity of the exam are considered.

**Students Included in the Study**

The study presented here started at the biotechnical faculty of the University of Ljubljana during the year 2000–2001 and is still continuing. For clarity this article includes only the data obtained during the year 2001–2002. University students of microbiology and animal husbandry attending the general chemistry course, university students of food science and technology attending the biochemistry course, and college students of animal husbandry were included in the study. The total number of students involved during the year was 223 (150 female and 73 male students). They had an average of three years of chemistry in a secondary school, and college students of animal husbandry were included in the study. The total number of students involved during the year was 223 (150 female and 73 male students). They had an average of three years of chemistry in a secondary school, slightly above the Slovenian average.

The students’ prior knowledge of natural sciences and math is comparable to that of students of similar age in other countries of the EU. After completing the general curriculum, eight years in primary school and four years in secondary school, Slovenian students take the *matura*, an external examination in five subjects, required for admission to academic higher education courses (in Slovenia and wider in EU). The compulsory subjects are Slovene, mathematics, and a foreign language. Students also have the option to take a final examination after an appropriate 4-year course, which is on lower level than *matura* examination, that gives the opportunity to continue education in vocational colleges.

**Methodology**

Most of the data and other information presented were obtained from a questionnaire, consisting of a combination of closed and open-ended questions, that was answered anonymously by the students at the end of the course. Additional information was collected from field notes and personal observations of teaching assistants and by interviewing the technicians involved in the laboratory exercises. Student success on the final exams during the study years 1998–2000 (previous system) was compared with the results of the study year 2001–2002 (current system). Scores for preliminary tests, reports, and final exam that contribute to the final grade of the course were collected, and linear (Pearson’s) correlation coefficients of students’ scores at individual segments of the course were calculated.

**Results and Discussion**

**Pre-Laboratory Work**

One of the main objectives of the project was to shift the time burden from the post-laboratory period to the pre-laboratory period (Figure 1). Data about the time burden were obtained from the actual duration of the sessions when students were together with teaching assistants and from students’ estimation of their private work. Students were asked to compare the time they devoted to a certain segment in the new system, with time they would spend, if exercises in general chemistry and biochemistry would be organized in the classical way, as they experienced the same year at organic chemistry, physical chemistry, and analytical chemistry exercises.

According to their responses, students on average spent only 20 minutes in preparation before they entered the lab in the previous system. Almost 20% of students would not prepare at all. When initial sessions and preliminary tests were introduced the pre-laboratory work was substantially prolonged. On average students studied for 43 minutes before the preliminary test and an additional 12 minutes before the laboratory exercise. Private study was almost tripled (Table 1).

Together with the initial session and written test, students on average spent 110 minutes for each exercise before they entered the lab. There were virtually no completely unprepared students. Additional benefits also arose from the segmentation of the pre-laboratory work. During the initial session students became familiar with the subject. At home they studied from the manual or other books containing suitable information. At the preliminary test students had the opportunity to compare their knowledge with the expectations of the teaching assistant. Before the preliminary test, students talked to each other for a few minutes discussing the subject and later, after finishing the test, they compared their answers. The segments of pre-laboratory work and discussion between the students certainly contributed to better understanding of the topic before they entered the laboratory (6).

Students generally agreed with the duration of the ini-
tial session, with the exception of microbiology students who preferred a longer initial session. The majority (86%) of the students liked that the preliminary tests were evaluated and that they contributed to the final grade of the course, indicating that students wanted to get something in exchange for the time spent studying before the laboratory work.

Laboratory Work

Each laboratory exercise started with a short introductory session (Figure 1). A few minutes were devoted to practical instructions and warnings about possible hazardous situations. The second part of the introduction was devoted to discussion of mistakes and misconceptions that had become apparent from the answers in the preliminary test. One of the most important gains of the system was that no time was spent on topics already covered by most of the students. If necessary, certain calculations that were already explained in the initial session were explained again. When problems were of a theoretical nature, analogies with topics already familiar to students were drawn. Difficult subjects were explained with the basic chemical concepts. As students were at least partially familiar with the exercises, real discussion developed instead of the usual one-way introductory session that preceded experimental exercises in the previous system.

The experiments were not changed much from previous years. Nevertheless, certain improvements were observed. The number of “thoughtless” questions was substantially lower, especially those connected to the theoretical background of the procedure. On the other hand, the frequency of questions like “How much of that solution?”, “Where can I find...?”, did not change appreciably. This can be explained by the fact that relatively little effort in the pre-laboratory work was devoted to explanation of the exact protocol. The time spent in the laboratory was not much shorter than in the past. This could be due to the low impact of pre-laboratory work on the laboratory skills or to the fact that certain critical points such as spectrophotometers, centrifuges, burets, and so forth, which are shared by more than one student, actually define the pace of the laboratory work.

Usually, when students were not forced to finish their report immediately after the laboratory exercise, they were not motivated to immediate interpretation of the data and to careful recording of experimental detail. It was much easier to leave that for later, and this “later” easily expanded to a few hours prior to the next exercise, when the students had to hand in their reports. Now, knowing that they have to evaluate their data immediately after the exercise, students

![Figure 1. The time scheme of chemical and biochemical laboratory exercises in the previous (upper scheme) and in the current system (bottom scheme).](image-url)

Table 1. Percentage of Students that Spend a Certain Quantity of Time in Preparation

<table>
<thead>
<tr>
<th>System</th>
<th>Event</th>
<th>Time (min)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
</tr>
<tr>
<td>Current</td>
<td>Preliminary</td>
<td>0.6</td>
</tr>
<tr>
<td></td>
<td>Laboratory</td>
<td>25.4</td>
</tr>
<tr>
<td>Previous</td>
<td>Laboratory</td>
<td>18.2</td>
</tr>
</tbody>
</table>

Note: All data are expresses as percentages. These data are an estimation of the students’ private study time before they enter lab.
talked to each other about their results, about calculations, and about the theoretical background. Those familiar with the subject were willing to provide the information, knowing from the results of the preliminary tests that they understood the basis of the exercise.

**Reports**

The time burden was shifted from the post-laboratory to the pre-laboratory work. The reports were not written at home, but were completed immediately after finishing the experimental work. Students had to finish their reports within 25 minutes, which is considerably less than the ∼90 minutes they would have spent writing their reports at home. Students were not allowed to communicate while they were writing the reports. Stopping potential discussion between the students might seem too restrictive, but the students had been encouraged to discuss the experiments, not only among themselves but also with their teaching assistant, during the laboratory exercise and, most importantly, for an additional few minutes immediately after the exercise.

Communication between students while writing their reports would probably have resulted in the copy–paste system that is, in our opinion, one of the major deficiencies of the home-written reports or those that are prepared with a group of students. The great majority of students included in the study (more than 75%) confirmed that they at least occasionally copy reports from their colleagues if they are allowed to finish them at home. In practice, this actually means that only a few students actually write their reports at home, while others either completely rewrite them or only slightly better, make a certain combination of copying and writing by themselves. This is in keeping with recently reported findings that students believe the classroom lab to be fundamentally different from a research or industrial lab (15).

**Final Exam**

Students wrote a final exam at the end of the course. All the groups of students performed better on the final exams under the new system (Table 2); however, the best progress was observed for college students. The relatively low percentage within this group can be attributed to the fact that a positive score in the general chemistry course is not obligatory for passing into the second year of the study. Additionally, college students performed relatively better on the theoretical part of the general chemistry course, which does not depend on the laboratory exercises.

The fact that students achieved better results was in accordance with their opinion about knowledge obtained during the course, which they expressed in the questionnaire at the end of the school year. The great majority of students believed that regular study during the course of laboratory exercises improved both understanding of the subject and the durability of their knowledge. Only three percent of students believed that understanding and durability were reduced as a result of the new system.

**General Evaluation of the New System**

Students liked the new system and only 17% were against its implementation for other subjects. Half of the remaining students would like to see other laboratory exercises organized in such a way as well, whereas the other half believes that the system is suitable only for more difficult subjects. Students were asked to evaluate the most negative and the most positive points of the new system. Only 40% expressed negative characteristics and 90% pointed out various positive characteristics. Only about 20% of the students declared that the workload was too high and among these one could also find comments such as: “Now I have to study more, but it is actually OK.” In general, positive comments on better preparation for practical work, motivation for regular study, and better theoretical background were stressed.

One of the main fears when introducing this system was that it could increase the time burden for the students. The goal of not increasing the total time for the exercise was not completely achieved, since the overall time was increased by 25 minutes, which is about 10% of students’ time devoted to the exercises (Figure 1). Although the majority of students actually spent more time working under the current system, only 8% felt they were doing so. Almost 61% of students believed that they spent less time than in other similar subjects. This discrepancy can be ascribed to the perception of students that time has now been better used.

Preliminary tests, reports, and final exam, all of which contribute to the final grade of the course, were compared and linear (Pearson’s) correlation coefficients (r) of grades for individual segments were calculated (Table 3). Correlation coefficients for the students of microbiology, food science and technology, and animal husbandry are very similar, although different teaching assistants in different courses (general chemistry and biochemistry) were involved. However, when correlations of individual segments were compared, relatively low correlation of scores for reports and final exam became apparent. On the other hand, correlations of preliminary tests

### Table 2. Success of Students on the Final Exams

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>No. of Students</td>
<td>Percent Who Passed</td>
<td>No. of Students</td>
</tr>
<tr>
<td>Microbiology</td>
<td>164</td>
<td>57</td>
</tr>
<tr>
<td>Food science and technology</td>
<td>161</td>
<td>80</td>
</tr>
<tr>
<td>Animal husbandry (university)</td>
<td>120</td>
<td>53</td>
</tr>
<tr>
<td>Animal husbandry (college)</td>
<td>155</td>
<td>4</td>
</tr>
</tbody>
</table>

### Table 3. Correlations of Scores for Evaluated Segments of Laboratory Exercises

<table>
<thead>
<tr>
<th>Area</th>
<th>Pre-test vs report</th>
<th>Report vs Exam</th>
<th>Pre-test vs Exam</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microbiology</td>
<td>0.57</td>
<td>0.40</td>
<td>0.70</td>
</tr>
<tr>
<td>Food science and technology</td>
<td>0.52</td>
<td>0.40</td>
<td>0.70</td>
</tr>
<tr>
<td>Animal husbandry</td>
<td>0.56</td>
<td>0.33</td>
<td>0.75</td>
</tr>
</tbody>
</table>

*Pearson’s linear correlation coefficients were calculated. *All values were significant at the α = 0.01 level except this value which was significant at the α = 0.05 level.
and final exam were relatively high. Low correlation of scores for reports and for the final exam could be ascribed to the fact that, for the reports, use of literature was allowed. Additionally, students had to link pieces of information they have obtained during the exercise in the short time immediately after the exercise. These abilities, which are important, are often not evaluated when the grade for the course is based solely on the exam. One could argue that students are now over-assessed. Nevertheless, if all student’s activities are assessed the burden is spread over many smaller segments, which is not so stressful. An additional benefit of dispersed evaluation is the fact that knowledge, ability, and motivation of students can be better assessed.

Conclusions

The revised structure for the laboratory exercises in chemistry for first-year students and the laboratory exercises of biochemistry for second-year students was widely accepted by both students and teaching assistants. Nevertheless, certain comments about its general applicability have to be addressed. Not only students, but also teaching assistants should be highly motivated for its proper implementation. In Slovenia teaching assistants are mostly new PhDs and teaching constitutes the most important part of their occupation. Additionally their qualification as teaching assistants depends on grades awarded by students.

During the course, teaching assistants were more occupied. They had to find additional time for the initial sessions and correction of preliminary tests, which could be a heavy burden for graduate students focused on their own research and working as teaching assistants. On the other hand, the time spent on post-laboratory activities is substantially reduced. The reports were shorter and, most important, students were better prepared for the final exam. The quantity of the work connected with assessment when the practical part was finished was substantially reduced compared to the previous system.

We believe that the system described is convenient for students where chemistry is not of primary interest, but is a subject that should provide some basic chemical knowledge needed for problem solving in their specific topics. The major focus on the pre-laboratory work enables the students with a relatively weak background in chemistry or biochemistry to integrate efficiently into the educational process. Only those practical exercises where students are well prepared and understand the practical procedures in the lab can have a meaningful impact on their understanding of the topics.

Acknowledgments

The authors would like to thank Milica Kac and Roger H. Pain for their valuable suggestions and discussion of the paper.

Notes

1. In the previous system the students would know in advance which experiment they would perform. In a short, ~20-minute introductory session just prior to the laboratory exercise, teaching assistants explained the theoretical basis and practical implementation of the experiment.

2. The teaching assistants corrected and scored the tests and returned them to the students at the beginning of the lab.

Literature Cited


