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Special Section: Innovative Laboratory Exercises

Special-Study Modules in a Problem-Based Learning Medical Curriculum

AN INNOVATIVE LABORATORY RESEARCH PRACTICE SUPPPORTING INTRODUCTION TO RESEARCH METHODOLOGY IN THE UNDERGRADUATE CURRICULUM

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We describe the organization of wet-lab special-study modules (SSMs) in the Central Research Laboratory of Dokuz Eylül Medical School, Izmir, Turkey with the aim of discussing the scientific, laboratory, and pedagogical aspects of this educational activity. A general introduction to the planning and functioning of these SSMs is given, along with specific examples. The wet-lab SSMs incorporate several innovative pedagogies: problem-based learning, research-based learning, practical laboratory education, team-based learning, and project-based learning. Oral and written evaluations show that the students find this activity rewarding. The wet-lab SSM model applied in the Research-Lab of Dokuz Eylül School of Medicine represents a format which is effective in training the students in research methodology, practical laboratory work, and independent learning.

Keywords: Active learning, laboratory exercises, medical education.

During the last two decades, medical education has gone through a radical change of curriculum throughout the whole world. This change was initiated by the declaration of the General Medical Council, "Tomorrow's Doctors," which placed a strong emphasis on moving from an overloaded medical curriculum to a more flexible one, including a core curriculum and options most often grouped under the heading "Special Study Modules" [1].

The content of Special Study Modules (SSMs), which are elective, is more flexible than the core curriculum and therefore supports an innovative perspective. Throughout the years, the practice of SSMs has evolved enormously, to encompass a range of activities covering different disciplines and formats: An SSM in medical informatics for the first year at Queen's University Belfast supported those students who were less skillful at using information technology [2]. At the University of Leeds, undergraduate medical students were introduced to the construction of an interactive multimedia learning resource utilizing computer-based facilities [3]. Fletcher and Agins [4] have described an SSM in occupational medicine used as a novel approach to undergraduate teaching in the medical school of the University of Edinburgh. Finally, there is an interesting evaluation of a SSM on "literature and medicine," organized at Oxford University [5].

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Dokuz Eylül University School of Medicine, which is the pioneer medical school in Turkey to implement a problem-based learning curriculum in 1997 [6], has since then structured a network of SSMs in its curriculum. Dokuz Eylül School of Medicine, as all other medical schools in Turkey, accepts students following the receipt of a high school diploma, with the prerequisite of taking a nationwide entrance examination from which around 1% of the applicants are accepted. The duration of the preclinical medical education is 3 years, and that of the clinical years, also 3 years (including the internship). As the whole system in Dokuz Eylül School of Medicine is strongly based on individual independent learning, it is essential that students acquire the research methodology which will not only help them in the pursuit of medical research, but also facilitate the search, processing, and evaluation of scientific information, that is, "learning scientifically."

SSMs are integrated into the first 3 years of Dokuz Eylül University School of Medicine [7] and are offered in four different fields: literature search, clinical research, laboratory research, and the lately-inaugurated social responsibility SSMs. In year 1, the SSM is structured as a literature survey for which students write and present a review, thus forming a back-up for the basic or clinical mini-research project SSMs to be undertaken in year 2. In year 3, the student has to select an SSM only if he/she has not yet fulfilled the necessary credits. In addition, it is motivating for a student to accumulate a number of SSM credits higher than required because it pro-

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TABLE I
Systematic procedure for the organization of special study modules (SSMs) in Dokuz Eylül University School of Medicine

I. Preparation	II. Registration	III. Application
I.1. Composing a SSM project	II.1. Announcement of the SSM list by the Medical School administration to the medical students (SSM topics, objectives, content, summary project, etc.)	III.1. Meeting of the SSM students with the particular SSM convenor and tutor
I.2. Applying for financial funding to relevant bodies (University Research Administration, Turkish Research Council, etc.)	II.2. Filling-out of the application forms by the students, indicating first/second/third choices for the SSMs	III.2. Introduction to the SSM
I.3. Application of the SSM module to the SSM Committee of the Medical School (an application form is filled-out)	II.3. Placement of the students in open SSMs according to the choices they have made and availability of places	III.3. Carrying out of the SSM yearly schedule-lectures, laboratory work, discussions
I.4. Approval of the SSM by the SSM Committee	II.4. Dissemination of the final SSM groups to faculty and students before the beginning of the semester	III.4. Oral presentation of SSM results
		III.5. Written presentation of SSM results

vides a "priority" during the selection process of elective rotations in higher years.

The Central Research Laboratory (R-LAB) of the Medical School has the mission to educate undergraduate medical students in research through a multitude of SSMs. The R-LAB SSMs are designed with the following pedagogical aims:

1. To provide a positive learning environment for the students in the areas which are of interest to them.
2. To support the students in the development of independent learning skills.
3. To educate the students in the basic principles of scientific methodology and to support the actual practice of a research project.
4. To acquaint them to basic research laboratory culture.
5. To offer them the possibility of learning some basic biochemistry and molecular biology lab skills.
6. To teach them generic skills such as project management and written/oral presentation of results of a scientific work.

In this article, we describe the organization of the wet-lab SSMs in the R-LAB of Dokuz Eylül Medical School with the aim of discussing the scientific, laboratory, and pedagogical aspects of this educational activity.

METHODOLOGY

Organization of SSMs and Activities

Under the umbrella of the Medical School administration, these modules are organized through a series of steps, which can be summarized as preparation, registration, and application (Table I). Table II gives a typical example of the schedule of an SSM with duration of 8 months for second-year medical students. It should be noted that before starting the practical work, all students in SSMs are required to obtain the approval of the "Clinical and Laboratory Ethical Committee" of the Medical School.

Assessment and Evaluation

SSM's are components of the medical curriculum and therefore all three forms of assessment take place: 1) assessment of the students by the mentors and the module convener; 2) assessment of the SSM by the SSM convener and the mentors, and 3) assessment of the module by the students. Students get course credits for their perfomance in the SSMs. The mentors of the SSMs as well as the SSM conveners continually observe the students. At the end of the SSM, the convener, together with the mentors, compiles a feedback form for each student. Oral feedback is given to the students during the small-group activities where mentors are involved, as well as following the students' final seminar.

The feed-back forms that the SSM students are asked to complete consist of a questionnaire having some open-ended questions regarding the students' opinions, as well as a five-point scale on their satisfaction.

SELECTED EXAMPLES OF SOME "WET-LAB SSMs"

Between the years 2004 and 2010, 16 wet-lab SSM's were carried out in Dokuz Eylül School of Medicine R-LAB. We categorize them into two groups: 1) Basic laboratory mini-research SSMs and 2) Educational laboratory mini-research SSMs (involving preparation of a student laboratory practical). The first category has as its mission to help the students become acquainted with basic research methodology, learn some laboratory work, and develop generic skills mentioned above. The second category has as its mission to help the students become acquainted with educational research practice and, again, learn some laboratory work and develop some generic skills. We describe below three "basic laboratory mini-research SSMs" and two "educational laboratory mini-research SSMs," performed under the supervision of the R-LAB team. The SSM students were educated on ethical issues and were involved in the preparation of the application to the Clinical and Laboratory Ethics Committee of the School of Medicine, before the start of the mini-project. Information on safe handling of biological specimens was also extensively covered and demonstrated.

Basic Laboratory Mini-Research SSMs

Comparison of Erythrocyte Membrane Protein Patterns in Hereditary Spherocytosis and Healthy Controls Using Sodium Dodecyl Sulfate-Polyacrylamide Gel Electrophoresis (SDS-PAGE) Technique—Five second-year medical

TABLE II

Eight-month schedule of a typical second-year special study module (SSM)—students meet regularly with their tutors one afternoon a week

Month number	Stages of the SSM	Activities of the SSM tutors	Activities of the students
1–2	Preparation and introduction to research	• Seminar on Dokuz Eylül University, scientific methodology • Seminar on planning research • Teaching data-base searching • Workshop on how to prepare a research project proposal • Tutoring the student activities	• Identifying the data sources and performing literature search • Sharing the information obtained within the group • Writing a mini-research project proposal and applying to the Ethics Committee • Planning of the practical laboratory work of the project
3–6	Practical laboratory work	Pre-analysis stage: • Seminar on laboratory safety • Seminar on keeping a laboratory log-book • Basic laboratory techniques Analysis stage: Tutoring on: • Choosing a lab method • Preparation of solutions • How to use basic lab equipment Post-analysis stage: Tutoring on: • Determination, calculation of lab data • Expression in “units” • How to consult a “biostatistician” • Preparing a project report	• Keeping a lab log-book • Preparation of chemicals • Weighing the chemicals and making the solutions • Collecting biological specimen from the patients • Performing the test(s) and making the measurement • Calculations • Repetition of tests, if necessary • Discussion of the results • Reading and discussing published articles • Preparing a research project report
7–8 (A)	(Depending on the SSM objectives) A. Pilot Study for preparing a lab practical and performing with first-year volunteer medical students	Tutoring on: • How to prepare a lab practical (experimental design) • How to make a presentation • How to prepare a poster • How to prepare a Laboratory Practical Manual	• Preparing a laboratory practical manual • Preparing how to perform the pilot study on first-year students • Preparing the lab benches, materials, and equipment for the pilot study • Preparing the feedback forms for the students and the tutors • Finding the volunteer first-year students • Conducting the laboratory practical acting the role of “tutors” • Collecting the filled-in feedback forms from the students and the tutors • Preparing the oral presentation of the SSM • Preparing the written report of the pilot study
7–8 (B)	B. In case of a basic laboratory research SSM	Discussing on: • How to read scientific articles • How to prepare a review • How to present data in graphics and figures • How to write a research report • How to make a presentation • How to prepare a poster	• Performing the statistical analysis of data obtained • Writing the research project report • Preparing an oral presentation • Preparing a poster • Writing a short article (not obligatory)

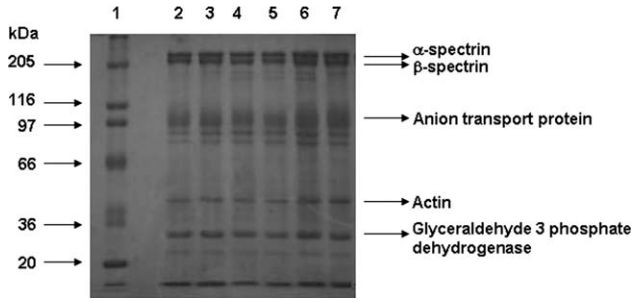

FIG. 1. **Electrophoretic profile of erythrocyte membrane proteins performed by the SSM students**. 7% SDS-PAGE was carried out (10 μg protein/well) and protein bands were stained with Coomassie blue. Lane 1: molecular mass standard; Lane 2–4: samples obtained from patients; Lane 5–7: samples obtained from controls.

students selected this SSM. Basic information related to erythrocyte membrane proteins and hereditary spherocytosis, as well as SDS-PAGE was given to the SSM students and this SSM was converted to a mini-research project [8]. The research plan included searching of the literature related to protein defects in "Hereditary Spherocytosis," structuring the experimental design, application of a mini-project to the ethical comittee, collection and storage of samples, preparation of erythrocyte membranes from whole blood [9], optimization of SDS-PAGE technique [10], application of the samples, and evaluation of data. The SDS-PAGE gels obtained by the students are shown in Fig. 1. The ratio between β-spectrin and anion transport protein was calculated by using densitometry. It was reported that the decrease of this ratio to lower than 0.97 was an indicator of spectrin deficiency [11]. By the realization of the "SSM work plan" and "research plan," this module facilitated the attainment of the objectives within the scheduled time, and a motivation was achieved for both the mentors and the students. The student feedback results are given in Table III which includes the three wet-lab basic laboratory mini-research SSMs.

Effect of Activated Protein C (APC) on Monocytic Differentiation In Vitro—Two-second year medical students selected this SSM [12]. The work plan was structured in three parts (Table II): 1) An introduction to scientific methodology and basic knowledge of cell biology, intracellular signaling pathways involved in cell proliferation and differentiation, and diseases related to these pathways [13], and cell culture methods. 2) Preparation and implementation of experimental laboratory work. 3) Evaluation of data and, oral and written presentation of results. The practical work encompassed culturing of THP-1 (monocytic leukemia cell line), preincubation of the cells with APC, addition of 1 ng/mL phorbol 12-myristate 13-acetate (PMA) (to induce differentiation), using dimethyl sulfoxide (DMSO) for vehicle; and performing the experiments according to the experimental design (Fig. 2). As can be seen from the microscopic investigation results (Fig. 3), APC was found not to effect the differentiation of THP-1 cells. Table III shows the student feedback results.

Measurement of Urine Hydroxyproline as a Parameter for Assessing Renal Osteodystrophy in Chronic Renal Failure—Five second-year medical students selected this module [14]. Students were first given basic information related to the mechanisms of chronic renal failure and renal osteodistrophy, evaluation of glomerular filtration rate (clearance), importance of calcium-phosphorus and vitamin D balance as well as the action of parathormone (PTH), and also the methods of measuring the hydroxyproline content in biological samples. The mentor solicited the participation of the students for structuring the mini-research plan. A clinical advisor from the Department of Nephrology was consulted at this stage. Patients ($n = 10$) with chronic renal failure from the Nephrology Department in Dokuz Eylül University Hospital were enrolled in this SSM after informed consent had been obtained. The control group ($n = 10$) was formed from healthy volunteers, who were handled by the medical students. The 24-hour urine

TABLE III
Results of written questionnaire applied to second-year students who have participated at the wet-lab mini-research special study modules

	SSM-1[a] Score		SSM-2[b] Score		SSM-3[c] Score	
Skills development	1-2-3 (%)	4-5 (%)	1-2-3 (%)	4-5 (%)	1-2-3 (%)	4-5 (%)
Med-line search	–	100	–	100	–	100
Use of the internet	–	100	–	100	–	100
Use of resources in English	20	80	–	100	20	80
Read a scientific article	20	80	–	100	20	80
Reach full-text articles	–	100	–	100	–	100
Make a research plan	–	100	–	100	–	100
Use a computer program	–	100	–	100	–	100
Collect data	–	100	–	100	–	100
Use basic laboratory techniques	–	100	–	100	–	100
Make a table	–	100	–	100	–	100
Make a graph	–	100	–	100	–	100
Prepare a scientific article	20	80	–	100	20	80
Prepare an oral presentation	–	100	–	100	–	100

Scores: 1: minimum and 5: maximum. Scores 1-2-3 and scores 4-5 are grouped together. Results are given in percentages of students in the SSM group.

[a] SSM-1: Comparison of erythrocyte membrane protein patterns in hereditary spherocytosis and healthy controls using sodium dodecyl sulfate-polyacrylamide gel electrophoresis (SDS-PAGE) technique ($n = 5$).

[b] SSM-2: Effect of activated protein C (APC) on monocytic differentiation *in vitro* ($n = 2$).

[c] SSM-3: Measurement of urine hydroxyproline as a parameter for assessing renal osteodystrophy in chronic renal failure ($n = 5$).

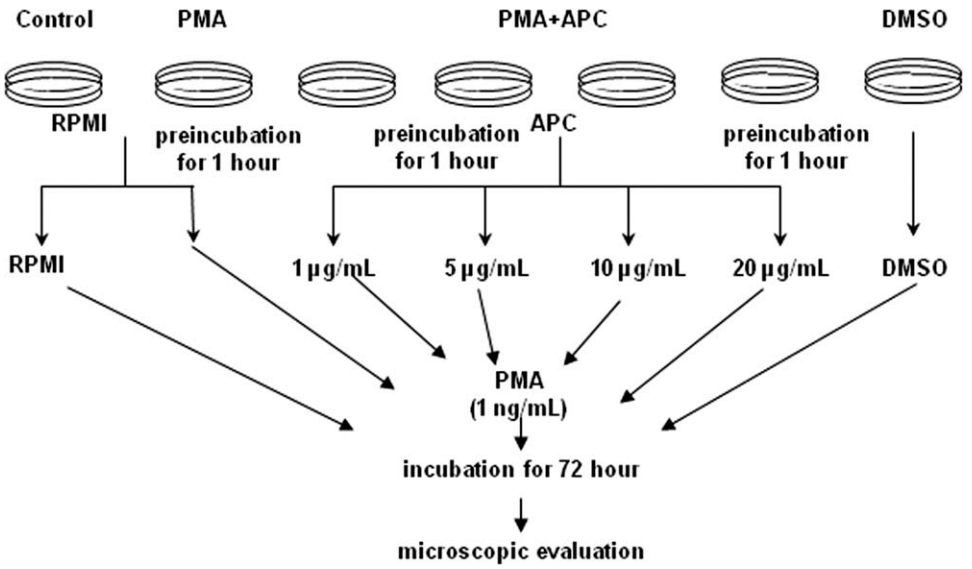

FIG. 2. **Experimental design of the special study module on "Effect of activated protein C (APC) on monocytic differentiation in vitro."**

samples were collected from the patients and stored at −80 °C before the assays. Hydroxyproline excretion in samples was measured by using the spectrophotometric method of Reddy *et al*. [15]. The levels of hydroxyproline in the samples were calculated from the standard calibration curve (Fig. 4). Results of the laboratory work have shown that the level of urine hydroxyproline was significantly higher in the chronic renal failure patients (3.21 µg/mL ± 1.43 µg/mL) compared with the healthy controls (1.53 µg/mL ± 0.52 µg/mL) ($p = 0.001$) (Fig. 5). The student feedback results are given in Table III. From the general evaluation of the questionnaires filled-out by the students of the three modules, it can be observed that in general the students were happy with the skills they have acquired, though there was a bit of difficulty reading and writing scientific articles.

Educational Mini-Research SSMs Involving Preparation of a Student Laboratory Practical

Preparation of a Student Laboratory Practical on the Activation of a Digestive Enzyme, Chymotrypsinogen to Chymotrypsin, in an "In Vitro" Enzyme Analysis Model—The aim of this SSM for second-year medical students was to develop a "practical" for first-year medical students to teach the characteristics of these enzymes (mainly, the digestive enzymes) [16]. This SSM had both "educational research" and "basic laboratory work" objectives. Six second-year students participated in this SSM. The research plan of the SSM involved the standardization of the method, the preparation of a laboratory practical for the first-year medical students, the application of this practical to first-year students as a pilot study, with the SSM second-year students as "tutors," getting the feedback, evaluation of the data, and presentation of the SSM results.

Laboratory experiment—The laboratory experiment to be developed into a student laboratory practical involved showing, using spectrophotometry, that chymotrypsinogen is converted to chymotrypsin by the proteolytic enzyme "trypsin."

In the set-up, three conditions were designed, all using the same substrate, *N*-succinyl-L-phenyalanine p-nitroanilide, which is specific for chymotrypsin:

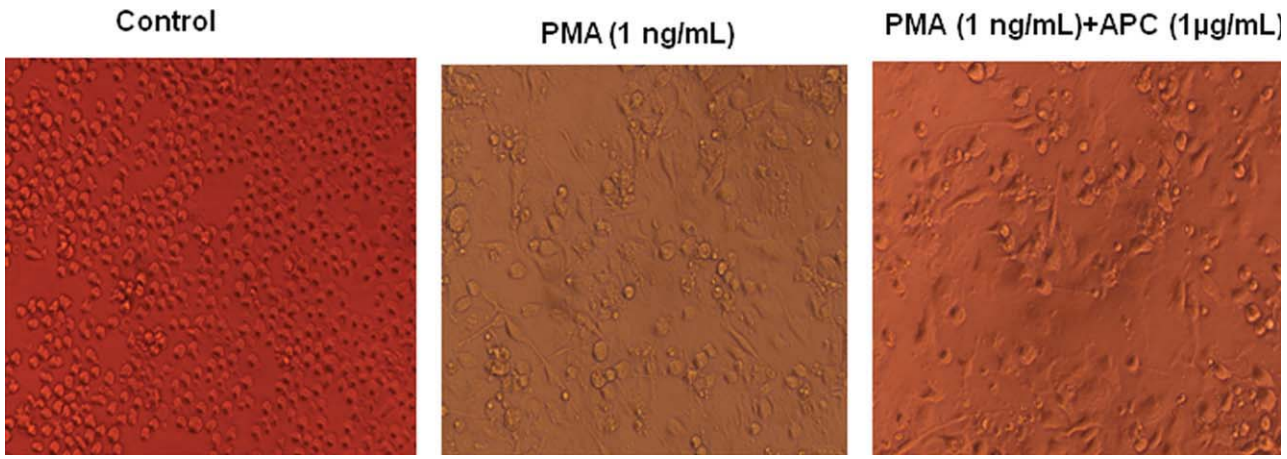

FIG. 3. **Microscopic images of THP-1 cells (phase contrast: 40 X)**. Control: cells were not treated with any agent. PMA: cells were treated with phorbol 12-myristate 13-acetate. PMA + APC: cells preincubated with APC were treated with PMA.

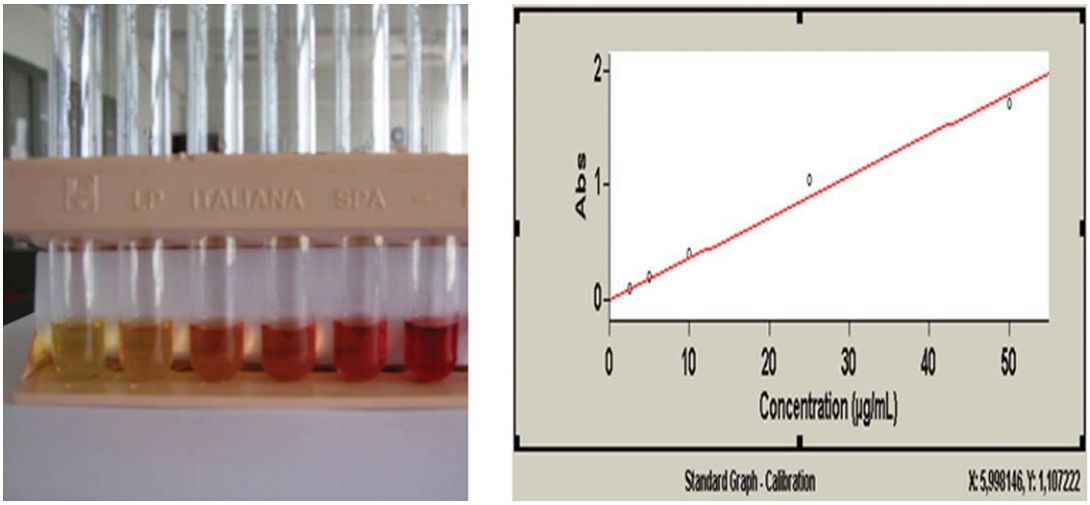

FIG. 4. **Preparation and construction of the hydroxyproline standard calibration curve by the students**. L-hydroxyproline was used as standard in range from 2.5 µg/mL to 50 µg/mL.

1. The chymotrypsinogen converted to chymotrypsin was used as enzyme.
2. Chymotrypsinogen itself was used as enzyme.
3. Pure trypsin was used as enzyme.

As expected, 1) set-up 1 representing the active chymotrypsin gave the highest activity with its substrate; 2) set-up 2 representing the "zymogen" form, gave low activity; 3) set-up 3 representing an enzyme (trypsin) which does not have any specificity for the substrate, gave no activity.

As can be seen from the above description, students not only studied experimentally the activation of a digestive enzyme, but also had the chance to discuss the basic terminology and concepts of enzymology.

In the following step, this experiment was written in a "laboratory practical" format to be assayed on year-1 students.

Next, the pilot study was organized to test this laboratory practical:

A volunteer group of 20 first-year students was included into this study. Six professors acted as observers during the application of the pilot study. The second-year SSM students acted as "tutors," each having a group of 3–4 first-year students.

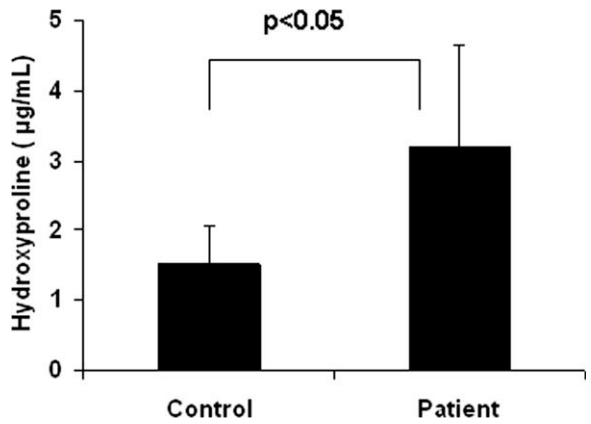

FIG. 5. **The level of hydroxyproline in patient and control groups.** Data presented are the mean ± S.D. of $n = 3$ experiments.

At the end of the practical, questionnaires were completed by 19 volunteer first-year students and the four professors and, evaluated separately. The evaluation consisted of six parameters, which were (*a*) clarity of goals, (*b*) clear and satisfactory explanation, (*c*) sufficiency of time, (*d*) sufficiency of equipment, (*e*) effectiveness of experiment, and (*f*) usefulness of discussion. The evaluation was based on scores ranging from 5 (very good) to 1 (very poor). The scores of 5 and 4 were accepted as successful (Table IV). Although the student group was small, they seemed to judge the practical very active and satisfactory. The students found that the activity was student-centered and facilitated learning. The possibility of using the spectrophotometers individually proved to be very useful. The organizers (convener and mentors) of the SSM rated this SSM as successful in the following ways:

TABLE IV
Results of written questionnaire applied to first-year medical students who have participated as volunteers in the pilot study for the two educational research SSMs

	SSM-4[a] Score		SSM-5[b] Score	
Skill I evaluated item	1-2-3 (%)	4-5 (%)	1-2-3 (%)	4-5 (%)
Clarity of the objectives	–	100	–	100
Clear and satisfactory explanation	–	100	–	89.5
Sufficiency of time	16	84	5.3	94.7
Sufficiency of equipment	–	80	–	94.7
Effectiveness of the experiment	–	100	–	100
Usefulness of the discussion	–	100		100

Second year students acted as tutors.

Scores: 1: minimum and 5: maximum. Scores 1-2-3 and scores 4-5 are grouped together. Results are given in percentages of volunteer students in the SSM group.

[a] SSM-4: Preparation of a student laboratory practical on the activation of a digestive enzyme, chymotrypsinogen to chymotrypsin, in an "*in vitro*" enzyme analysis model ($n = 19$).

[b] SSM-5: Preparation of a student laboratory practical on a lactate dehydrogenase (LDH) enzyme model ($n = 19$).

1. It fulfilled the aims set out at the beginning for the second-year students (including introduction to educational research as well as practical laboratory work).
2. The results of this pilot study would bring new aspects and provide new perspectives to biochemical practicals in medical schools.

Preparation of a Student Laboratory Practical on a Lactate Dehydrogenase (LDH) Enzyme Model—Seven second-year medical students in Dokuz Eylül University School of Medicine selected this SSM [7]. The "research plan" was structured through the discussion of the students with the mentors, as follows:

1. further searching of the LDH determination methods through databases;
2. standardization of a selected LDH determination method (spectrophotometric-UV) [17] within the laboratory conditions;
3. preparation of a laboratory practical manual for prospective students;
4. application of a pilot study on a voluntary first-year medical student group (20–25 students);
5. getting oral and written feedback from the volunteer students; as well as from professors as observers;
6. preparation of an oral and written presentation on results and outcomes of the SSM.

A volunteer group of 20 first-year students was included in the pilot study. Four professors acted as observers during the application of the laboratory practical. The feed-back forms were completed by 19 of the volunteer students. The evaluation consisted of six parameters (Table IV).

It can be seen that in both of the SSMs, where students were not only engaged in practical laboratory work but also participated in a mini-research project to test a newly designed laboratory practical (on students 1 year younger than themselves), they are satisfied with the activity. In the oral feedback session, some of the SSM students expressed their feelings as: "We learned how to do experiments"; "It was fun to actively participate"; "We felt like teachers." Some also agreed "it was a bit long and tiring." However, the results of the questionnaires show that in this type of SSM, students also felt (as with the basic laboratory mini-research SSMs), the least satisfaction, with the acquisition of skills in use of resources in English. In addition, some expressed that they did not gain adequate skills on making a table or a graph.

The above two SSMs were also evaluated by the second-year SSM students. Table V shows the results of written questionnaires applied to second-year medical students who participated as tutors in the pilot study for the two educational research SSMs.

TABLE V
Results of written questionnaires applied to second-year medical students who have participated as tutors in the pilot study for the two educational research SSMs

	SSM-4[a] Score		SSM-5[b] Score	
Skills development	1-2-3 (%)	4-5 (%)	1-2-3 (%)	4-5 (%)
Med-line search	16.7	83.3	16.7	83.3
Use of the internet	–	100	14.2	85.8
Use of resources in English	33.3	66.6	28.6	71.4
Read a scientific article	16.7	83.3	–	100
Reach full-text articles	16.7	83.3	–	100
Make a research plan	16.7	83.3	–	100
Use a computor program	16.7	83.3	28.6	71.4
Collect data	16.7	83.3	16.7	83.3
Use basic laboratory techniques	16.7	83.3	–	100
Make a table	33.3	66.6	16.7	83.3
Make a graph	33.3	66.6	40.0	60.0
Prepare a scientific article	16.7	83.3	14.2	85.8
Prepare an oral presentation	–	100	–	100

Scores: 1: minimum and 5: maximum. Scores 1-2-3 and scores 4-5 are grouped together. Results are given in percentages of students in the group.
[a] SSM-4: Preparation of a student laboratory practical on the activation of a digestive enzyme, chymotrypsinogen to chymotrypsin, in an "*in vitro*" enzyme analysis model ($n = 6$).
[b] SSM-5: Preparation of a student laboratory practical on a lactate dehydrogenase (LDH) enzyme model ($n = 7$).

DISCUSSION

If learning means creating a change in the way that students think, the way they approach and solve problems and make conclusions, then new education strategies are definitely needed [18].

SSMs were introduced by "Tomorrow's Doctors" [1] to allow students to study, in depth, areas that they are particularly interested in, beyond the requirements of the core curriculum. In Dokuz Eylül University School of Medicine, SSMs are educational activities that provide the students with an environment in which to practice independent study and self-education, to learn and practice the basic principles of scientific methodology, and to develop presentational skills during the first 3 years of medical school. Forty to fifty SSMs have been designed as clinical, laboratory research or social responsibility SSMs for around 150 second-year medical students each year during the years 2002–2010. Between 2004 and 2010, only 16 wet-lab SSMs were organized from R-LAB. It should be noted that financial support for many of the laboratory research SSMs comes from the funding of the projects of the SSM convenors/mentors, and not directly for the SSM, which is a challenging factor for the wet-lab SSMs in the undergraduate education. In line with this observation, we feel that the main limitation of our work is the number of students (2–7) in the SSMs. However, each of these SSMs demands a great deal of thought, dedication, and time management. They need to be "tailored" according to the needs and interests of the students and the interests and experience of the convenors/mentors. Moreover, we have not encountered in the educational literature, a project involving a more extensive review of laboratory SSMs.

Although the general aim and organization of the SSMs discussed in this article are similar, it can be easily observed that the practice may vary depending on the subject of the particular SSM as well as the preferences

of the SSM convenors. It is, in fact, within the scope of the SSM philosophy to offer medical students a variety of subjects as well as different ways of treating these subjects and to allow for flexibility.

In this article, we described wet-lab SSMs and discussed the laboratory as well as the pedagogical perspectives. Two types can readily be identified: "Basic laboratory mini-research SSMs" and "Educational mini-research SSMs involving laboratory work." This shows the richness that the SSMs have to offer from the educational perspective. The Dokuz Eylül R-LAB model of a wet-lab SSM seems to be original in that, under the umbrella of the PBL curriculum, it incorporates research education, laboratory practical education, and generic skills development—three significant aspects of education—in a sufficiently integrated, student-centered style.

It is interesting to note that various SSM applications have also been operating in the medical schools around the world. The Faculty of Medicine and Health Sciences, University of Malaysia Sarawak, Department of Pediatrics and Health Care has decided to review its curriculum [19]. Regarding the SSMs, which are composed of generic and complementary courses, electives, and additional topics, the following perspective was noted: "the usefulness of these SSMs was discussed at length and the committee decided to retain them; it was agreed that the "Generic and Complementary" SSMs help students to improve their transferable skills. The "electives" provide students an opportunity to pursue their own interests and also to remedy their weaknesses."

It is worth while to point out the following outstanding features of the SSMs treated above:

1. They foster training of research for undergraduate medical students.
2. They introduce students to a laboratory culture and teach basic laboratory skills to the students.
3. They support teamwork and communicational skills.
4. They teach independent learning skills.
5. They introduce students to tutoring and educational research perspective.
6. They teach students how to make oral and written presentations.
7. They reinforce the assessment skills: self- and peer-assessment of the students.

A significant perspective of this work, which merits further discussion, is the practical training aspect, which is integrated with the research perspective. There is a growing emphasis on the planning, methodology, and evaluation of laboratory practicals as components of undergraduate education [18, 20, 21]. Recently, Parra *et al*. have described a novel research-based laboratory course designed to strengthen the research-teaching nexus [22]. There are common points between their 10-week laboratory course of guided research experiments and our eight-month (once a week) wet-lab SSMs described in this manuscript: the experiments are a direct extension of faculty research interests; the research is most often financed by the project budget of the faculty; the experiments are flexible and "hypothesis driven, allowing original research to be conducted," and students often endup publishing in peer-reviewed journals. In addition, both activities support undergraduate research as well as laboratory education. However, there are significant differences: In our model, the student-centered approach is more pronounced; the emphasis on the development of generic skills (team-work, communication skills) is preponderant, ethical issues are sufficiently treated, and extensive oral and written feedback are taken both from the students and the faculty. Thus, students acquire self- and peer-assessment skills. We think that the type of students involved (chemistry versus medical) and the educational system used can partially account for these differences. There is an expanding body of literature discussing the need and the benefit of introducing research in the undergraduate curriculum [23–25]. The students take responsibility for designing their own research plans with minimal facilitation from the module mentors. It is encouraging, exciting, and effective for them. They progress in their independent learning skills. They acquire self- and peer-assesment and oral and written communication skills. They learn how to plan and write a research proposal. They strengthen their literature searching and reading skills. In fact, this is a "student-centered approach" which has been discussed recently in this journal [26].

In summary, we think that the wet-lab SSMs incorporate several pedagogical principles that all innovative educators strive for. They incorporate elements from research-based learning, practical laboratory education, problem-based learning, team-based learning, and project-based learning in an efficient manner.

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