HOW WE TEACH | Classroom and Laboratory Research Projects

An explorative vs. traditional practical course: how to inspire scientific thinking in medical students

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Eckel J, Zavartskaya O, Schüttpelz-Brauns K, Schubert R. An explorative vs. traditional practical course: how to inspire scientific thinking in medical students. Adv Physiol Educ 43: 350–354, 2019; doi:10.1152/advan.00120.2018.—Recently, medical students’ scientific thinking skills have been identified as an important issue in medical education. Scientific thinking cannot be imparted in conventional lectures, but rather requires actively involving students. We modified a practical course in physiology. A study was designed to test whether the new course fosters scientific thinking without impairing the transfer of physiological knowledge. The study group consisted of 226 first-year medical students at the Medical Faculty Mannheim of Heidelberg University. Written consent to participate in the study was obtained from all participants. The group was then randomly divided into two groups (traditional vs. modified course). The subject of both courses was a laboratory experiment in skeletal muscle physiology. In the traditional course, the students addressed topics already presented in lectures. In the modified course, students dealt with the same topics as in the traditional course, but the experiment was expanded to include one issue not taught before. When working on this issue, the students were instructed in scientific thinking. All participants filled out a questionnaire with 15 multiple-choice questions addressing the physiological subject matter and four open-ended questions addressing the criteria of methodological physiology. Physiological knowledge in both groups did not differ [F(1) = 2.08, P = 0.15], Scores in scientific thinking in the modified course were higher (mean = 4.20, SD = 1.89) than in the traditional course (mean = 2.04, SD = 1.91) with F(1) = 70.69, P < 0.001, η² = 0.24 (large effect). Our study demonstrates that small adjustments to courses in medical education can promote scientific thinking without impairing knowledge transfer.

practical course; scientific thinking; undergraduate medical students

INTRODUCTION

Recently, medical students’ scientific thinking skills have been identified as an important and timely issue in medical education (13, 23). “Scientific thinking encompasses the ability to generate, test, and evaluate hypotheses, theories, and data, and to reflect on this process.” (22). It is part of the “scholar” role in different physician competency frameworks, e.g., the CanMEDS in Canada (14), the framework for undergraduate medical education in the Netherlands (33), and the National Competency-based Catalogue of Learning Objectives for Undergraduate Medical Education in Germany (16). Scientific thinking skills are not only essential for researchers, but also a prerequisite for responsible clinical professionalism. Students need to understand scientific research principles, scholarly inquiry, as well as the role of research evidence in health care. In keeping with this, the German Masterplan Medical Studies 2020 purports to change the study structure and teaching content to strengthen, among other things, scientific thinking. These developments are in accordance with the recommendations of the Scientific Council in Germany and other political organizations (2, 12, 35). Other countries also consider scientific thinking to be an important part of medical training (11). Medical schools employ different methods to engage their students in scholarly undergraduate research activities. These methods include research-driven curricula (6), research electives (18), compulsory research projects for graduation (15), etc. In particular, research methodology and evidence-based medicine have increasingly been introduced as topics in medical education (7, 27, 31). However, German medical schools still strongly emphasize the teaching of knowledge and medical skills and often lack the resources to involve all or even most undergraduates in undergraduate research as part of the course of study. University clinics are obviously challenged when it comes to harmonizing patient care with teaching and research at the highest level in critical economic situations. Hence, students often encounter science in a passive and abstract way, e.g., teachers only show research results or present a scientific method. In 1984, the Association of American Medical Colleges had already called for a change in the teaching of fundamental science to medical students. Volpe (34) stated:

The inability of students to appreciate the scope, meaning, and limitations of science reflects our conventional lecture-oriented curriculum with its emphasis on passive learning. The student’s traditional role is that of a passive note-taker and regurgitator of factual information. What is urgently needed is an educational program in which students become interested in actively knowing, rather than passively believing.

The current situation at medical schools in Germany is not very different; in fact, more than 30 yr later, medical schools still have problems implementing student-centered, active learning.

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Students should not be passively instructed, but should rather actively discuss medical topics and procedures related to their studies, as well as reflect on scientific concepts to encourage metacognition. Studies have shown that small-group activities especially improve enthusiasm and student performance in science courses (29). The goal of the learning process is for students to not just memorize knowledge, but to have the ability to apply it in different contexts and transfer it to new problems in a solution-oriented manner. Inquiry-based learning and teaching is often considered the method of choice in science education. The special effectiveness of actively involving students in courses can also be explained by the fact that different learning channels are addressed so that students can better memorize new learning content (3). For example, Modell and colleagues (25, 26) could show that “. . . laboratory instruction is more effective when students verbalize predic-
tions from their mental models than when they only ‘discover’ the outcome of the experiment.” Furthermore, it is essential to keep in mind that learning promotes learning. This means previous knowledge should be activated to improve associations and links to different memory content. The more knowl-
edge about certain subjects already exists, the better the connectiv-
ity to new learning content. Teachers should make sure that students correctly integrate new knowledge into the exist-
ning knowledge structure (30). Explicit feedback when perform-
ing a task is essential in this context because it allows students to receive information on how well they understand the sub-
ject, what they have done correctly, and what they can do better (8, 17). If necessary, teachers should provide further explana-
tion or repeat the key ideas and concepts to improve student learning (4). These strategies can be summarized in the learn-
ing principles of constructivism (19).

Instead of offering an additional course, we modified an existing practical course in physiology to have a more inter-
active and explorative format based on the principles of con-
structivism (19). Courses in physiology are predestined to transfer basic knowledge as well as scientific thinking because experiments are used to demonstrate physiological processes. During the demonstration of an experiment, it is possible to introduce the steps of scientific methodology as the basis of scientific thinking. Thus, in the explorative course, we inter-
actively taught the research cycle (literature research/theory, research questions/hypothesis, research design, data gathering, interpretation, and communication of results) as the foundation of scientific thinking to show students that research is not an accidental discovery, but rather requires a systematic approach. The implementation of the principles of constructivism in the practical course can be found in Table 1.

We hypothesized that students who attended the modified course would show better performance in a test of scientific thinking than students attending a traditional course, while the transfer of physiological knowledge would not be impaired.

### METHODS

**Sample.** The study group consisted of 226 first-year students at the Medical Faculty Mannheim at Heidelberg University. Written con-
sent for participation in the study was obtained from all partici-
pants. The group was randomly divided into two groups (107 students in the traditional course vs. 119 students in the modified course). The unequal number of students in the groups resulted from the fact that 1) all students had been allocated to 14 sub-
groups at the beginning of their studies with varying numbers of dropouts in the different subgroups due to ex-matriculation or illness; and 2) the allocation of 7 subgroups to each of the 2 study groups was random. Both courses were run in parallel.

We considered the constructive ideas on teaching described in the *INTRODUCTION* when designing the new course: giving students’ exist-
ing ideas attention, encouraging student inquiry, as well as cooper-
ative learning among students, and providing feedback.

The topic of the practical course was the regulation of contractile force in skeletal muscle. The basic learning objectives were the following: students should be able to demonstrate an understanding of 1) the role of the recruitment of motor units and 2) the enhancement of motor nerve action potential frequency (summation, tetanus) for contractile force adjustment. These issues had been presented to the students in lectures before and had been discussed with the students in a seminar before the practical course. In the traditional practical course, the participants addressed the same issues again by studying these responses on themselves. They stimulated the *N. medius* by appropriate protocols (single pulse: pulse duration 0.2 ms, increasing pulse amplitude from 0 to 15 mA in 0.5-mA steps for recruitment of motor units; and double pulse: pulse duration 0.2 ms, pulse amplitude 5 mA higher than the pulse producing the maximum response in the recruitment experiment, stimulation frequency of 1, 2, 5, 10, 15, and 20 Hz for the tetanus) and measured the resulting contraction of the thumb. They accomplished this task independently in groups of two to three students, with the teacher being available to answer questions. Thus, after visiting the lectures and attending the obligatory seminar, i.e., before attending the practical course, they knew the outcome of the experiment. We described this setting as nonexplorative because the students were not exposed to a setting with an unknown outcome.

In the modified practical course, the students attended the same lectures and seminars as described above. Thereafter, they addressed the same basic learning objectives as in the traditional course, but on an intact in vitro mouse skeletal muscle preparation stimulated by appropriate protocols. Because of the nature of the experiments (intact mouse muscle), this was done in a group of ~15 students. Of note, the use of an in vitro model in the modified course was unavoidable to enable the implementation of the subsequent explorative task (see below). However, to account for the difference in the setting when students were addressing the basic learning objectives, a test checking the transfer of basic physiological knowledge was part of the study. In the modified practical course, students were additionally exposed to an active explorative task: they studied how skeletal muscle contrac-
tion depends on the extracellular calcium concentration. This issue had not been taught in detail before. Thus, after attending the lectures and the obligatory seminar, i.e., before attending the practical course, the students did NOT know the outcome of the experiment. We described this setting as explorative because the students were exposed to a setting with an unknown outcome. During this part of the practical course, the teacher coached the students in an interactive setting. In particular, the students hold group discussions to interact-
ively find answers to the following questions based on their prior

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**Table 1. Principles of constructivism on which the practical course was based**

<table>
<thead>
<tr>
<th>Principle</th>
<th>How It Was Implemented in the Course</th>
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<tbody>
<tr>
<td>Authentic task</td>
<td>A real experiment was conducted.</td>
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<tr>
<td>Knowledge construction</td>
<td>Students constructed the required knowledge about scientific inquiry based on their prior knowledge. Teacher functioned as moderator.</td>
</tr>
<tr>
<td>Experiential construction</td>
<td>Students conducted the experiment in small groups.</td>
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<tr>
<td>Evaluation</td>
<td>The course finished with a multiple-choice examination.</td>
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knowledge obtained in lectures or reading textbooks: What do you know about the role of extracellular calcium in skeletal muscle contraction? What do you expect to happen to contractile force when extracellular calcium is removed? How would you remove extracellular calcium in the real experiment? How do you explain the observations made? Thus only the procedure of the experiment and not the outcome of the explorative task were discussed. During the discussion, the teacher summarized the contributions of the students and emphasized the biological variability and measurement uncertainty to demonstrate the complexity of real experiments.

**Material.** Due to the lack of tests to measure scientific thinking at this basic level, scientific thinking was explored with the following four open-ended questions. 1) You are interested in the functionality of skeletal muscle. You want to know (because it is not yet known) how skeletal muscle is influenced by noradrenalin, the transmitter of the sympathetic nervous system. Name four steps that you would take to find this out. 2) How do you operationalize that noradrenalin influences skeletal muscle? 3) Why are repeated measurements necessary in experimental studies? 4) What is the basis of every experimental study? These questions were content valid because they ask for the content students were expected to learn in this course, regardless of whether they attended the traditional or the modified course.

Two raters identified the following content categories as correct answers to the open-ended questions following a rubric: (a) research the literature; (b) propose a hypothesis; (c) plan and conduct the study to test the hypothesis; (d) interpret study results relating to the hypothesis; (e) contraction force; (f) biological and technical variability; (g) model/theory. A maximum test score of seven could be achieved.

**Animals.** The skeletal muscle preparations used in this study were harvested from animals used in scientific projects on the same day as the practical course. As a consequence, no additional animals were used for the purpose of the practical course. The investigation conforms with the U.S. Guide for the Care and Use of Laboratory Animals (8th edition, National Academy of Sciences, 2011). Approval for the use of laboratory animals in these studies was granted by a government committee on animal welfare (I-17/17). The skeletal muscle preparations used in this study were harvested from adult, 8- to 12-wk-old male mice used in other approved scientific projects being carried out on the same day.

**Procedures.** Students passed through two consecutive learning units during a 4-h course on a single day. In the first unit, they either started with the traditional (control group) or the modified (intervention group) course. Both groups were tested after one-half of the time (2 h) allocated for the whole practical course had passed. Afterward, they rotated so that, in the second unit, the control group was exposed to the modified course, and the intervention group to the traditional course. This crossover design was used to avoid unequal treatment of students in the course of study that could deprive them of a potentially effective teaching intervention.

During the test, students were asked to fill out a questionnaire containing the open-ended and multiple-choice questions. Participation was voluntary. Ethical approval for this study was obtained from the Institutional Review Board of the Medical Faculty Mannheim of Heidelberg University (no. 2016–634N-MA).

**Data analysis.** Data analysis was performed using Microsoft Excel 2010 (Microsoft) and GraphPadPrism 7.01 (GraphPad Software). Data are presented as means ± SD and analyzed using weighted Cohen’s 𝑘 and one-way ANOVA; a value of 𝑃 < 0.05 was considered statistically significant. According to Cohen’s (9) guidelines, a small effect size of ANOVA is 0.01, medium effect is 0.059, and a large effect is 0.138. Weighted Cohen’s 𝑘 (10) was used to calculate the interrater reliabilities to ensure reliability of results of the open-ended question (poor agreement: 𝑘 < 0; slight agreement: 𝑘 = 0–0.20; fair agreement: 𝑘 = 0.21–0.40; moderate agreement: 𝑘 = 0.41–0.60; substantial agreement: 0.61–0.80; perfect agreement: 𝑘 = 0.81–1.00).

**RESULTS**

Scores in scientific thinking in the modified course were higher than in the traditional course with 𝐹(1) = 70.69, 𝑃 < 0.001, 𝜎 = 0.24 (large effect) (Fig. 1). An average weighted Cohen’s 𝑘 of 0.67 was determined, i.e., substantial agreement of the two raters was achieved (item 1: 𝑘 = 0.57; item 2: 𝑘 = 1.0; item 3: 𝑘 = 0.79; item 4: 𝑘 = 0.91). Physiological knowledge in both groups did not differ [𝐹(1) = 2.08, 𝑃 = 0.15, 𝜎 = 0.009] (Fig. 2).

**DISCUSSION**

Our study demonstrates that small adjustments to courses in medical education can facilitate scientific thinking without...
imparing knowledge transfer. To examine the effects of our
treatment, we used an intervention control group design with
an objective knowledge measurement. We opted for a cross-
over design with the measurements at the end of the first
treatment to ensure that students in the control group were not
disadvantaged in the end-of-block assessments compared with
the students of the interventional group. We could show that
students learn more about scientific inquiry when they are
actively involved in an explorative experiment in practical
physiology courses compared with an exercise without an
explorative task. This is in accordance with prior studies. For
instance, Kabapinar (20) showed in his study that interactions
in the learning setting can effectively foster the understanding
of ideas and the correction of misconceptions. Khalili et al. (21)
applied constructivist learning principles to project-based
learning in a 4-wk course at school. Students had higher scores
on a post-knowledge test than on the pre-test. Unfortunately,
there was no control group, making it impossible to assume
that the 4-wk course alone had this effect.

Of note, the level of scientific thinking that could be
achieved in our study was still quite low. This could be
explained by the missing inclusion of the scientific inquiry
topics into the end-of-module assessment. Ruey (28) recom-
ments, as a conclusion of her study, the implementation of
suitable assessment methods when applying constructivist in-
structional strategies in online learning courses for adults.
Learning objectives, learning methods and assessment formats
have to be aligned to be effective (5). We propose that aligning
the modified course with an appropriate assessment might
further increase the effect of the course on the level of scientific
thinking. Although active learning can demonstrably enhance
understanding and provoke self-regulated learning, many stu-
dents prefer learning formats that effectively prepare them for
their examinations (32). Therefore, to facilitate scientific think-
ing, it is essential to choose assessment methods that require
the understanding of the taught topics and not only the repro-
duction of knowledge. However, in some cases, examination
rules and regulations will have to be changed before changing the
assessment methods.

We implemented both courses in a laboratory, which is a
setting more likely to facilitate interaction between students
and teachers, as Mikeska et al. (24) showed in their study. They
observed a large difference (according to Cohen’s d) between
88 video-type laboratory and 88 video-type nonlaboratory
sessions, with more student-directed as well as more teacher-
directed activities and more support for self-directed learning in
the laboratory sessions.

Abrahams and Millar (1) showed that practical courses, in
their case part of 25 “typical” science lessons in English
secondary schools, quite often do not foster scientific inquiry.
Teachers focused much more on theoretical knowledge about
scientific ideas than on the understanding of scientific inquiry
as a process. It is, therefore, important that medical schools
give teachers the opportunity to learn about active learning
methods, discuss with experts about how to apply them in their
courses, and have the time to modify these courses. This could
be achieved through individual training or, as in our study, by
an educational team that supports the projects.

Limitations. A fully randomized assignment of the partici-
pants to the experimental groups was not possible because we
conducted the experiment in regular teaching sessions. Never-
thless, neither the study participants nor the raters knew about
the respective group assignment (control group, test group).
Furthermore, the interrater reliability of the first item for
testing scientific thinking was low. The horizon of expectations
for this item should be sharpened. Nevertheless, this limitation
is derogated through the large learning effect that we could
demonstrate with our intervention.

Conclusion. We could show that an explorative format is
superior for learning scientific thinking in courses on physi-
ology without impairing knowledge transfer. Experiments are
already used to demonstrate physiological processes in these
courses so that little effort is needed to achieve these learning
effects.

DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the authors.

AUTHOR CONTRIBUTIONS

J.E., K.S.-B., and R.S. conceived and designed research; J.E. and K.S.-B.
analyzed data; J.E., K.S.-B., and R.S. interpreted results of experiments; J.E.,
O.Z., K.S.-B., and R.S. edited and revised manuscript; J.E., O.Z., K.S.-B.,
and R.S. approved final version of manuscript; O.Z. and R.S. performed experi-
ments; O.Z. and R.S. prepared figures.

REFERENCES

1. Abrahams I, Millar R. Does practical work really work? A study of the
effectiveness of practical work as a teaching and learning method in
2. Arbeitsgemeinschaft der Wissenschaftlichen Medizinischen Fachge-
ellschaften. AWMF-Stellungnahme: Förderung der Wissenschaftlichen Me-
dizin Schon in der Studentenschaft Ausbildung [AWMF Statement: Promotion of
Scientific Medicine Already in Student Training]. Frankfurt am Main, Germany: AWMF, 2008.
3. Atkinson RC, Shiffrin RM. Human memory: a proposed system and its
control processes. In: Psychology of Learning and Motivation, edited by
4. Augustin M. How to learn effectively in medical school: test yourself,
5. Biggs J Enhancing teaching through constructive alignment. High Educ
6. Boyer Commission on Educating Undergraduates in the Research
University. Reinventing Undergraduate Education: A Blueprint for America’s Research Universities. Stony Brook, NY: State University of New
York, 2008.
7. Bradley P, Nordheim L, De La Harpe D, Innvar S, Thompson C. A
systematic review of qualitative literature on educational interventions for
evidence-based practice. Learn Health Soc Care 4: 89–109, 2005. doi:
8. Brookhart SM. A theoretical framework for the role of classroom assess-
ment in motivating student effort and achievement. Appl Meas Educ 10:
9. Cohen J. Eta-squared and partial eta-squared in fixed factor ANOVA
10. Cohen J. Weighted kappa: nominal scale agreement with provision for
11. Cumming A, Ross M. The Tuning Project for Medicine—learning out-
comes for undergraduate medical education in Europe. Med Teach 29:
12. Deutsche Forschungsgemeinschaft. Empfehlungen der Senatskommiss-
ion für Klinische Forschung—Strukturierung der Wissenschaftlichen Ausbildung
für Medizinerinnen und Mediziner [Recommendations of the Senate Commis-
ッション for Clinical Research—Structuring of Scientific Training for Physicians].
13. Duggan E, Doran K, O’Flynn S, O’ Tuathailhagh CM. Providing research
opportunities for medical students: challenges and opportuni-

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