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

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Eckel J, Zavaritskaya 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 scientific methodology. 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 \( F(1) = 70.69, P < 0.001, \eta^2 = 0.24 \) (large effect). Our study demonstrates that small adjustments to courses in medical education can promote scientific thinking without impairing knowledge transfer.

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.
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 predictions 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 knowledge about certain subjects already exists, the better the connectivity to new learning content. Teachers should make sure that students correctly integrate new knowledge into the existing knowledge structure (30). Explicit feedback when performing a task is essential in this context because it allows students to receive information on how well they understand the subject, what they have done correctly, and what they can do better (8, 17). If necessary, teachers should provide further explanation or repeat the key ideas and concepts to improve student learning (4). These strategies can be summarized in the learning principles of constructivism (19).

Instead of offering an additional course, we modified an existing practical course in physiology to have a more interactive and explorative format based on the principles of constructivism (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 interactively 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 consent for participation in the study was obtained from all participants. 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-

| Principle | How It Was Implemented in the Course |
|-----------|--------------------------------------|
| Authentic task | A real experiment was conducted. |
| Knowledge construction | Students constructed the required knowledge about scientific inquiry based on their prior knowledge. Teacher functioned as moderator. |
| Experiential construction | Students conducted the experiment in small groups. |
| Evaluation | The course finished with a multiple-choice examination. |

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’ existing ideas attention, encouraging student inquiry, as well as cooperative 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. medianus* 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 nonexploratory 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 contraction 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 interactively find answers to the following questions based on their prior
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 (by writing on the blackboard) that the students had performed scientific inquiry by going through the following steps: topic identification, knowledge gap determination, hypotheses development, systematic hypotheses testing, and data interpretation. Thus the steps of scientific inquiry were identified in a joint effort by the students together with the teacher. The teacher’s role was to moderate and summarize the steps. Additional learning objectives for the modified course were to understand biological variability and to develop scientific thinking. Afterwards, one or two students conducted the experiment while all of the other students watched the recording of muscle force that was projected onto a white wall using a projector. The students then discussed and interpreted the results in a group discussion moderated by the teacher. In this context, the teacher also 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 whether they attended the traditional or the modified course.

Data analysis. Data analysis was performed using Microsoft Excel 2010 (Microsoft) and GraphPad Prism 7.01 (GraphPad Software). Data are presented as means ± SD and analyzed using weighted Cohen’s $\kappa$ 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 $\kappa$ (10) was used to calculate the interrater reliabilities to ensure reliability of results of the open-ended question (poor agreement: $\kappa < 0$; slight agreement: $\kappa = 0–0.20$; fair agreement: $\kappa = 0.21–0.40$; moderate agreement: $\kappa = 0.41–0.60$; substantial agreement: $0.61–0.80$; perfect agreement: $\kappa = 0.81–1.00$).

RESULTS

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

DISCUSSION

Our study demonstrates that small adjustments to courses in medical education can facilitate scientific thinking without forms 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).

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 harvested from animals used in other approved scientific projects being carried out on the same day.

![Number of correct answers](http://advan.physiology.org/content/1/2/352/F1.large.jpg)

**Fig. 1.** Scientific thinking test scores in the control (traditional) and test (modified) courses. Values are means ± SD; $n = 107$ in the control and $n = 119$ in the test group. *$P < 0.001$. The 95% confidence interval of difference between means was 1.666–2.664.

![Number of correct answers](http://advan.physiology.org/content/1/2/352/F2.large.jpg)

**Fig. 2.** Physiological knowledge test scores in the control (traditional) and test (modified) courses. Values are means ± SD; $n = 107$ in the control and $n = 119$ in the test group. $P = 0.15$. The 95% confidence interval of difference between means was $-0.1688$ to $+1.092$. 

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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 intervention 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. Khaliq 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) recommends, as a conclusion of her study, the implementation of suitable assessment methods when applying constructivist instructional 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 students prefer learning formats that effectively prepare them for their examinations (32). Therefore, to facilitate scientific thinking, it is essential to choose assessment methods that require the understanding of the taught topics and not only the reproduction 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 participants to the experimental groups was not possible because we conducted the experiment in regular teaching sessions. Nevertheless, 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 physiology 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 experiments; O.Z. and R.S. prepared figures.

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