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Teaching scientific principles in undergraduate medical education – a scoping review on international examples

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Abstract

Background

The constant growth of medical scientific knowledge, stronger calls for evidence based medicine and changing roles of physicians are examples for the relevance of teaching scientific principles in undergraduate medical education. The acquisition of scientific skills is comparably weak in undergraduate medical education. This scoping review addresses the following questions: Which examples on teaching scientific principles in undergraduate medical education can be identified in international literature? What is known regarding their educational success and how can they be integrated into undergraduate medical curricula?

Methods

A systematic scoping review search was conducted in PubMed. Criteria for eligibility were English or German language, publication in a peer-reviewed journal, publication date after 1 st of January 2000 and the publications had to report educational interventions in undergraduate medical education on one of the following basic scientific principles: searching literature, formulating scientific questions, reading and critical appraisal of literature, writing, presentation and understanding of the research process. After full-text screening, 29 studies were included in the analysis.

Results

Educational interventions focused on literature search (N=14), critical appraisal of scientific publications (N=13) and the formulation of scientific questions (N=13). Evaluation data were included in 16 publications. Outcomes included measures of student satisfaction, student knowledge and scientific competence based on tested instruments. Results were quite heterogeneous regarding the success of educational interventions.

Conclusions

Publications in this field of medical education vary considerably regarding reporting of results and inclusion of evaluation data, making a comprehensive analysis of the educational interventions a difficult task. Nevertheless, some ideas for the implementation of scientific principles in undergraduate medical education can be named. Student knowledge of and student attitude towards scientific principles in medical education can be fostered by integrating different didactic approaches, by including self-study time and by integrating these principles vertically in undergraduate medical curricula along with clinical aspects.

Background

Today physicians are expected to fulfill different roles. Next to being clinical experts they should be scholars, health advocates, communicators, collaborators, leaders and professionals, as it is documented in the six CANMedS roles (1). In this framework the role of the scholar is described as the ability to “[…] maintain and enhance professional activities through ongoing learning, critically evaluate information and its sources and apply this to practice decisions, facilitate the learning of patients, families, students, residents, other health professionals, the public, and others, as appropriate, contribute to the creation, dissemination, application, and translation of new medical knowledge and practices” (1, p. 645).

In traditional medical education, the facilitation of basic knowledge and its clinical application have played major roles so far, while education in science and scientific principles has not been emphasized (2). Some authors point out that scientific principles are rarely taught in comprehensive ways at medical schools (see for example 3,4). This is changing. Internationally a stronger call for Evidence-based Medicine (EbM) and the constant growth of medical knowledge make it almost indisputable to educate medical students in scientific principles (5–8). Future doctors need to learn and understand how to handle and to navigate through increasing information and how to assess quality and relevance (4,9). University education in medicine should enable all students to develop basic scientific understanding regardless of later career choices (10). Medical schools are expected to "[…] equip students with knowledge, skills and habits of mind to integrate new scientific discoveries into their practice […]" (11, p. 1).

A recent systematic review by Stone and colleagues on student attitudes towards research in undergraduate medical education shows that students are interested in and generally have positive attitudes towards research (12). On the other hand, many students do not feel well prepared to handle scientific results or interpret findings (3,10,13). At the same time teachers and medical faculties regard competence in generic scientific skills as highly relevant for medical students. These include the ability to systematically collect information on the current state of research, the critical appraisal of scientific publications as well as presentation and critical discussion of results (14). There seems to be a gap in medical education when medical faculty highly value the role of scientific principles in medical education but students do not feel well prepared in scientific skills.

The understanding and knowledge of fundamental scientific principles is a precondition for the successful integration of EbM in medical education and future everyday medical practice (14). Understanding scientific principles is a universal tool and should be a first step in scientific education (see 4,16). Core ideas of scholarship include experience in literature search, ability to formulate questions, reading and critical appraisal, scientific writing and presentation and a basic understanding of the research process (4,16,17). These core ideas represent basic scientific principles and can be considered as prerequisites in order to fulfill all five steps of EbM (ask clinical questions, aquire evidence, critical appraisal, apply evidence, assess and reflect). To avoid confusion, the term scientific principles in medical education relates to these aforementioned aspects of science. The term basic sciences in medicine is commonly used to address aspects of medical undergraduate education such as basic anatomy or biochemistry and relates to fundamental medical knowledge (18,19).

This scoping review addresses the following questions: Which examples on teaching scientific principles in medical education can be identified in international medical education literature? How can these principles be integrated in undergraduate medical curricula and are educational strategies in teaching basic principles of science successful? By answering these questions, the review is intended to be a helpful tool for readers who are interested in integrating basic principles of science in medical education. There is a need to identify potentially fruitful examples of teaching the scholarly role in medical education and to successfully integrate these into undergraduate medical curricula in order to foster the desired learning outcomes.

There have been reviews on teaching scientific principles in medical education, but regarding the progression and continuing development of medical studies both have to be considered as outdated (17,20).

Methods

A scoping review can be used in order to investigate a body of literature that has not yet been reviewed and which is characterized by a complex and heterogeneous nature (21). "[…]Scoping reviews are an ideal tool to determine the scope or coverage of a body of literature on a given topic and give clear indication of the volume of literature and studies available as well as an overview of its focus" (22, p. 2). It is used to map research findings and literature in a given field. In terms of teaching scientific principles in medical education the scoping review can inform practice (i.e. educators and faculty) about the way teaching has been conducted and organized and what type of evidence can be reported (22). This review is interested in describing concepts of educational interventions on scientific principles in medical education rather than summarizing the evidence and assessing the appropriateness of specific educational interventions. Moreover, terms and definitions in the field of teaching science in medical education are not well established, which is another reason for conducting a scoping review.

Searching for educational interventions on scientific principles in undergraduate medical education cannot be based solely on EbM interventions, as these often include postgraduate training, clinical care and patient-centred approaches that do not necessarily encompass the basic scientific principles named above. On the other hand, science in medicine is a very broad field and it is not clear what kind of evidence can be expected and reported.

The systematic scoping review on current and international examples of teaching basic scientific principles in medical education follows PRISMA guidelines and adheres to AMEE guidelines (6,23).

All publications from January 1st 2000 until May 1st 2019 were included in the search. Earlier reviews on the topic (17,20) were main reasons for time restriction of the search.

As search is restricted to studies and publications in medical education, MEDLINE was selected as main database and PubMed was used as search engine. Additionally, relevant journals in medical education were searched for appropriate publications. These included (in alphabetical order) Academic Medicine, Advances in Health Science Education, BMC Medical Education, Clinical Teacher, Education for Health, GMS Journal for Medical Education, Medical Education, Medical Education Online and Medical Teacher.

Search terms were formulated based on the core ideas of scholarship named above. Search terms used were "medical education", "teaching science", "scholar", "scientific principles", "reading", "writing", "critical appraisal", "evidence" and "research" (see appendix 1 for complete search term). Search was restricted to title and abstract. This search was complemented by MeSH-terms "undergraduate medical education", "medical students" and "research". In this case search can not be restricted to MeSH-terms as these were unspecified for publications regarding the teaching of scientific principles.

In a further step, results of both searches were merged and duplicates removed.

Articles were included if they focused on one of the following scientific principles based on the core ideas of scholarship: searching literature, formulating scientific questions, reading and critical appraisal of literature, writing, presentation and understanding of the research process. Publications were required to report concrete educational examples or educational interventions referring to one of the basic principles of science named above. Studies were excluded if they did not focus on undergraduate medical education and included no example for teaching interventions on scientific principles in undergraduate medical education. Studies that included programs for medical residents or research staff or other medical faculty were not included in the review. Other criteria for exclusion were focus on clinical training, language (neither English nor German) or if the publications were general commentaries and letters to the editors. Titles and abstracts of studies were screened by the two authors for eligibility.

Results

The search in Medline via PubMed resulted in 3264 identified publications. 689 publications were identified through MeSH (Medical Subject Headings) terms via PubMed (including PubMed (601) and PubMed Central (188)). After duplicates were removed, 2784 publications were screened in Title and Abstract. Of those, 242 articles were eligible for full-text analysis (see PRISMA flow chart in Fig. 1).

After a thorough full-text analysis, 25 publications were included. Main reasons for exclusion were reference to basic sciences in medical education such as anatomy or biochemistry, inclusion of medical staff and faculty, postgraduate education, comments or letters to the editors or general a lack of specific examples of educational interventions. Additional hand-search in relevant journals led to the identification of 4 additional publications. Finally, 29 publications were included in this scoping review. In Table 1, an overview and short description of the publications and their educational interventions is presented.

Table 1
Overview and short description of educational interventions on scientific principles

Author and Year	Short description	N (students per year)	Mandatory (Yes / No)	Teaching quantity	Timing of educational intervention (Study year)	Evaluation (Yes / No)[1]
Abali et al. 2014 (35)	Online guided e-journal intervention for reading and critical appraisal of scientific publications; students responded online to determined set of questions	127	Yes	No information; self-directed learning, 1-hour time window to answer questions online	1st	Yes
Aronoff et al. 2010 (33)	Integration of scientific knowledge into medical clerkship in 3rd year medical students; online didactic intervention to facilitate teaching of scientific skills while students participate in clinical clerkships away from their medical faculty; integration of critical appraised topic (CAT)	153	Yes	6 online didactic modules, including mandatory student assignments; modules had to be completed within a given time; in a 2nd step 4 critically appraised topics have to be completed by students	3rd	Yes
Buchberger et al. 2018 (48)	Improve students skills in reading and interpreting medical literature; an evaluation of instruments for assessing quality of studies	167	No	4 classes of 90 minutes each	3rd	Yes

[1]If Yes, see Table 2 for more details

Author and Year	Short description	N (students per year)	Mandatory (Yes / No)	Teaching quantity	Timing of educational intervention (Study year)	Evaluation (Yes / No)[1]
DiGiovanni et al. 2011 (37)	Process of discovery: students gain understanding of clinical and translational research; students create research proposals on specific topics; oral and poster presentation of results	562 (across 6 years)	Yes	2 lecture series (approx. 12 hours) and student research project; project groups are mentored by senior faculty with similar research interests	4th	Yes
Eckel et al. 2017 (14)	Systematic collection of learning objectives regarding scientific competencies at a German medical faculty	No information	Not specified	Not specified	All	No
Ferwana et al. 2012 (25)	Description of a full EbM curriculum at a medical faculty in Saudi Arabia	No information	Yes	3 year PBL curriculum, no information on exact teaching hours	Across 1st to 4th	No
Finkel et al. 2003 (57)	EbM course, asking relevant questions, synthesize knowledge, communicate with patients and families and critically appraise validity of research findings	No information	Yes	4 week curriculum; 50 minutes lecture plus 75 minutes seminar per week;	1st	No

[1]If Yes, see Table 2 for more details

Author and Year	Short description	N (students per year)	Mandatory (Yes / No)	Teaching quantity	Timing of educational intervention (Study year)	Evaluation (Yes / No)[1]
Fleming 2011 (26)	Oxford curriculum, small-group tutorials with students from different subjects; critically appraise evidence, present and discuss findings, write essays and discuss	No information	Yes	Weekly small-group tutorial;	Elective within first three years	No
Heiman et al. 2018 (27)	Description of newly developed medical curriculum; science in medicine and opportunities for student research projects; science in medicine is presented in organ-based modules and include space for repetition and deeper understanding; areas of scholarly concentration (students pursue research projects)	No information	Yes	Science in medicine spans across 2 years	Not specified	No
Holloway 2004 (55)	Description of a course on the basics of EbM (asking questions, searching evidence, critical appraisal, apply, evaluate)	100	Yes	Approx. 25 student contact hours; lectures, small-group seminars, laboratory sessions, workshop	1st and 2nd year, mandatory	Yes

[1]If Yes, see Table 2 for more details

Author and Year	Short description	N (students per year)	Mandatory (Yes / No)	Teaching quantity	Timing of educational intervention (Study year)	Evaluation (Yes / No)[1]
Hosny and Galy 2014 (36)	Teaching EbM in a problem based curriculum; based on clinical scenarios students formulate questions, search evidence, appraise and apply evidence to answer clinical questions	196	Yes	3 month, about 20 student contact hours; interactive lectures and computer-based seminars and tutorials; individual study time	6th	Yes
Idler et al. 2016 (29)	Presentation of an interprofessional summer university program; students form interprofessional tandems, formulate research questions and pursue a scientific project	20	No	90 student contact hours across 2 weeks	Undergraduate medical students	Yes
Ilic et al. 2012 (32)	Ability to formulate questions and effectively search literature; how can these abilities be taught effectively? Randomized controlled trial	121	No	2-hour workshop plus self-directed learning tasks (intervention)	3rd year	Yes

[1]If Yes, see Table 2 for more details

Author and Year	Short description	N (students per year)	Mandatory (Yes / No)	Teaching quantity	Timing of educational intervention (Study year)	Evaluation (Yes / No)[1]
Ilic et al. 2013 (31)	Mixed-methods study including a controlled trial and focus groups on blended learning versus a didactic approach on key concepts of EbM; formulating questions, searching and appraising the evidence, applying the evidence to clinical scenario and short presentation of evidence	61	No	Didactic intervention: 20 hours tutorial sessions (small group tasks and large-group discussions); Blended learning: one-day workshop on concepts of EbM, eight tutorials for student presentation of clinical EbM scenarios; peer-to-peer learning formats	2nd year	Yes
Jabaut et al. 2016 (41)	Case study on the integration of EbM in biochemistry; literature search, selection of studies, critical appraisal and presentation of findings is integrated into teaching of biochemistry; teaching is based on a clinical case	No information	Yes	Not specified	Not specified	No

[1]If Yes, see Table 2 for more details

Author and Year	Short description	N (students per year)	Mandatory (Yes / No)	Teaching quantity	Timing of educational intervention (Study year)	Evaluation (Yes / No)[1]
Laskowitz et al. 2016 (56)	Extensive presentation of the evolution of two scholarly programs on research training for medical students; 3rd year at Duke University School of Medicine; Stanford University integrated a required scholarly concentration, students are able to choose from a variety of scholarly concentration programs	100	Yes	Duke: full study year dedicated to scholarly experience, minimum of 10 months; Stanford: about 12 units of 10–12 teaching hours per student across different study years	1st through 4th year (Stanford); 3rd year (Duke)	No
Marusic et al. 2014 (28)	Presentation of a vertically integrated curriculum on research methodology in medical education; basic principles of science, literature search, statistical analysis, student research project, presentation, writing research reports	No information	Yes	Total of 270 teaching hours per student across 6 years	1st through 6th year, yes	No

[1]If Yes, see Table 2 for more details

Author and Year	Short description	N (students per year)	Mandatory (Yes / No)	Teaching quantity	Timing of educational intervention (Study year)	Evaluation (Yes / No)[1]
Möttönen et al. 2001 (49)	Project of teaching students literature search and the appraisal and use of literature in medical practice; case-based learning approach includes self-directed problem-solving: students have 1 week to answer predesigned questionnaire, based on a patient case and to present findings	92	Yes	One week of self-directed learning based on presentation of patient case in group session;	Not specified	Yes
Moßhammer et al. 2011 (51)	Integrating a research task into students experience in general practice; a conceptual model is presented; including development of a research question, development of a research design, preparation of staff in general practice, observation of student progress by physicians, data collection and analysis	140	Yes	Not specified; small-group courses	5th year	No

[1]If Yes, see Table 2 for more details

Author and Year	Short description	N (students per year)	Mandatory (Yes / No)	Teaching quantity	Timing of educational intervention (Study year)	Evaluation (Yes / No)[1]
Rees et al. 2014 (40)	Description of a peer-teaching project in EbM; UK National Institute for Health and Care Excellence (NICE) champions; presentation of EbM principles and effective search strategies; students formulate questions and search literature	No information	No	1-day workshop; small-group tutorials	1st through 3rd year; part of a vertically integrated curriculum	Yes
Sastre et al. 2011 (24)	Development, implementation and evaluation of a workshop on teaching literature searching skills; formulating clinical questions, development of a search strategy, appraisal of the literature found	98 students	No	3 hour workshop;	3rd year	Yes

[1]If Yes, see Table 2 for more details

Author and Year	Short description	N (students per year)	Mandatory (Yes / No)	Teaching quantity	Timing of educational intervention (Study year)	Evaluation (Yes / No)[1]
Schor et al. 2005 (39)	Presentation of the scholarly project initiative at the University of Pittsburgh School of Medicine; structured courses on scientific skills and research, foster critical and analytical thinking, provide mentorship, teach presentation skills, self-directed learning, scientific writing, research presentation	25 (pilot)	No (pilot)	Not specified	1st -4th year, yes	No
Stockler et al. 2009 (58)	Presentation of evidence abstracted from research literature to solve real people ´s problems (PEARLS); short presentation on evidence regarding problems encountered in clinical attachment	> 2000 across several years	Yes	3 hours of tutorials	3rd year	No
Tamariz et al. 2017 (30)	Description and evaluation of an adapted research curriculum; team-based curricular intervention; formulating research questions, literature search, statistical analysis, scientific writing	50	No	16 hours workshop	undergraduate	Yes

[1]If Yes, see Table 2 for more details

Author and Year	Short description	N (students per year)	Mandatory (Yes / No)	Teaching quantity	Timing of educational intervention (Study year)	Evaluation (Yes / No)[1]
Tamim et al. 2009 (59)	Implementing EbM in undergraduate medical education; students are introduced to research methods and design, literature search, scientific writing and applying for research grants; in later stages of curriculum, scientific principles are integrated into organ- and disease-specific modules	No information (all 1st year students)	Yes	16 weeks;	1st through 3rd year, yes	No
Widyahening et al. 2012 (34)	Evaluation of a module on medical research at three different universities; lectures on research design, literature search, data analysis, group discussions and presentations, scientific writing; small-group assignment to develop an evidence-based case report based on patient care	526 students at three medical schools	Yes	6 week curriculum	Between 3rd and 6th year	Yes

[1]If Yes, see Table 2 for more details

Author and Year	Short description	N (students per year)	Mandatory (Yes / No)	Teaching quantity	Timing of educational intervention (Study year)	Evaluation (Yes / No)[1]
Zier and Stagnaro-Green 2001 (60)	Introducing medical students to research and promoting student research activities; presentation and discussion of Office of Student Research Opportunities (OSRO); OSRO advises students, organizes mentoring program, research activities such as the research day and research funding for students	No information	No	Not specified	1st and 2nd year	No
Zier and Coplit 2009 (50)	Individual scholarly project and independent research experience (INSPIRE); students develop a research question, close mentoring of students, presentation of research area, presentation of results (research day), writing skills, developing a poster, in-depth feedback by peers and mentors	4 (pilot)	No	12-week curriculum (pilot)	4th year	Yes

[1]If Yes, see Table 2 for more details

Author and Year	Short description	N (students per year)	Mandatory (Yes / No)	Teaching quantity	Timing of educational intervention (Study year)	Evaluation (Yes / No)[1]
Zier et al. 2012 (61)	Presentation of a research training program for medical students; research projects are integrated early in medical curriculum, encouraging self-directed learning and understanding of clinical research in patient care; distinct programs: patient-oriented research, training and leadership (PORTAL), fellows as mentors experience (FAME), summer research scholars program, scholarly year	15	No	Not specified	Across all years, yes	Yes

[1]If Yes, see Table 2 for more details

A wide range of teaching interventions was found. Most of the publications included interventions on literature search (N = 14), critical appraisal of scientific publications (N = 13) and the formulation of scientific questions (N = 13). Presenting scientific results (N = 10) and student research projects (N = 10) were also part of publications identified in this review. Teaching interventions varied lengthwise, from three hours of workshop (24) to full-grown vertically integrated study programs (25–28). Educational strategies included up to 270 teaching hours across 6 study years dedicated to teaching scientific principles and EbM in medical education (28). Description of the educational interventions varied from very specific to global and broad. Specific descriptions of interventions were found when the program included few teaching hours and was designed for very specific reason, while broader and global descriptions were found for full study programs.

A majority of educational programs was mandatory (N = 16). Three publications presented elective summer schools developed for students with interest in research and scientific projects (16,29,30)

Timing of educational interventions was most often between 1st and 3rd study year. In three of the identified curricular interventions teaching of science is spread across more than three study years, as for example in the full study program on EbM described by Marusic (28).

Not all publications included evaluation data. Data regarding outcomes of the educational intervention or indicators of successful implementation of the educational strategy were lacking in 13 studies (see Tables 1 and 2). Evaluation data were included in 16 publications (see Table 2). Outcomes included measures of student satisfaction, pre- and post-measurement of student knowledge, measures of scientific competence based on tested instruments and randomized trials testing different standards of educational interventions (see for example 31,32). Results were quite heterogeneous: some studies showed improvement in student competencies regarding basic principles of science (see for example 29,30,33,34), some were able to identify higher competencies in intervention groups (but no improvement over time, see for example 24,32,35,36), while others did not find any sort of higher or improved competencies through their educational intervention (see for example 31,37).

Table 2

Summary of evaluation of educational interventions

Author and Year	**Outcome**	**Method**	**N**	**Result**	**Global rating***
Abali et al. 2014 (35)	Student satisfaction; factual knowledge and reasoning competency	Evaluation of student feedback; student performance in exam	127	Students find intervention useful; high performance in factual knowledge (more than 95% of students with correct answers); majority of students with high level in reasoning (> 90%)	+
Aronoff et al. 2010 (33)	Student mastery of EBM skills	Pre- and postcourse survey; Fresno test of competence in EBM	139	Postcourse test scores were significantly higher; average improvement of about 10% of the total test score; systematic analysis of student performance in different areas of EBM competencies is presented	+
Buchberger et al. 2018 (48)	Assessment of student knowledgeQuality assessment of studies by student and expert raters	Analysis of agreement rates between student and expert raters; postcourse assessment	167	Agreement rate of 66 to 80% between student and expert ratings; 73% of students rated knowledge gained as weak or low	0
DiGiovanni et al. 2011 (37)	Student evaluation on interest, importance and student understanding of research in medicine	Pre- and postcourse survey; student end-of-course evaluation	562	No significant improvement in student interest in research; Significant improvement in student knowledge and in student understanding of translational science;	0, +
Holloway 2004 (55)	Student evaluation; assessment of student competencies for each EBM-step	5-step evaluation module based on clinical vignette; assessment in two distinct student cohorts;	97	Students' scores in EBM test modules and general satisfaction differed for each EBM step; most students passed test modules successfully; dissatisfaction in open comments	0
Hosny and Ghaly 2014 (36)	Student satisfaction and tutor satisfaction	Web-based postcourse student questionnaire; self-adminstered tutor ques tionnaire	130	High overall student and tutor satisfaction (> 80%); students found practical training of EBM very helpful	+
Idler et al. 2016 (29)	Assessment of student knowledge and competencies in science and interprofessional work	Pre- and postcourse questionnaire; assessment of student satisfaction at the end of the course	21	Significant improvement in student knowledge, scientific and interprofessional competencies; high satisfaction of students with the programme	+, +

*Global rating: 0 = no differences or improvement after educational intervention; + = positive differences or improvement through educational intervention;

Author and Year	Outcome	Method	N	Result	Global rating*
Ilic et al. 2012 (32)	Student literature searching competencies; student self-perceived competency in EbM	Assessment of competencies in both intervention and control group (Fresno tool); postcourse Clinical Effectiveness and Evidence-based Practice questionnaire	121	No significant differences between intervention and control group regarding competencies; Students of the intervention group rated their confidence in formulating clinical questions and awareness of information resources as higher	0, +
Ilic et al. 2013 (31)	Students´ competency in EbM, rating of student perception of intervention type	Controlled trial; two groups: blended learning approach vs regular tutorial sessions; Berlin tool for EBM competencies in both groups	61	No significant differences regarding EBM competencies; students in blended learning approach had a higher confidence in critical appraisal of studies	+
Möttönen et al. 2001 (49)	Student use of information sources and satisfaction	Postcourse survey, final exam and assessment of information retrieval	92	Main information sources are textbooks, followed by Medline search instruments; high overall student satisfaction	+
Rees et al. 2014 (40)	Students´ confidence in literature search and use of different EBM resources	Pre- and postcourse survey	191	Students confidence in literature search was higher after the intervention (difference not statistically tested); in postcourse survey students stated more often to use EBM guidelines and textbooks as main information resources;	+, +
Sastre et al. 2011 (24)	Students´ attitudes towards literature search, use of resources and student knowledge of clinical question formation	One pre- and two postcourse surveys; second postcourse survey 8–12 weeks after intervention	100	Significantly more positive attitudes towards EBM and literature search in postcourse assessment; stronger confidence in using EBM resources in postcourse surveys	+, +
Tamariz et al. 2017 (30)	Students´ knowledge and perception of research competence	Pre- and postcourse survey; knowledge as percentage of correct answers to a validated survey	50	Knowledge and perceived competence significantly increase after intervention;	+, +

*Global rating: 0 = no differences or improvement after educational intervention; + = positive differences or improvement through educational intervention;

Author and Year	Outcome	Method	N	Result	Global rating*
Widyahening et al. 2012 (34)	Students´ knowledge, attitude, application and future use of evidence-based medicine teaching	Pre- and postcourse survey; assessment of knowledge and attitude regarding evidence-based teaching and learning (11 items)	526	Knowledge of EBM and attitude towards EBM significantly increase in two out of three medical schools under study	+, +
Zier and Coplit 2009 (50)	Student satisfaction	Post-course assessment (4 items)	4	Students report increasing likelihood to pursue a research project, better understanding of medical and translational research	0
Zier et al. 2012 (61)	Student satisfaction	Post-course assessment (4 items)	15	Students report increasing likelihood to pursue a research project, better understanding of medical and translational research	0
*Global rating: 0 = no differences or improvement after educational intervention; + = positive differences or improvement through educational intervention;					

Discussion

Goal of this review was to present a scoping and practical review on reported approaches of implementing scientific principles in medical education, beneficial for interested curriculum planers and faculties for planning future educational interventions regarding the topic. Based on a thorough scoping review, 29 publications describing educational interventions on scientific principles in medical education were identified. These interventions varied regarding their timing in medical studies (1st through 6th year), their scope and volume (from single course to full study programs), their integration in local medical curricula (vertical vs. horizontal integration, mandatory vs. voluntary programs) and their teaching interventions (diverse didactic elements). A majority of educational interventions was mandatory. Evaluation data or evidence regarding the successful integration of the interventions into undergraduate medical curricula was included in only 16 of 29 identified publications. Introduction into literature search, question formulation and the critical appraisal were the scientific principles most commonly found (see also 38). Only few educational projects described aspects of scientific writing or composition of scientific manuscripts (26,39).

What can be learned from this scoping review? When looking at the educational interventions that included substantial evaluation (pre- and postcourse measures or control-group setting) and which showed positive effects regarding outcomes such as students' knowledge or attitude, some common characteristics of these interventions can be identified. Students acceptance of scientific principles in medical education and students practice of scientific skills such as literature search can be fostered by integrating different didactic approaches, such as peer-to-peer teaching, blended learning or virtual patient cases (29,31,40). Accordingly, these diverse didactic formats should be integrated when planning medical curricula, if suitable. For example small group exercises, with students working together in order to understand and critically analyze a scientific paper or publication, support collaboration with only minimal intervention by faculty (see for example 35). Self-study time and the possibility to practice skills such as literature search or critical appraisal are essential for students to develop an understanding of evidence in medicine and to adopt these skills (26,31,37,40,41). Educational interventions should plan sufficient time for self-practice so that students achieve a sense of mastering of relevant tools or databases (24,40). Integrating digital resources and demonstrating their use and relevance for patient care has also been shown to be a promising way, especially when students have the opportunity to integrate their theoretical knowledge into real-life cases (24,31,40). By doing so, scientific principles and research can be linked to practical interventions (24). This includes question formulation based on clinical problems or medical information as well as integrating a literature search and the critical appraisal into patient settings such as bed-side teaching.

Quite a number of studies in this review integrate teaching of scientific principles in basic and medical skills. However, such an approach needs scholars and faculty willing to accentuate scientific skills within their respective medical curricula. Based on a general overview of different curricula at medical schools participating in the project “Undergraduate Medical Education for the 21st Century”, Mahoney and colleagues identified potential threads and opportunities of curricular reform processes, especially regarding integration of scientific principles and EbM (42). Two important preconditions for vertical integration of scientific competencies and EbM are leadership and identification with research. Integration of scientific principles such as formulating research questions, searching and appraising evidence should be integrated into regular existing curricular courses, such as biochemistry or others. Integration into existing courses might help to overcome faculty skepticism, potentially better than lone standing lectures and classes that are added to already crowded medical curricula (42).

Educational interventions should not only focus on extending students’ knowledge on scientific principles, but also on changing students´ attitudes towards them. Students who adapt an understanding and a positive attitude towards these skills are more likely to integrate them in their future medical practice. As changing attitudes might be a goal that needs a longer period of time, vertical curricular integration of scientific principles in medical education appears most promising. This is addressed in the hierarchy of evidence based medicine teaching (43). Most evidence supports the notion of interactive learning, with integration of EbM teaching into clinical teaching. Examples of successful interactive integration can be found in this review (33,41). Compared to knowledge, attitudes are harder to assess. A possible form of assessing such soft skills can be student portfolio. Portfolio enables faculty to document the development of learning objectives such as the ability of critical thinking and attitudes towards EbM which are not easily covered by standard evaluations or written exams (27).

Integration of scientific principles in bedside teaching is possible if web-based information resources are accessible and if teaching staff is well trained (see (33,44,45). Motivation for self-directed learning of students can be triggered by handouts, resources such as critically appraised topics (CAT) or abstracts or short presentations that integrate a clinical case. Structured feedback on the process and results should be given by teachers and instructors.

The development of scientific curricula in existing medical study programs is an ongoing process. Often, different aspects of scientific principles have been taught within existing educational programs but little effort has been invested in linking these educational parts into a vertically integrated scientific curriculum. Vertical integration of scientific principles allows faculty to lay the basics in early study years and to build up on these aspects in the forthcoming years of the program, allowing students to develop skills step-by-step. This process can be fostered by curricular mapping or curricular inventory (see for example 14). A modular integration of scientific skills enables students to draw connections to clinical care and to experience its clinical relevance, as presented in this review. By doing so, integration of scientific principles does not necessarily lead to a higher amount of teaching hours per student in an already crowded medical curriculum (33,42,46).

Since an early review of Green on graduate medical education training and evidence-based medicine in 1999, the importance of scientific principles and evidence in medical education has grown. Green stated that "[…] the teaching of EBM knowledge and skills must move beyond the journal club into the core curriculum" (17, p. 693). Many of the educational interventions presented in this review are integrated into undergraduate curricula on a mandatory basis. Still there is considerable variation regarding course objectives, amount of teaching-time and integration into clinical practice and care.

Limitations

Transmission of findings from international publications is difficult as formal and structural aspects of medical studies vary considerably. Medical students in Canada or USA attain a bachelor degree often before entering medical colleges. This is not the case in most European countries. There is also high variation in international medical curricula (47). On the other hand, international consensus is placed on the scholarly role of medical doctors. There are defined characteristics that are of global relevance (1,15). Therefore, a foundation of scientific principles should be based on internationally comparable outcome frameworks (15).

Reporting strategies of the educational interventions differed substantially. Some studies report precisely, describe the educational intervention and present evaluation data including pre- and post-measures of student knowledge and student attitude (32,34,38,41). Others characterize the intervention briefly and present post-course evaluation data of student satisfaction (35,48–50) or report on the educational intervention without any kind of evaluation (25,28,51). A number of tools for assessing student competencies in EbM have been developed such as the Berlin tool and the Fresno test (52–54), but they are rarely applied in the studies included in this review. Only 16 out of 29 studies included evaluation data, all other publications did not present any measures at all. This makes a comprehensive analysis of the interventions found a difficult task. Further research is needed, especially regarding questions of educational strategies, integration and successful implementation into existing curricula. It has been noted before that publication of these trials in medical education, especially with a focus on EbM-interventions, lack accuracy in reporting interventions (54). The classification rubric for evidence-based practice assessment tools in education (CREATE) is a framework which provides recommendations regarding assessment of educational interventions in EBP. Different assessment categories are named, amongst them attitudes, knowledge, skills or benefit to patients. Methods of assessment can range from self-report to performance assessment, activity monitoring up to patient-oriented outcomes (7). A variety of instruments to measure students skills in, knowledge of and attitudes towards EbM exist (38). These instruments should be used to reflect the success of educational interventions on scientific principles.

It remains unclear when and how scientific principles should be addressed in medical education (33,55). Introduction in early undergraduate level can be problematic, as it concurs with other basic and medical skills and students might not develop an understanding of its later clinical relevance (55). In postgraduate level introduction can be problematic as it concurs with clinical care. Nevertheless, the latter has been shown to improve not only skills but also attitudes and behavior regarding EbM (38,54).

Conclusions

This scoping review resulted in a multifaceted and diverse overview on current examples of teaching scientific principles in undergraduate medical education. Based on these results, some practical suggestions on the integration of these principles in existing medical curricula can be named here:

- Integrate scientific principles vertically in the medical curriculum so that forthcoming teaching can build upon basics (27,33,35).
- Plan sufficient amount of time for the teaching of scientific principles (28,56).
- Use diverse didactic elements, but use them in a meaningful way (blended-learning, peer-to-peer approaches, see (27,40,49).
- Give students the opportunity for self-directed learning (26,37,48,55) .
- Evaluate and use feedback and integrate new forms of evaluation, such as attitudes towards scientific principles in student portfolio (27,31,55).
- Give students the opportunity to integrate clinical knowledge and allow for clinical transfer (33,41).

These suggestions support the successful integration of scientific principles in undergraduate medical education. As scientific medical knowledge continually grows, there is a need for structured training in the foundations of medical sciences for future physicians. Only by early practice in scientific principles can undergraduate medical students be enabled to develop scientific skills and practice EbM later on in their medical practice.

Abbreviations

AMEE
Association for Medical Education in Europe
CREATE
Classification rubric for evidence-based practice assessment tools in education
EbM
Evidence based Medicine
MeSH
Medical Subject Headings
PRISMA
Preferred Reporting Items for Systematic Reviews and Meta-Analyses

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

All data generated or analysed during this study is included in this published article [and its supplementary information files].

Competing interests

The authors declare that they have no competing interests.

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Author´s contributions

NV and SK contributed to the design of the study and the scoping review. NV searched the literature. NV and SK screened and analysed the literature. NV drafted the original manuscript and interpreted the findings. SK and NV read and approved the final manuscript for submission.

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Figures

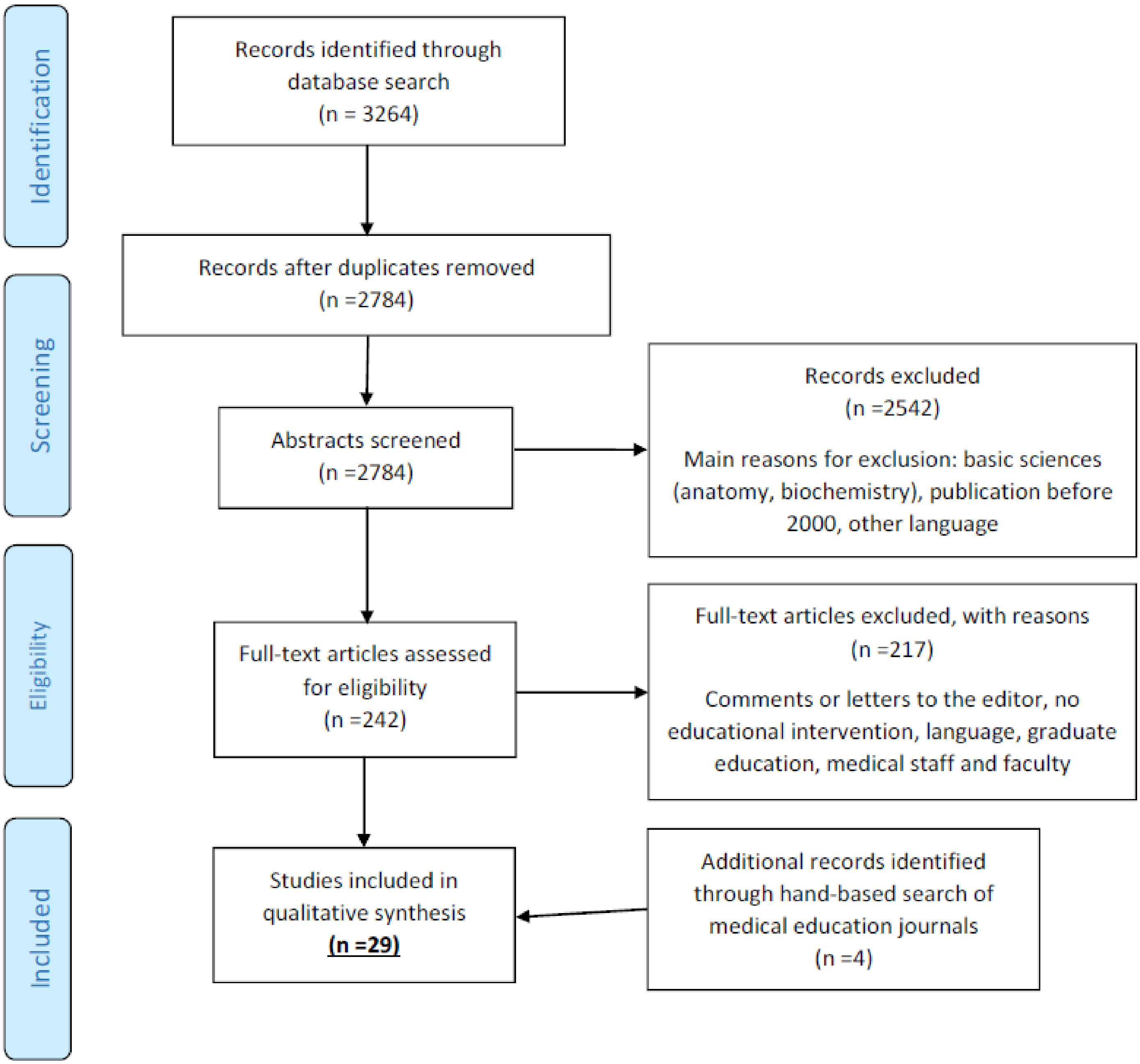

Figure 1

PRISMA flow-chart of the literature selection process

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