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WEB PAPER

Exploring the integration of the biomedical research component in undergraduate medical education

C. VAN SCHRAVENDIJK[1], R. MÄRZ[2] & J. GARCIA-SEOANE[3]

[1]Vrije Universiteit Brussel, Belgium, [2]Medical University of Vienna, Austria, [3]Universidad Complutense, Spain

Abstract

Background: A task force of MEDINE (Thematic Network on Medical Education in Europe) organized a survey of European Medical Schools.

Aim: To investigate the link between education and biomedical research in the medical curriculum questioning university staff responsible for the curriculum.

Method: The survey was online between 10/2006 and 3/2007. Answers pertained to the situation in the academic year 2005/06.

Results: Ninety-one medical schools/faculties in 26 countries participated, but response rates to some questions were lower due to incomplete responses. In undergraduate programs, 3/4 of the schools offer research courses and in 2/3 students can do research themselves. However, in most schools, fewer than 10% students choose this option. In about half the medical schools writing a thesis is a requirement for graduation, although the term "thesis" is interpreted broadly. Color map analysis revealed the link between medical education and biomedical research: about 25% of the medical schools had little emphasis on research in their undergraduate curriculum.

Conclusions: We identified the curriculum elements most suitable to improve the link between medical education and research for the initial stage (years 1–3) as literature search techniques, statistics and epidemiology, while for the advanced stage (years 4–6), writing a thesis was most relevant.

Introduction

Ever since Nobel prizes have been awarded, but particularly in the last six decades, medical knowledge has increased exponentially and medical research has been the driving force. Biomedical sciences became highly interdisciplinary, with biologists, biochemists, physicists and mathematicians participating, each making their own expert contributions to the growth of medical knowledge. In the 90s of the last century, following developments in the USA, several Western European universities responded to this need by looking for research capacity beyond medical students. Programs were established in specific areas of the biomedical sciences, in which non-medical students were educated and trained. Graduates became researchers at the Masters level in 4 or 5 years and the best further matured into independent researchers holding a PhD within less than 10 years after leaving secondary school. In describing these developments and throughout this report, our term "medical research" refers to the broadest possible range of activities aiming at the exploration and acquisition of medical knowledge. This can include bench work based on molecular, cellular or whole animal models, clinical studies, observational studies in the general population or in patient or relatives populations, meta analyzes, qualitative studies based on interviews and focus-group discussions and other modes of investigation.

While biomedical research became an academic discipline on its own, medical education followed a different path.

Practice points

- We recommend that all undergraduate students complete a written assignment as part of their medical degree requirement. The written assignment can be done in any medical subject. It can be a literature review, an epidemiological or clinical study, or it can be based on experimental work. The assignment should include a hypothesis, methodology, critical discussion and bibliography.
- Training in research methodology should be offered in connection with the written assignment.
- Such training should emphasize topics related to clinical/epidemiological investigation design, experimental design, biomedical statistics, search for literature references, surveys, bibliography, databases, etc.
- Undergraduate medical students involved in research should be supported by specific structures and organizations.

Correspondence: Prof. Dr C.F.H. van Schravendijk, Doctoral School of Life Sciences and Medicine, Diabetes Research Center, Unit of Protein Biochemistry, Vrije Universiteit Brussel – GF, Laarbeeklaan 103, B1090 Brussels, Belgium. Tel: 32 2 4774558 – 4549; fax: 32 2 4774515; email: chrisvs@vub.ac.be

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The medical curriculum in Europe, defined by the EC directive as academic studies of six years or 5500 hours of teaching (77/452/EEC), increased its predominant focus on patient-oriented knowledge and care. Although medical doctors are the first to experience the need for more evidence-based knowledge in order to deliver better patient care, their capability to inspire medical research programs, and participate in them, is often limited by lack of training during their studies and by the reduced amount of time available for research even in university hospitals. Yet Nobel prizes in Physiology or Medicine were awarded in the last two decades to 13/46 laureates with an MD degree (28%) suggesting that medical doctors remain crucial for leading-edge growth of medical knowledge and technology. In addition, the current literature in medical education as well as the students themselves underline the need for basic science understanding as a strategy to achieve better patient care (Cooke 2010; Cooke et al. 2010; Frenk et al. 2010; Sigler et al. 2010). It is therefore, important to develop a critical insight into the current link between the medical curriculum and its biomedical research component. This report focuses on the situation of Medical Schools in Europe.

The development of biomedical programs over the last 20 years has shown that science and research capabilities can be taught by introducing science- and research-oriented topics and training activities in the academic curriculum. These can be introductory courses, presented during the first year(s), on what science is and how it works, but also general courses in research-related methodologies, such as biostatistics, bioinformatics, literature search techniques, principles of epidemiology, making graphs, tables and presentations. Practical training can be provided through research projects carried out in a laboratory over various periods of time, followed by written reports or assignments of predefined extent and detail and by a public presentation and defense of the results. Along the way, medical students exposed to research-oriented topics become more skilled in linking basic science with clinical knowledge and they can also develop a (self-)critical attitude and investigative approach when analyzing and discussing their own research observations or those of their peers. However, the time available for such research training is rather limited in the medical curriculum. Thus, the ideas about the need of this research component in the medical curriculum, especially on what should be a minimum exposure for all medical students, will vary. It is therefore, to be expected that different universities will display various degrees of integration of the research component in their compulsory six years basic medical curriculum. In some curricula, highly interested students may choose additional research components as electives, while in other schools this may not be readily possible.

Such differences became apparent in the Tuning in medicine project. TUNING Educational Structures in Europe started in 2000 as a project to link the political objectives of the Bologna Process and at a later stage the Lisbon Strategy to the higher education sector. Over time Tuning has developed into a Process, an approach to (re-)designing, develop, implement, evaluate and enhance quality of first, second and third cycle degree programs (Tuning Project website 2012). The Tuning Project in medicine, led by the University of Edinburgh, began in 2004 under the auspices of the MEDINE Erasmus Thematic Network for Medical Education in Europe, coordinated by the University of Bristol (MEDINE2 is coordinated by University of Edinburgh). The outcomes were expressed as a two-level model, with 12 major "level-1" outcomes, each of these further defined by a set of more detailed "level-2" outcomes. The level-1 outcomes are suitable for implementation as curriculum themes, while the level-2 outcomes can be used to determine discrete items of teaching, learning and assessment (www.tuning-medicine.com).

In this survey, the "ability to apply scientific principles, method and knowledge to medical practice and research" was rated as "Very Important" for undergraduate medical education in Europe. However, it scored the second lowest of the Level-1 learning outcomes. Moreover, corresponding Level-2 learning outcomes were not included in the final report, as they were rated very low compared to other learning outcomes, with a low level of consensus between respondents. These were "Ability to analyze and disseminate experimental results," "Ability to apply statistical analysis to data," "Ability to design research experiments," and "Ability to carry out practical laboratory research procedures." Many respondents apparently felt these were "Not Appropriate" for undergraduate medical training. The Tuning Brochure can be downloaded from www.tuning-medicine.com.

The apparent lack of coherence concerning the place of biomedical research in the undergraduate medical curriculum motivated the MEDINE Task Force 5 on Medical Education and Research to further investigate this heterogeneity in European Medical Schools. The aim of our study was to analyze the link between the research component, as defined above, and medical curricula in EU countries. For this purpose, a separate online survey was employed in which medical schools were approached to provide a fact-based overview of the research component in their medical curriculum for the academic year 2005–06.

Methods

Our survey was not a Tuning survey; it did not ask for ranking the importance of learning outcomes, but explored the status quo of the biomedical research component in the medical curriculum of the responding medical schools in the academic year 2005–06. "Survey Monkey" (Finley 1999) was used to perform the electronic web-based survey. Our recruitment strategy was aimed at the faculty experts within each medical school, with demand for facts rather than for ambitions and responses restricted to one completed questionnaire per school.

A total of 66 questions were asked. The questions and responses can be viewed online in the project report itself (Van Schravendijk et al. 2007). Thirteen questions required a yes/no response; they are listed in Table 1. Other questions had to be answered by selecting from 2 to 7 choices. The remainder were open-ended questions for which textboxes were provided. In addition, many questions were augmented with textboxes, where answers could be supplemented with more detailed information or comments.

Table 1. Survey questions that had to be answered with yes or no.

2	Does your Faculty/Medical School curriculum contain explicit well-defined ''research'' related topics, subjects, disciplines or courses?
4	Does your Faculty/Medical School curriculum contain explicit well-defined ''research'' related topic(s) among compulsory courses for all students?
8	Has your Faculty/Medical School implemented topics in the curriculum related to computer science (using computers and networks, internet applications, at school or at home, etc.)?
10	Has your Faculty/Medical School implemented topics related to experimental- and or clinical/epidemiological investigation design, biomedical statistics, etc.?
12	Has your Faculty/Medical School implemented topics related to search for literature references, surveys, bibliography, databases, etc.?
14	Does your Faculty/Medical School require the preparation of a scientific work in a written form? (building-up, preparing and defending a critical medical review from the literature, composing an epidemiological study, a clinical case study, etc.)?
16	Does your Faculty/Medical School require the presentation of the results of a scientific work? (developing communication skills, e.g. preparation of speech, drawing of tables and figures, posters, oral presentation skills with feedback, etc.)?
20	Are undergraduate (BSc/basic-preclinical) students involved in research?
22	Are undergraduate (MSc/clinical) students involved in research?
24	Are specific structures/organizations established for the undergraduate students who are involved in research?
26	Has the student research-organization its own scientific meeting specially arranged for students?
29	Is the student workload of study programmes at your Faculty/Medical School expressed in ECTS credits?
34	Does your Faculty/Medical School issue a diploma supplement?

Note: The number in the left column identifies the position in the survey. See also Figure 1.

The survey consisted of three parts: undergraduate studies (34 questions), PhD schools (24 questions) and specialty training (eight questions). Here, we report only on part 1, undergraduate studies. All questions pertained to the actual situation in the academic year 2005–06. The survey website was open from 15 October 2006 to 31 March 2007. Individual results are treated confidentially: specific characteristics of schools were not revealed except in a confidential individualized feedback to that school.

Data were analyzed in two ways. First, overall response characteristics were calculated from the Survey Monkey data, using the input of all responding institutions for each question. Second, for a deeper understanding of correlations between responses to the different questions in each institution (the institutional response structure), we used the macro application in Microsoft Office Excel to construct color maps. To generate a comprehensive institutional response structure, responders were only included in this analysis if they had answered at least 50% of the yes/no questions (listed in Table 1). This analysis was therefore done on a subset of 63 institutions, 48 of them identified schools. A map was constructed from the answers to the 13 yes/no questions (Figure 1). Each row corresponds to a question, and each column to the answers of an individual institution to all questions. The color green was assigned to "yes" answers, and the color red to "no". This color code is specified on the right (Figures 1 and 2) or left (Figure 3) of the chart. The columns were then sorted from left to right according to the number of "no" answers of each institution, so that the institutions with more affirmative answers are placed on the left, and the ones with the most negative answers on the right. At the bottom of the chart, four regions depending on the number of "no" or empty answers of each institution were defined, resulting in an "undergraduate research commitment group" classification. Individual responders were classified in one of two overarching groups, with the more committed institutions (with 0–6 "no or empty" answers) in the green area, and the less committed institutions (with 7–13 "no or empty" answers) in the orange and red area. Then, the green group was subdivided into light green for 0–2 "no or empty" answers and dark green for 3–6 "no or empty" answers, and the less committed group was sub-divided into orange for 7–8 "no or empty" answers and red for 9–13 "no or empty" answers. The data of all three sub-studies were analyzed following the same approach.

Frequency histograms were calculated for the green and red groups to identify critical differences in answers. Sensitivity, specificity, positive and negative predictive values (NPVs) were calculated on the basis of affirmative and negative answers; the Fisher Exact Test was used with $p < 0.05$ for significance. The error on averages was calculated as standard error of the mean for n independent determinations.

Results

Response statistics

A total of 113 questionnaires were completed of which 22 were excluded from the analysis. Of these six were useless or empty, 10 were duplicates, four were not from medical schools and two were from non-European schools. Of the 91 included in the analysis, 55 were from identified universities/schools. A list of countries represented in the survey and the number of responding schools as well as the total number of medical schools in each country is provided in Table 2.

Overall response characteristics at the undergraduate level

The majority of the responding universities made an effort to support the involvement of undergraduates in research activities, but almost 1/3 of the schools (22/86) were found not to offer research related topics either in the compulsory or in the elective part of their curriculum. When present, the research related topics were not confined to a particular stage of the curriculum, but rather distributed over the whole period of learning, both in schools with one-cycle (continuous) and two-cycle systems of medical education (Van Schravendijk et al. 2007). The number of responding schools varied per question. Therefore, absolute response rates are given in addition to relative response fractions.

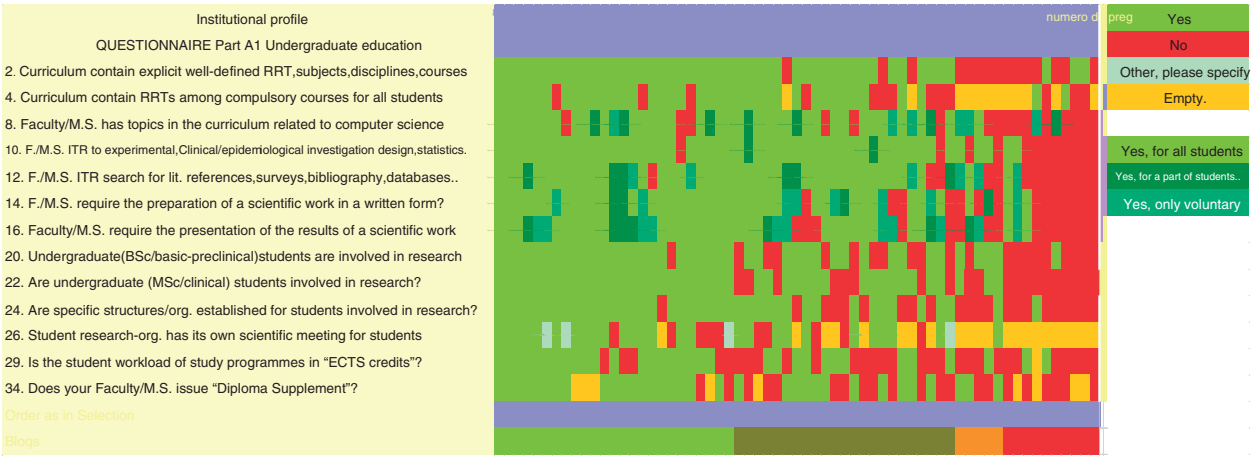

Figure 1. Undergraduate research commitment group classification. The answers to the questionnaire are analyzed in a color chart, drawn from the answers to a selection of 13 of those questions. In the figure, each row corresponds to a question, and each column to the answers of each institution to the items in the questionnaire. We selected the color green for "yes" answers, and the color red for "no" answers. The color code is specified on the right of the color chart. This kind of analysis allows us to see the general outline of the answers to the questionnaire items, even if some of those answers are vague and could be considered as "noise." The analysis includes the answers of 63 institutions. The columns are displayed left to right according to the number of "no" or empty answers of each institution, so that the institutions with more affirmative answers are placed on the left, and the ones with the most negative answers on the right. At the bottom of the chart we selected four regions depending on the number of "no" or empty answers of each institution. A global overlook reveals that 25 out of 63 institutions (40%), shown over the green band, have answered "yes" to most of the 13 questions, which shows they have a great level of commitment to research programs for undergraduate students, whereas there are 10 universities (16%), shown over the red band, with very little to no implementation of research related topics in their curriculum. Over the dark-green band there are 23 institutions, which means that a sum of 76% of universities are over the general green band area, and 24% are over the red and orange area.

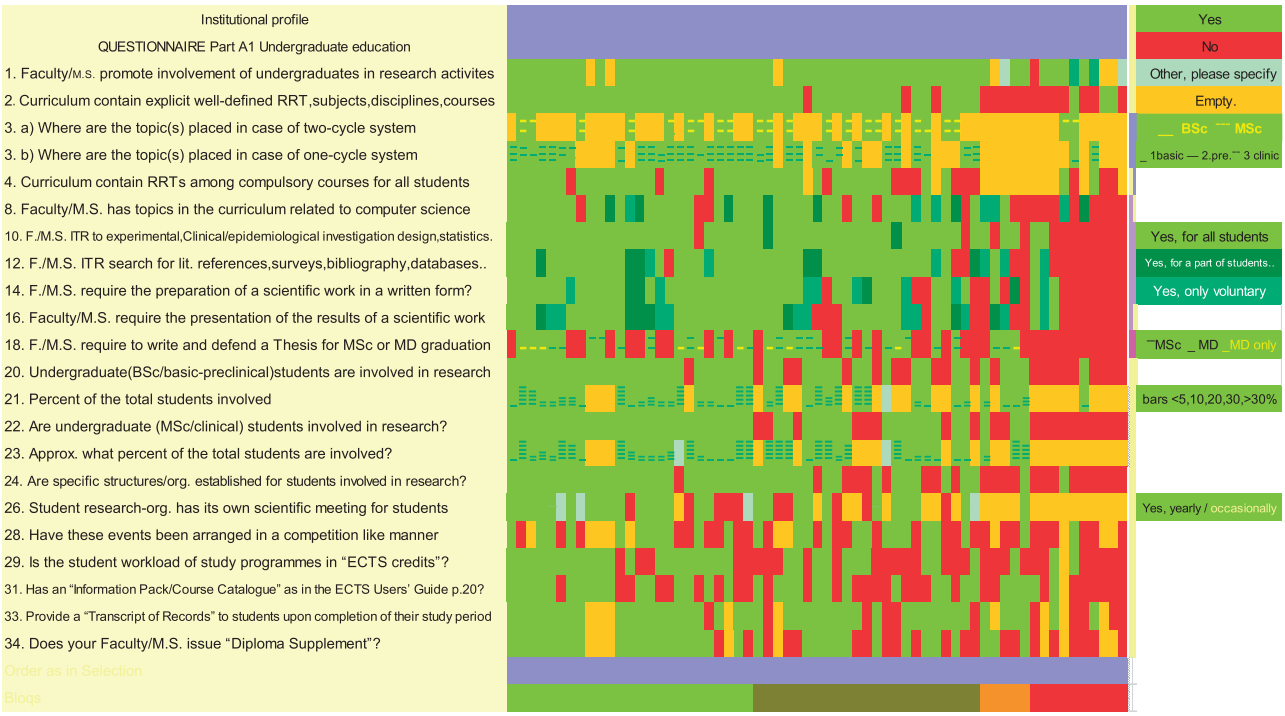

Figure 2. Undergraduate education questionnaire comprehensive color chart. This figure shows the Comprehensive Color Chart for all questions included in the Part A1 of the questionnaire related to link between Undergraduate Education and research, excluding free text commentary items. Color groups line at the bottom of the graph are defined by the Undergraduate Research Commitment Group Classification done with the selected items as shown in the previous figure.

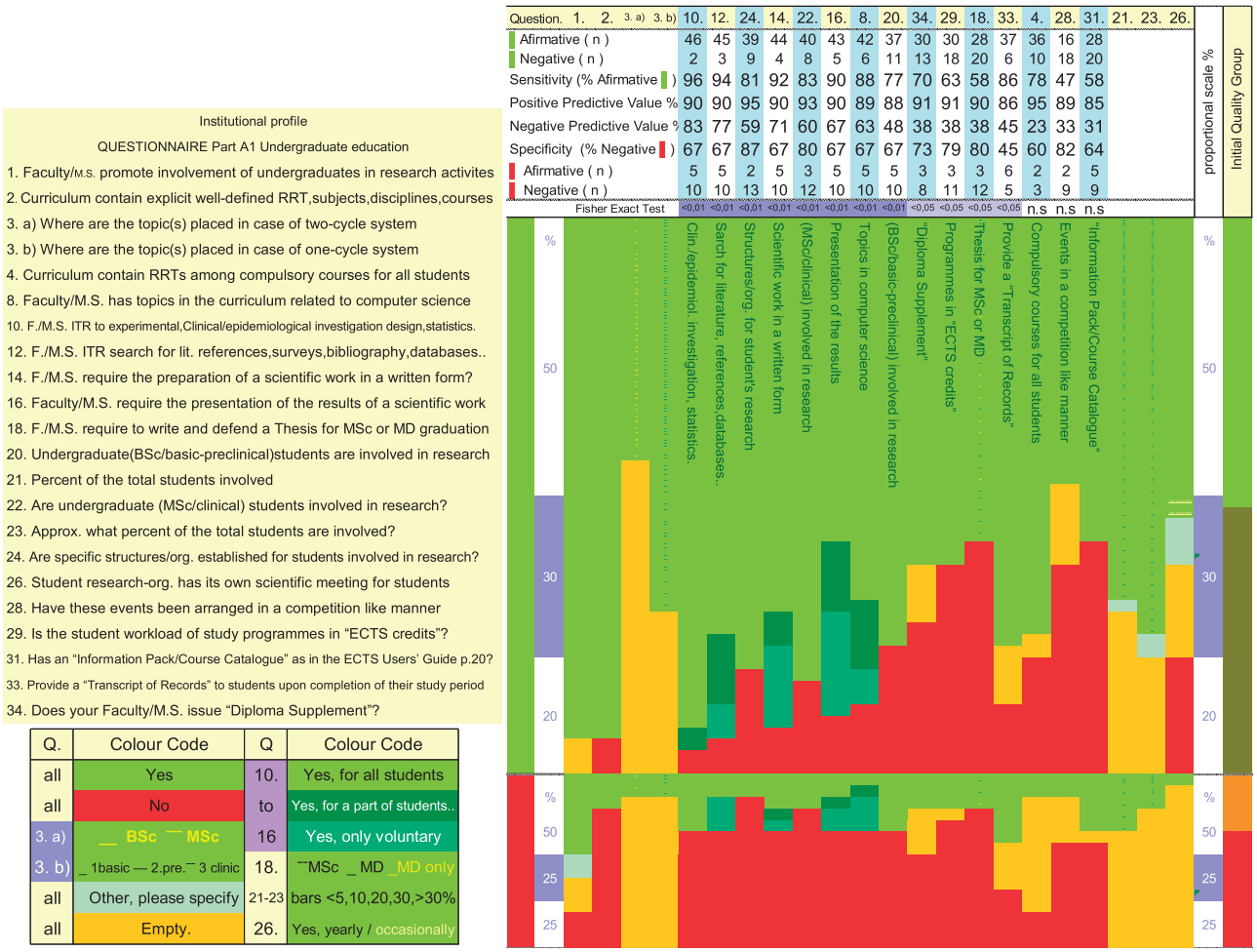

Figure 3. Comparisons between green and red groups. In this figure, we have combined the light green and dark green institutions (right ordinate), combining them in a new joint "green" group (see left ordinate green column), and we have joined the red and orange institutions (right ordinate) in a joint "red" group as well (see left ordinate red column). We analyzed the answers to 15 questionnaire items using the Fisher Exact Test. Eight of these items showed a highly significant ($p < 0.01$) level of differences between both groups; four of them showed a significant level ($p < 0.05$) and the remaining three showed a close level of approximately $p = 0.05$, which indicates that there is a clear difference between both groups in practically every item analyzed. In the graph, we have sorted the columns (i.e. the questions 4–39) left to right from low to high according to the range obtained by the sum Sensitivity, Specificity, Predictive Positive Value (PPV) and NPV. We can see that, for all comparisons, the PPV is greater than the NPV, which indicates that an affirmative (yes) answer is clearly associated with the green group, whereas a negative (no) answer is associated with the red group but not so strong. In other words, there are items in the questionnaire with some negative answers in the green group. The analyzed columns at the leftmost area of the document give us an overview of the main differences between the groups: the institutions in the green group have implemented it, while the institutions in the red group do not. This can be a good indicator of a basic standard where institutions need to focus in order to develop activities that will enable them to go from one group to the other. Training courses on the basic knowledge required for a research project, such as bibliography searches, statistics or epidemiological research design seem to be the first step to take. It is worth noting that the third position in the rank is for question number 24 "Are specific structures/org. established for students involved in research?", followed by questions number 14, 22 and 16, which refer to the development or presentation of scientific work by students, 14 and 16 with a 90% Sensitivity and a 67% Specificity, and 22 with less Sensitivity but more Specificity, while "Writing a thesis for MSc or MD degree" (question number 18) is required by only barely over half of the institutions in the green group and 25% of the universities in the red group showing greater Specificity than Sensitivity (Sensitivity 58% and Specificity 80%), with an NPV of 38%, which indicated that not only the red group institutions gave a negative (no) answer to this item.

Most schools (75%, 64/86) had a range of auxiliary science courses to support scientific activities of students and medical doctors. In 43/59 schools such courses are compulsory. But this leaves about 25% (more than 20 schools) in which students remained devoid of instruction in topics like search techniques for literature references, surveys, bibliography and databases.

Many schools had additional specific support structures for undergraduate students involved in research: 40 out of 61 schools relate that these are present. More than half (24/40)

Table 2. Total number (T) and surveyed number (S) of medical schools for each participating country.

Country	# Medical Schools Surveyed	# Medical Schools Total	Fraction S/T (%)
Austria	1	3	33
Belgium	4	9	44
Bulgaria	1	5	20
Czech Republic	1	7	14
Denmark	2	3	67
Estonia	1	1	100
Finland	2	5	40
France	2	47	4
Germany	4	37	11
Greece	1	7	14
Hungary	2	4	50
Italy	3	33	9
Lithuania (Letland)	1	2	50
Malta	1	1	100
Norway	1	4	25
Poland	2	13	15
Portugal	1	6	17
Russia	1	57	2
Slovakia	2	3	67
Slovenia	1	1	100
Spain	5	31	16
Sweden	3	6	50
Switzerland	1	5	20
The Netherlands	1	8	13
Turkey	3	15	20
UK	8	27	30
SUM	55	340	

Note: Only 55 of the 91 analyzed responses can be mapped to a specific country.

had yearly scientific meetings especially arranged for students. In 18 out of 50 schools (36%) such events have a competitive character.

In about half the medical schools (32/61), writing and defending a thesis is not a formal requirement for graduation (the exact definition of "thesis" varies, see also the discussion). Two out of three schools (41/61) report that undergraduate students at the initial stage (years 1–3) can be involved in research, but this always applies to a minority of students; in the majority of schools (20/38) this fraction is 10% or less. These schools also report that undergraduate students at the advanced stage (years 4–6) are involved in research and here the actual participation is somewhat larger. On the other hand, there seems to be a group of 20–30% of medical schools in which undergraduates (at both stages) do not have any adequate possibilities to get involved in research during their medical studies.

Color map analysis

To analyze our data in more detail, we first examined the responses to the 13 questions, which only allowed yes/no responses (Table 1 and Figure 1). In all cases, a "yes answer" indicated a more research-oriented approach. We analyzed whether the group of responders that answered "no" to these questions belonged consistently to the same set of medical schools. The statistical approach is described in the Methods section; the results are depicted in Figures 1–3.

The analysis includes the answers of 63 institutions. The columns are displayed left to right according to the number of "no" or empty answers of each institution, so that the institutions with more affirmative answers are placed on the left, and the ones with the most negative answers on the right.

At the bottom of the chart, we selected four regions depending on the number of "no" or empty answers of each institution. A global overlook reveals that 25 out of 63 institutions (40%), shown over the green band, have answered "yes" to most of the 13 questions, which shows they have a high level of commitment to research programs for undergraduate students, whereas there are 10 universities (16%), shown over the red band, with very little to no implementation of research related topics in their curriculum. Over the dark-green band there are 23 institutions, which means that a sum of 76% of universities are over the general green band area, and 24% are over the red and orange area. It indicates that in undergraduate education, near 25% of the responding medical schools consistently have little research emphasis in their curriculum.

The Color map for all questions included in the Questionnaire Part A1 Undergraduate level (Figure 2) shows a clear differentiation between committed and less committed schools for the link between education and biomedical research.

Items associated with a strong commitment to research related topics

A statistical analysis of the distribution of the responses among the "green" versus the "red" schools revealed 10 marker questions and their ranking (Table 3 and Figure 3). This identifies items that would place a school in a category with a stronger link to medical research in its curriculum. In the initial stage (years 1–3), these are primarily research methodology related courses, for example in literature search techniques and in statistics and epidemiology. In the advanced stage (years 4–6), graduation on the basis of (amongst others) a scientific text, which can be defined as a thesis was observed to be an important indicator for a more viable link between biomedical research and medical education. Also, the presence of specific organizational and infrastructural support for research students was an indicator of quality in the link between teaching and research (Table 3).

Discussion

Response statistics

The opening page of the survey that provided the data for our study contained a statement assuring confidentiality. Nevertheless 40% of respondents did not reveal their identity. The overall participation counting identified universities was only 16% (55/340) of EU institutions; this fraction increased to 27% when all respondents were taken into account (91/340). While these figures are low, respondents are distributed all over Europe. In eight out of the 26 countries, participation was ≥50%, several of these being new EU member states.

Table 3. Items associated with a strong commitment to research related topics in the undergraduate curriculum.

10	Implementing topics related to experimental- and or clinical/epidemiological investigation design, biomedical statistics, etc.
12	Implementing topics related to search for literature references, surveys, bibliography, databases etc.
24	Introducing specific structures/organizations for undergraduate students that are involved in research.
14	Introducing the requirement for the preparation of a scientific work in a written form (i.e. building-up, preparing and defending a critical medical review from the literature, composing an epidemiological study, a clinical case study etc.).
22	Involvement of undergraduate (MSc/clinical) students in research.
16	Introducing the requirement of a presentation of the results of a scientific work (i.e. developing communication skills, e.g. preparation of a speech, drawing of tables and figures, posters, oral presentation skills with feedback, etc.).
8	Implementation of topics in the curriculum related to computer science (using computers and networks, internet applications, at school or at home, etc.).
20	Involvement of undergraduate (BSc/basic-preclinical) students in research.
34	Introduction, by the Faculty/Medical School, of the diploma supplement.
29	Expression of the student workload of study programmes by the Faculty/Medical School in ECTS credits.
18	Faculty/Medical School require to write and defend a Thesis for MsS or MD graduation.
33	Provide a ''transcript of Records'' to students upon completion of their study period.

Notes: The items are ranked top to bottom according to their importance following the analysis illustrated in Figure 3.
The number of the item relates to the corresponding questions of the survey (see ref. Van Schravendijk et al, 2007). The selection is based on the comparison of the frequency histograms of responses from the committed (green) versus the uncommitted (red) groups as visualized in Figure 3. Ranking of the improvements is based on the p-values obtained for differences between the two groups as tested by the Fisher exact test, with the lowest p value for item 10, all values being $p < 0.05$ and item 10–20 $p < 0.01$. For more detailed information of this analysis, see the legend of Figure 3.

We deliberately approached institutional experts with our survey, but only asked for and accepted one completed questionnaire per institution. We cannot be certain that the answers of each respondent perfectly reflect the factual situation within each of his/her university; indeed, we might have seen considerable variation if more expert responders were included. We know that at least some questionnaires were answered by groups of colleagues, but this was no obligation.

A recent cover story published in Science indicated that science literacy should be taught to students early in their educational development and that reading, writing and oral communication are critical components (Hines et al. 2010). A book which surveyed USA colleges (Pope 2006) argues that successful institutions involve undergraduates in research projects. Among medical educators there are concerns about the low recruitment of medical students for academic careers, leading to shortages of expertize for medical research, but also for academic teaching. Again, the prevailing strategy proposes to ''catch them early'' during the undergraduate years (Roberts 2010).

A striking result of our survey was that only half the medical schools required the writing of a thesis for graduation. Even if a thesis was required, in many cases there was no requirement for original data collection. Thus the exact definition of ''thesis'' varies among different countries and different universities. Writing a thesis is a formal requirement for graduation at the Master level outside of medicine, so it is to be expected that the transition to the two-cycle system, although still debated in the field of medical education (Mirecka 2005; WFME and AMEE 2005; van Schravendijk and Mirecka 2007), implies a thesis. On the other hand, schools that do not have the two-cycle system can also require a thesis for graduation (Van Schravendijk et al. 2007).

A recurrent theme in the literature is that Europe should live up to its own aspirations and increase its competitiveness by improving many aspects of higher education in the field of research, including medical research. It must be a cause for concern that in 25% of medical schools in Europe there is no clear place for research-related topics in the medical curriculum. Improvements are also justified in many of the remaining 75% of schools. Positive figures are coming from several Dutch Medical Schools, where almost 15% of the students had published at least one scientific paper during the last three years of their medical studies. This achievement is based on considerable effort put into scientific education and research training of these students (van Eyk et al. 2010).

Despite these encouraging achievements, major increases of the research component in the undergraduate medical curriculum will be hard to implement, because there is simply not enough time in six years of study to lay a strong foundation in all medical students for a career in biomedical research. Therefore, medical students that stand out among their peers in interest and talent for research should have the option to develop their abilities in this area through electives and a research-oriented study track. Even when such options are available, it is expected that medical researchers with an MD will remain the exception and the majority of researchers in this field will have graduated in the biosciences. This should not prevent medical schools from trying to identify and improve their key activities that shape the interaction between medical education and research, and nurture their medical graduates that want to make a lasting impact on the future of medicine (Ley & Rosenberg 2005).

The survey, upon which this study is based, was carried out six years ago. Positive developments have occurred since then. Several universities have recently initiated lecture chairs specifically dedicated to teach scientific research competencies and research literacy to medical students. We also have indications that a consensus is emerging concerning the integration of the research component in medical undergraduate education. Over the last few years, workshops in the AMEE and IAMSE conferences have been organized on promoting research literacy skills and on defining core competencies for undergraduate medical education. The MEDINE2 project has recently organized a survey and reached an interesting degree of consensus within the network on this issue (data to be published soon). Last but not least, the World

Health Organization has, together with PLoS Medicine, recently launched a thematic action for 2012 entitled "No Health Without Research", which resulted in a large collection of papers that can be reached via the open source channels (see link to PLoS Medicine Collection 2012). All these initiatives and processes fit into the emerging notion that teaching of evidence-based medicine needs to be explicitly supported by a deeper understanding on how medical research could contribute to tomorrow's medicine for patients. Therefore, we expect it is both necessary and possible to define level 2 competences for the "ability to apply scientific principles, method and knowledge to medical practice and research" (www.tuning-medicine.com).

A last word of concern is required for the possible relationship between curriculum quality and the link between biomedical research and the curriculum. While we have presented arguments and literature references underlining the importance of this link, the question whether improving this link would result in better curricula and, subsequently, in better doctors, remains an open one. To better understand this relationship in our own data while maintaining confidentiality, we compared our (light and dark) green universities on the one hand and our (orange and) red universities on the other hand with the overall world university rankings of 2007 according to the Times Higher Education and the Shanghai (ARWU) ranking systems. Among 42 identified universities in the green group, 13 and 12, respectively, classified in the top 200 of these ranking systems, while none of our seven identified (orange and) red universities did. This might suggest that schools with a stronger link between teaching and research actually belong to more prestigious universities, but it remains unclear whether these also produce better medical doctors. We assume that the quality of an inspiring environment of teachers and investigators will remain the critical bottleneck for any medical curriculum to produce doctors motivated to make a difference in shaping tomorrow's medicine (Archer 2007; Neul 2010; Vale 2010). A possible correlation between the strength of the research-teaching link and the publication activities of medical students can be investigated. Such studies should focus on measuring the research output of medical students of the schools that we have ranked in our European survey, using published methodology (van Eyk et al. 2010).

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Notes on contributors

CHRIS VAN SCHRAVENDIJK is the senior professor teaching an introductory course on Scientific Thought in the first Medical Bachelor year and a final Bachelor course on Formulation and Development of a Scientific Hypothesis in the third Bachelor year. He is responsible for the scientific track in the Bachelor of Medicine of the Vrije Universiteit Brussel and he is also Director of the Doctoral School of Life Sciences and Medicine, with more than 250 PhD students.

RICHARD MÄRZ (who publishes as Marz since he started his scientific career in the USA as a biochemist) is active in curriculum development at his own institution and in several countries in eastern and south-eastern Europe. He was responsible for formulating the research component of the medical curriculum of the Medical University of Vienna that went into effect in 2001.

JORGE GARCIA-SEOANE is the Vice Dean for Academic and Teachers of the Faculty of Medicine. He is responsible for the coordination and curriculum planning in the Bachelor and Master of Medicine. He is professor in Physiology in the first and second year and is responsible for the scientific track and investigation work in the end year in the Bachelor and Master of Medicine of the Faculty of Medicine of the "Universidad Complutense de Madrid".

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