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Developing research skills in medical students: AMEE Guide No. 69

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Abstract

This Guide has been written to provide guidance for individuals involved in curriculum design who wish to develop research skills and foster the attributes in medical undergraduates that help develop research. The Guide will provoke debate on an important subject, and although written specifically with undergraduate medical education in mind, we hope that it will be of interest to all those involved with other health professionals' education. Initially, the Guide describes why research skills and its related attributes are important to those pursuing a medical career. It also explores the reasons why research skills and an ethos of research should be instilled into professionals of the future. The Guide also tries to define what these skills and attributes should be for medical students and lays out the case for providing opportunities to develop research expertise in the undergraduate curriculum. Potential methods to encourage the development of research-related attributes are explored as are some suggestions as to how research skills could be taught and assessed within already busy curricula.

This publication also discusses the real and potential barriers to developing research skills in undergraduate students, and suggests strategies to overcome or circumvent these. Whilst we anticipate that this Guide will appeal to all levels of expertise in terms of student research, we hope that, through the use of case studies, we will provide practical advice to those currently developing this area within their curriculum.

Introduction

Concerns have been expressed over the lack of numbers of future doctors wishing to conduct clinical research and the abilities of the 'physician-scientist' to conduct research (Goldstein & Brown 1997; Zemlo et al. 2000; Association of American Medical Colleges (AAMC) 2001; Sung et al. 2003; Cooke et al. 2006). Basic scientific research is expanding, yet the number of clinical academics participating in research is shrinking (Goldstein & Brown, 1997; Zemlo et al., 2000), perhaps reflecting that clinicians are required to choose between performing research or practicing medicine and are finding it increasingly difficult to include both in their careers. The reasons for this appear to be the financial costs of doing both research and clinical practice, the increasing demands and workload of clinical practice and the increasing specialisation and knowledge required for basic scientific research (Goldstein & Brown 1997; Zemlo et al. 2000; AAMC 2001; Sung et al. 2003; Cooke et al. 2006). Such concerns are not restricted to the medical profession; they extend into other vocational subjects such as veterinary medicine. (Selborne 1997). Ensuring the door to research is not closed to future medical professionals requires them to understand the basic skills of research and to have an awareness of a research ethos at an early stage.

The purpose of this Guide is to identify the skills and attributes that medical students require to understand and/or participate in research, and the role that these research skills

Practice points

- Those with responsibility for undergraduate medical programmes as well as medical students themselves need to be made aware that research is an important part of scholarship and professional practice.
- Good doctors needs specific research skills and develop specific research-related attributes. Training in research skills and the development of research attributes is therefore required to ensure that students are competent both as future practitioners and clinical or basic science investigators.
- Explicit and measurable research-related curricular outcomes should be articulated.
- Curricula should be designed with ample opportunity to engage in research. Specifically targeted teaching and learning activities can be used to develop research skills and attributes in undergraduate students. Such opportunities should encourage active involvement and be contextualised within the medical curriculum.
- Independent learning activities are vital to the development of research-orientated and research-aware students. Independent research projects can provide such awareness.
- Anticipating barriers to research teaching linkages and considering ways to deal with them are both important and must be taken into account when developing the undergraduate curriculum.

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play in the curriculum. It is therefore important to consider what is meant by the term research, what is meant by a skill and what is meant by an attribute. In this Guide, research is defined in its broadest sense, not the strict scientific definition of research, which is limited to performing a methodological study to test and prove a hypothesis. Research involves the collection and processing of new information and interpreting these through logic and previous knowledge and experience. For this Guide, research will be viewed as a learning process/ inquiry that involves searching for knowledge by a process of establishing facts, considering new ideas and postulating new theories to update expertise.

A skill is something that can be taught, practiced and mastered and in which an individual can become proficient. An attribute is an attitude, ethos and way of thinking that can be acquired and developed. Although skill and attribute have been viewed as almost synonymous in the recent Enhancement Themes 'Graduate attributes of the 21st Century' and 'Research-Teaching Linkages: Enhancing Graduate attributes' from the Quality Assurance Agency (QAA) for Scotland in the UK (http://www.enhancementthemes.ac.uk/themes/21stCGraduates/) and (http://www.enhancementthemes.ac.uk/themes/ResearchTeaching/default.asp), and although they often develop together, we will regard them as distinct entities for this Guide.

Research skills and attributes are important outcomes of higher education and programmes should permit students to acquire, develop and master these. Furthermore, medical education guidelines may specify that undergraduate medical curricula should have outcomes for the graduate such as the following from the General Medical Council (GMC):

> '*apply to medical practice biomedical scientific principles, method and knowledge*' and also '*apply scientific method and approaches to medical research*' (General Medical Council, GMC 2009).

These two outcomes are defined in the 'The doctor as a scholar and a scientist' domain. In the light of this, we previously attempted to establish which research skills and attributes could and should be outcomes of medical undergraduate programmes irrespective of whether such graduates intended following a research career or not (Laidlaw et al. 2009).

This Guide develops these finding and provides ways to define, develop and overcome barriers to the achievement of these outcomes in a medical curriculum. Case studies will be used throughout the Guide to highlight particular opportunities where research skills can be taught and attributes developed.

It is hoped that this Guide will appeal not only to those at the start of their journey in terms of developing undergraduate research skills, but also to educators and teachers who seek a review of the current debate on research as part of the undergraduate medical and health professions curriculum. The Guide hopes to answer some of these questions and is divided into 3 main components:

- Defining the research skills and the attributes vital to research and why these may be important for future doctors.
- A review of methods to develop research skills and research- related attributes in medical and health professions undergraduates as well as potential ways to assess these skills and attributes.
- Potential barriers to research related training in an already busy curriculum.

What are the relevant research skills and attributes and why are they important for medical practitioners?

Medical undergraduate programmes are elements within the sphere of higher education and must therefore fit institutional requirements; one reason why such training should be incorporated into undergraduate medical education. In Europe, the Bologna Process (http://www.ehea.info/) aims to create a 'European Higher Education Area' of complementary national systems in 47 countries to ensure comparability of higher education qualifications and systems. This process involves the implementation of three levels of a qualification framework across courses with an emphasis on standardised learning outcomes. All level outcomes include aspects of research skills and associated attributes. For example, one of the first level outcomes is that an individual with such a qualification would '*have the ability to gather and interpret relevant data (usually within their field of study) to inform judgments that include reflection on relevant social, scientific or ethical issues*'. http://www.ehea.info/Uploads/qualification/QF-EHEA-May2005.pdf.

Similarly, the Tuning Project (http://www.unideusto.org/tuning/) is a European project which has generated agreed outcomes for medical degree programmes in Europe and although there is no specific requirement to develop practical research skills, two of the level 2 outcomes clearly indicate a need for students to have developed skills related to using evidence to inform practice. The first outcome – '*Apply the principles, skills and knowledge of evidence based medicine*' – requires students to be able to search for and critically appraise current literature and the second – '*The ability to apply scientific principles, method and knowledge to medical practice and research*' – requires students to have a working knowledge of research methodology and practice, and to develop research attributes.

In a survey of experts involved in medical, veterinary and dental curricula design in Scottish and selected English universities, Laidlaw et al. (2009) reported 10 research related skills and attributes that were considered important for a professional either pursuing or not pursuing research as part of their main career. When comparisons were made between the skills and requisite attributes identified for both groups of professionals, the seven highest ranked were found to be common to both (Table 1). This suggests that not only are research-related skills and requisite attributes already likely to be a component of medical undergraduate curricula and therefore not require extra space or time, but they may be missed through the absence of context or the stereotypical method of a silo approach to subject learning.

Table 1. Graduate attributes and skills perceived to be important from a research and professional standpoint for medicine, veterinary and dental surgery. (Laidlaw et al. 2009).

Attribute/skill	Ranking
Inquiring mind/-curiosity	1
Core knowledge	2
Critical appraisal	3
Understanding of the evidence base for professional practice	4
Understanding of ethics and governance	5
Ability to work in a team	6
Ability to communicate	7

This Guide will examine each of the skills and attributes identified by Laidlaw et al. (2009) and provide further evidence of their importance in terms of enabling medical graduates to engage in research activities later in their careers.

Curiosity and an inquiring mind

Doctors should be inquisitive (GMC 2009), constantly keeping up to date with the ever-changing medical literature. In a professional context, an inquiring mind encourages continual professional development. In a research context, it is a key driver of scientific endeavour. The requirement for doctors to be curious has been identified for some time. In 1949, Gibbon wrote *'Of far greater importance than teaching either a fundamental background or a technical skill is the indoctrination of the surgical aspirant with a philosophy. This philosophy is that of the inquiring mind.'* (Gibbon 1949).

In the Association of American Medical Colleges' (AAMC) report on Contemporary Issues in Medicine, the 'Basic Science and Clinical Research' section recognises the need to educate physicians to be inquisitive (AAMC 2001). This was also the highest ranking attribute in Laidlaw et al.'s (2009) study. Curiosity was also identified by medical students, patients, general practitioners, service chiefs and newly qualified doctors as a top ten attribute of a doctor (Rabinowitz et al. 2004). Although Patterson and colleagues in their analysis of job requirements of a physician (Patterson et al. 2008) did not identify a competency domain entitled 'an inquiring mind', their definition of the domain 'conceptual thinking, problem-solving' contained elements that reflect this attribute.

These comments and findings emphasise the role that curiosity plays, not just in doctors wishing to pursue a research career but also in those who wish to work solely in a clinical environment.

A core knowledge

A doctor should have a core of knowledge relating to his/her practice, whilst a researcher should have a core of knowledge relating to their research area. For a clinical investigator, these areas will overlap. Core knowledge allows for quick and accurate decision making in relation to treatment options for patients (GMC 2009). For researchers, it allows them to ask relevant questions and develop new research pathways (Shaw & Green 2002). The GMCs *Tomorrow's Doctors* document states that *'The graduate will be able to apply to medical practice biomedical scientific principles, method and knowledge relating to: anatomy, biochemistry...'* (GMC 2009). A similar sentiment can be found in the AAMC Learning Objectives for Medical Student Education which states students must have '*Knowledge of the normal structure and function of the body (as an intact organism) and of each of its major organ systems'* (AAMC 1998).

Patterson and colleagues (Patterson et al. 2008) found that in their job analysis study, clinical and technical knowledge and expertise was the top skill out of the 14 identified. In a course described by Fishleder (Fishleder et al. 2007), aimed at training physicians, knowledge of the basic and clinical medical science is listed as one of their core competencies. Medical students are also aware of the importance of a core of medical knowledge and rank it as highly desirable. (Rademaker et al. 2007) This evidence shows that core knowledge relating to medicine is required for both professional and research inclusive careers. Governing bodies acknowledge this fact, as do curriculum experts and students. Since all scientific knowledge is underpinned by research the distinction between core knowledge and research knowledge is perhaps unnecessary.

Critical appraisal

Analysis, critical evaluation and synthesis of new information are vital to the ability to practice medicine; they are also the core skills required of researchers (Hay 2004). The appraisal of data, whether these be a patient's laboratory results or experimental results, is essential to setting high professional standards. Evidence- based practice is reliant on the critical appraisal skills of its practitioners (Rosenberg & Donald 1995). The GMC and other regulatory bodies recognise this as a skill in which graduates should show competency (AAMC 2001; GMC 2009). This skill was listed third most useful in the survey of expert opinion by Laidlaw (Laidlaw et al. 2009). It was also recognised in a study by Price et al. (1971) which demonstrated that doctors need to be able to *'seek out, evaluate, analyse, and interpret research, published or clinical data'*. This quote neatly links research to the practice of medicine. Critical appraisal is a skill that medical students have recognised as important (Rademaker et al. 2007) and is explicitly set out in the core competencies for courses designed to develop physician investigators (Fishleder et al. 2007).

Evidence base for professional practice

Evidence based practice is not just acquiring the knowledge of the evidence base but encapsulates an understanding of why an evidence base is required for professional practice and/or research and how it is applied. There must also be an understanding of how the evidence base is acquired. Being able to recognise the relevance and applicability of published research to practice is critical to professionalism (Rosenberg & Donald 1995). The AAMC's 2001 Basic Science and Clinical Research reports that medical students must demonstrate an *'appreciation of the role and importance of clinical research and investigation into the care of patients'* as well as *'an* *appreciation of how the body of medical knowledge is built and advanced'*. These attributes are viewed as vital to clinical competence and are the foundation of evidence based medicine (EBM), an approach which integrates research evidence with clinical expertise to create the best options for patients (Akobeng 2005). The Canadian Medical Education Directives for Specialists advance this by stating that specialists should '*contribute to the development of professional, scientific knowledge'*. Curricula design experts viewed this attribute as the fourth most important attribute for a combined research and professional career (Laidlaw et al. 2009), but Dutch medical students did not view it as so vital, rating it 31st out of 35 competencies (Rademaker et al. 2007).

Ethics and governance

A knowledge and understanding of the ethics and governance of both professional practice and research is also important to practitioners. This allows doctors to practice both clinically and in their research within specified limits, but also to understand the limits placed on others, for example in published research. Informed consent is one key area where an understanding of ethical governance spans both clinical practice and research (Carmen & Joffe 2005). The GMCs Tomorrow's Doctors states that students need to understand the ethical and governance issues relating to medical research and to professional practice (GMC 2009) and similar sentiments are expressed in other curricula guidelines (AAMC 1998; AAMC 2001). The importance of an awareness of ethical issues in professional medical behaviour was also noted by experts in the field (Patterson et al. 2008; Laidlaw et al 2009; Lambe & Bristow 2010) and training courses for physician investigators specifically include ethical and responsible action training within their core competencies (Fishleder et al. 2007). Medical students also identify ethical values as being an important attribute of a good physician (Rademaker et al. 2007; Sehiralti et al. 2010). This evidence supports the role of a comprehensive understanding of ethical issues and the governance of practice and research as being important in undergraduate medical education.

Ability to work in a team

Both medical practice and medical research is generally a team effort. The ability to work well within a team environment is an important skill for clinicians and researchers (Leonard et al. 2004; Kessel & Rosenfield 2008. This evidence is reflected in educational guidelines, for example, the GMC's Tomorrow's Doctors states that a doctor should be able to *'Learn and work effectively within a multi-professional team'* (GMC 2009).

Ability to communicate

Good communication is vital for patient health outcomes (Stewart et al. 2000) and patient satisfaction with their health care (Williams et al. 1998; Griffith et al. 2003). Good communication is also a requirement of a researcher (Shaw & Green 2002). Price et al. (1971) noted that a good physician is: *'able to communicate well in everyday work and relationships (with patients, relatives, assistants, students, colleagues, the public, etc.)'*.

The ability to communicate effectively with patients and colleagues is a skill ranked highly as being important to effective practice (Rabinowitz et al. 2004; Laidlaw et al. 2009; Lambe & Bristow 2010). Likewise, in a job analysis study by Patterson (Patterson et al. 2008) the importance of effective communication was highlighted by a top three ranking in all the specialities studied.

The importance of communication in both clinical practice and medical research is highlighted by the AAMC's Medical School Objectives report (AAMC 2001) where they state that medical schools must ensure that graduates should have demonstrated that they have *'the ability to communicate effectively with a clinical researcher, either in a clinical or consult context'*. Finally, medical students also rate communicative ability as being a highly ranked skill for effective doctors (Sehiralti et al. 2010).

In summary, it would seem that there are several core skills and attributes that are highly relevant for medical undergraduates who wish to pursue a purely practice-oriented career. These same core skills and attributes are equally important to develop in those who wish to conduct research in their future practice or combine it with clinical practice. This means the 'extra' space need not be found within a curriculum for their teaching or development as they should be viewed as part of the core curriculum for *all* undergraduates.

The rest of this Guide will focus on how to develop these skills and requisite attributes in all learners, within an undergraduate curriculum and discuss the issues and possible barriers that may arise.

How to develop research skills and associated attributes in graduates

Strategies for developing the research skills and associated attributes can be achieved at two different levels; within the main curriculum and through specific extra-curricular courses:

(a) By adopting a philosophy that integrates skills development into the curriculum design
and
(b) Through the introduction of specific methodologies/tasks/activities to achieve the individual skills and develop the attributes at different stages and times within the curriculum.

By using these two approaches it is possible for students to gain the skills and develop the ethos to allow them to practice with an evidence- based understanding of that practice and apply their understanding to research situations. This section will describe examples from the literature in which research skills and associated attributes can be developed in medical students.

At the Curriculum level

Self-directed and independent learning. Adopting a student-centred approach in the curriculum as well as adopting a similar approach in teaching methodology can facilitate self-directed and independent learning skills/learning strategies, including the important qualities of curiosity and critical appraisal, amongst others. These methods may include project-based learning, case-based learning, and inquiry – based learning. One, presently popular way is the use of problem-based learning (PBL) methodology within the curriculum design. PBL is a student–centred method of learning originally pioneered at McMaster University; (for a recent review see Schmidt et al. 2011). A practical Guide to the use of this methodology is provided by AMEE Guide No 15 (Davis and Harden 1999) and AMEE Guide 36 (Taylor & Miflin 2008).

PBL encourages the development of professional knowledge and problem-solving by providing the opportunity for learning through reflection on and of activities and individual experiences, as well as learning through specific activity and context (Maudsley & Strivens 2000). Watmough and colleagues (Watmough et al. 2009, 2010) provided an evaluation of the move from a traditional to PBL curriculum at the medical school in Liverpool, UK, which will provide insight for those considering adopting this style of teaching methodology.

Skills such as critical thinking, problem solving, communication and team working can be fostered by PBL. With more didactic approaches, the use of patient cases and scenarios can promote the consolidation of core knowledge (Jones 2009). It should be noted that there have been concerns expressed about the strength of core knowledge, particularly in the basic sciences, in PBL curricula (Nandi et al. 2000). Despite the promising potential of PBL-based curricula, studies have shown that there is little evidence to suggest that it improves either the acquisition of knowledge or clinical performance over other curricula styles (Colliver 2000; Smits et al. 2002). Problems with PBL approaches even include dysfunctional behaviour in some PBL groups (Hitchcock & Anderson 1997; DeGrave et al. 2001; Hendry et al. 2003). Hybrid courses are said to successfully combine didactic teaching with PBL components. An illustration of this is the case-orientated problem-simulated (COPS) curriculum at Dalhousie University Faculty of Medicine in Canada (Lee et al. 2010).

Alternatively, there is the clinical case method of interactive learning which relies more upon the tutor; teacher-centred learning. This is based around an expert-led group discussion of clinical cases during which the students are required to solve a problem through discussion and critical thinking (Tarnvik 2007). It is therefore perfectly possible to deliver self-directed learning in a non-PBL based curriculum. Mixed, blended learning, consisting of didactic and PBL-teaching approaches, can deliver core knowledge effectively whilst at the same time encouraging self-directed learning (Spencer & Jordan 1999; Nandi et al. 2000).

In conclusion, some PBL-based teaching methodology and activities should be included in a curriculum that wishes to develop and instil research skills and attributes such as critical analysis, inquiry, communication and team working. However, it is not necessary to exclusively adopt a PBL-based curriculum since other mixed curricula can easily develop the research-related skills and attributes using other teaching methods.

Integrated teaching

Traditional curricula often have a discipline/subject format, thus making it frequently difficult to integrate context and knowledge; such integration is one claimed advantage of PBL over traditional curricula (Barrows 1985; Dahle et al. 2002). However, integrated traditional curricula which use patient cases/scenarios to contextualise didactic teaching can achieve all the advantages of PBL and avoid the discipline-orientated focus on subjects for content/core knowledge and skills acquisition (Harden et al. 1984). This is especially true if the small group working, problem-solving and clinical reasoning, that is associated with patient cases, is used to appropriately contextualise and integrate the knowledge and skills. Tips for developing an integrated curriculum are provided by the recent article by Malik and Malik (2011).

Evidence-Based Medicine

Explaining the evidence-based approach to the practice of medicine is important in reinforcing the acquisition of research skills and attributes. EBM can be defined as the enhancement of a clinician's skills in diagnosis, treatment, prevention and related areas through the systematic framing of relevant and answerable questions and the use of current best evidence in making decisions about the care of individual patients (Sackett et al. 1996; Donald & Greenhalgh 2000). In essence, it translates into the use of the best evidence in the scientific literature to provide best care for an individual patient. (For recent examples of how this has been introduced and evaluated see Liabsuetrakul et al. (2009) and Taheri et al. (2008).

This approach can be used to develop and master critical thinking, literature searching, team-working and communication skills; clinical reasoning and core knowledge can also be developed. Underlying the application of an EBM-approach is the use of cognitive flexibility theory through self-directed, problem-based and contextualised learning to develop research skills (Liabsuetrakul et al. 2009). This approach can be broken down into steps that can be built into EBM session or activities:

(1) How to formulate a clinical question,
(2) How to search for evidence for this,
(3) How to critically appraise this evidence,
(4) How to integrate evidence into practice
(5) How to evaluate and monitor practice

There is a cautionary report about the introduction of EBM into curricula which states that it can disengage students if not planned and conducted carefully (Holloway et al. 2004). There is, however, advice on how to use tools and a toolkit for measuring the effectiveness of EBM and evidence-based practice (EBP; Holloway et al. 2004; Ilic 2009) and how to promote its use and integration into undergraduate medical curricula (Meats et al. 2009). One approach has been to set up lectures/support that describes EBM and use a skills development matrix and appropriate assessment methodology (Taheri et al. 2008).

Research-teaching linkages

One strategy which combines many of the techniques and design approaches listed above is to use research-teaching linkages to inform the curriculum design and content (Healey 2005a, 2005b; 2008; Struthers et al. 2008). This involves making teaching research-led in all its aspects. It should be made explicit to students that all teaching is research-based and relies on evidence-based approaches. Research and critical thinking skills are thus part of the advertised outcomes or competencies. Research staff should be involved in the programme to provide up-to-date information, cutting-edge scientific and medical methodologies and to supervise research projects. Medical School faculty should be encouraged to become involved in the area of medical education perhaps through completing a post graduate certificate in Medical Education or by becoming involved in medical education research.

Thought must therefore be given to the design and style of curricula adopted by institutions and how they may influence the ability to develop research-related skills and attributes within their undergraduates. However, such skills and attributes can also be developed through specific teaching activities.

Specific teaching activities

Specific teaching and learning activities can enhance the acquisition of research-related skills and develop research-related attributes and are described in the following sections (See case studies 1 and 2, in Appendix 1 for specific examples). Those that are covered and referenced in the previous section include:

- **Small groups** to facilitate team working communication skills.
- Use of **patient cases/scenarios** for developing critical thinking and problem-solving skills as well as reinforcing the acquisition of core knowledge.
- **Teaching clinical skills with patient cases** for the maximum effect on clinical reasoning and inquiry.

Research projects

Probably the most authentic way to develop research skills and foster the development of appropriate research attributes is for the learner to undertake an independent research project of some kind during the undergraduate programme (Shankar et al. 2006; Laidlaw et al. 2009). Research projects should be a part of the core curriculum and students should be made aware of the research profile at the institution. The maxim 'inform and involve' are useful guide posts for this research- centred approach (Shankar et al. 2006; Burgoyne et al. 2010).

There are a number of ways in which the learner can become involved or participate in research.; one such example is that from the University of St. Andrew's, Scotland, UK, where all student undertake a research project as part of their core curriculum (Laidlaw et al. 2009).

Other ways involve:

- Increasing the number of students undertaking intercalated degrees
- Offer summer research projects to an increased number of undergraduates students (Junge et al. 2010).

Research projects are sometimes referred to as scholarly projects/activities designed to develop analytical skills, self-directed-learning and communication skills (Coplit 2009; Boninger et al. 2010; Green et al. 2010; Junge et al. 2010; Mirabel et al. 2010). Appropriately focused electives can also achieve the same outcomes (Dowell & Merrylees 2009; Riley et al. 2009). All such research activities require good organisation and resourcing and depend upon IT support, staff team work and regular communication between staff and students (Boninger et al. 2010).

A recent AMEE Guide on student-selected components (SSCs) (Riley et al. 2009) shows how central they are in providing opportunities to develop research skills. Appropriately designed student selected components can provide the opportunity to apply knowledge in new situations and develop critical thinking, reasoning, new learning skills, analytical skills and independent learning. SSCs permit new approaches to learning by students and also allow time, space and opportunity for students to obtain extra (or non-core) research skills and research-related attributes (See Appendix 2, Case study 3).

Publishing papers from such research projects, scholarly activities and SSCs also enhances the acquisition of research skills (Griffin & Hindocha 2011).

Independent research courses

An alternative or even complimentary approach to projects or SSCs is to design and run specialised courses which focus on research methods, reading research reports, developing critical thinking, knowledge transfer and/or offering specific research-related exercises (Marusic and Marusic 2003; Diaz-Torres et al. 2009; Millar et al. 2009; Reitmanova 2009; Balster et al. 2010; Coil et al. 2010). These research projects can be extended to include medical education research for those students who wish to become educators (Andreatta et al. 2009). Research courses may be short and intensive or extend over the entire curriculum, but should be made explicit to students through a research skills matrix. For an example of such matrix see case study 4 in Appendix 3.

Assessing research skills

Research skills and their appropriate attributes, if an essential part of a curriculum must be assessed to demonstrate competency; there are several ways this can be achieved.

Portfolios. Portfolios can be used to record the development of research skills and attributes. The mere process of recording, selecting and reflecting on what a student should enter into their portfolio helps to consolidate and extend learning. Suggestions of how to how to use portfolios is provided by AMEE Guide 45, Tartwijk and Driessen (2009) and Driessen et al. (2005). If used properly, portfolios promote reflection on learning and experiences. If portfolios are to be used successfully, they should ideally provide a continuous narrative document through the learning process and:

- focus on subject-related attributes
- record life experiences, career-orientated activities, extra-curricular activities and employment
- be tracked through final year courses and obtain input from relevant employers

However, even if all of these ideals cannot be attained, recording the acquisition of skills and representing the development of attributes is a useful career skill to learn.

Summative assessment. Whilst it is difficult to summatively assess research skills and more so to assess attributes of individuals, by framing the research question within the context of a knowledge-based problem, it is possible to judge the abilities of students to collect and then interpret data typically encountered within the research environment. The example case study in Appendix 4 offers one way that research skills could be summatively assessed. Three example questions (and answer keys) are shown which can help assess the development of basic research skills. At its simplest, students can be asked to use literature searching and retrieval skills to track down specific publications. By guiding students to use specific search tools, such as PubMed™ and Medline™, best practice can be inculcated, particularly if full text access to the article is essential to complete an assignment. Question 1 in Appendix 4 shows an example of a literature searching task completed by second year medical students who are required to obtain full text copies of a number of articles. In order to answer the question fully, students are expected to locate the full text copy of the article, answer the question and provide the correct citation. Summative assessment questions can be designed to test skills of data interpretation and can be linked to a knowledge-based component that is formally taught within the curriculum (Question 2, Appendix 4). The question on interpretation of World Health Organisation (WHO) data which is presented on a log-linear scale tests both an understanding of how epidemiological information is collected and codified, as well as simple data interpretation and arithmetical skills (an abbreviated answer key is provided).

The final example that illustrates the linkage between a traditional knowledge-based assessment and one that requires students to use skills of data interpretation and data processing is framed around an assessment conducted during an integrated gastrointestinal systems module (Question 3, Appendix 4). In this question students are required to synthesise graphical data and textual information to derive a hypothesis that could explain the research results. Their understanding of key concepts in public health medicine, gastro-intestinal physiology and cancer biology are tested in other parts of the same question.

Research skills can be practically examined in an OSCE (Objective Structured Clinical Examination) style station, as described by (Berner et al. 2002). Other methodologies include the use of an asynchronous discussion forum for peer feedback on critical appraisal (Koops et al. 2011), the

Table 2. Curricula approaches which can enhance the development of research skills and attributes towards research, in undergraduate medical students.

Approach to learning (Curriculum level)
• Blended teaching involving didactic and self-directed/independent learning
• Patient scenarios/cases
• Integrated curriculum
• EBM approach to the teaching
• Situational and experiential learning
• Make the most of the institution's existing and on-going research activities and link these to teaching

Table 3. Essential elements required in the curricula to develop research skills and attributes towards research, in undergraduate medical students.

Learning element (Teaching and assessment activity)
• Research projects/SSCs
• e-portfolios
• Scientific/research skills matrix
• Assessment of the skills and attributes or recording of competency.
• Core curriculum must ensure relevant and appropriate research expertise is gained by all graduates
• Small group work

development of a preliminary evaluation tool for EBM (Holloway et al. 2004) and the use of an approach called the Peer and Self-Evaluation System (PSES) for team work assessment (Strom et al. 1999). This suggests despite there being little published work on the assessment of research skills in medical students there are already several techniques that are currently already in use in some institutions.

Students completing a substantial research project are often assessed via a submitted dissertation (as is the case for all students at St. Andrews Medical School (http://www.st-andrews.ac.uk/medicine) and those completing an intercalated degree). Care must be taken when assessing such dissertations however to ensure bias resulting from different experiences of supervision does not impact on the grades awarded by supervisors, as was shown in a study on the marking of SSC reports (MacDougall et al. 2008).

In summary, to develop the research skills in medical students listed previously, their curriculum should encompass the elements and approaches shown in Tables 2 and 3.

Barriers to Developing research skills and attributes; how to overcome them

A number of barriers to instilling graduate attributes towards research were identified by a project designed by Struthers and colleagues 'Enhancing graduate attributes in Medicine, Dentistry and Veterinary Medicine' (Struthers et al. 2008). Those interviewed as part of the project stressed the importance of students acquiring research skills and developing research-related attributes, but felt that there were obstacles to success, coming from both a staff and student perspective. The following section will examine the barriers identified in that study and discuss them with reference to other literature.

Finding time in a busy curriculum

In many cases, the pressures on a five year medical degree means that time to conduct a meaningful research project has frequently been crowded out of the curriculum. However, despite the shared mission of training doctors for medical practice the diversity of approaches taken by some medical schools to achieve this aim (Putnam 2006) has resulted in some institutions fitting research into the scheduled undergraduate curriculum. Duke University School of Medicine takes, what is viewed by some, a more radical approach and devotes their entire third year to scholarly investigation in their mission to graduate clinician-researchers and clinician-educators (Grochowski et al. 2007).

In the UK, the GMC's (2003) *Tomorrow's Doctors* had previously suggested that 25 –33% of the total curriculum should be devoted to student selected components (SSCs). Although this time has been reduced in many institutions, the concept of SSCs is now firmly integrated into most UK medical curricula. SSCs are offered across the five years of the curriculum and students are encouraged to select at least one SSC during their course which allows the opportunity to complete an independent research project or audit or another research related activity. The more recent version of *Tomorrow's Doctors* (GMC 2009) states that *'The curriculum must allow for student choice for a minimum of 10% of course time*'. It will be interesting to see what impact this reduced time and reduced emphasis on student selected components has on the opportunities for students to gain research experience.

At the University of St. Andrews, Scotland, UK (www.st-andrews.ac.uk) *all* medical students on the undergraduate Medical Honours course complete a 10- week dissertation which can either be based around the critical appraisal of a clinical question or a primary research project.

Other universities use an intercalated degree which adds an additional year to the course but provides opportunity for research for some students who opt to take this opportunity. If schools wish to consider how best to increase the number of students taking intercalated degrees they may have to begin by earmarking funds for student research bursaries.

Therefore there are many creative options which allow institutions to provide opportunities for research experience within the undergraduate medical curricula. It would seem that this barrier is more imagined than real.

If institutions perceive they cannot provide opportunity within the core curriculum, interested students can also gain research experience through extra-curricular activities. To this end, they can take 'time out' after their initial degree or gain research experience during vacation time. St. Andrews in Scotland (www.st-andrews.ac.uk) has introduced a Masters in Research and encourages their medical students to complete this Master's degree between their pre-clinical and clinical undergraduate years. Many institutions offer summer placements with researchers, sometimes with bursaries to encourage participation. Organisations such as the Nuffield Foundation (http://www.nuffieldfoundation.org/) and the Royal Society (http://royalsociety.org/) offer bursaries to allow students first-hand experience of research, especially during summer vacations.

Limited opportunities and resources

Opportunities for research activities are limited within hospital wards and in the community, since saturating clinics and community organisations with students engaged in research projects is not often seen as feasible. In general, it is the academic staff of the medical school who supervise student research opportunities and so the experience the students receive is most likely to be linked to the research of the Department (Struthers et al. 2008). However there are further barriers:

Firstly, there is the time required to obtain ethical approval which can often restrict the research opportunities and narrow the fields of study (Robinson et al. 2007).

Secondly, there is the cost of a laboratory based project. Research staff may be reluctant to let students loose on expensive equipment. There is also a cost overhead for helping students submit abstracts to conferences, although one solution to this problem is for schools to offer to cover costs of presenting at conferences. A number of academic staff actively encourage their students to publish; however there is a time commitment from staff to assist students in transforming their project into a publishable paper.

Time spent supervising students is valuable time spent away from faculty research with less immediate benefit. As a consequence, there are often not enough laboratory-based opportunities for students to experience research. Current trends in the UK are to designate academics as either being research focused or teaching focused. A consequence of this is that research staff are becoming more remote from the teaching and from students (Drennan 2001). Researchers are often viewed by students as being remote and difficult to approach and unused to talking to students at a level they can understand. Students need to be enthused by research and researchers and made aware of the opportunities that research can provide. Boosting the links between teaching and research would go part of the way to resolving this issue.

Assessment

It is a common aphorism oft quoted that assessment drives learning. Faculty would prefer students to focus on learning itself rather than on learning for assessment purposes. To encourage this, considerable time is spent devising varied learning opportunities within the curriculum to support knowledge acquisition. Students tend to focus on what is examined as ultimately that which determines whether they pass or fail. Unless research attributes and skills are assessed, students will always see research-related tasks as optional extras to the curriculum and will be less likely to get involved. Although it is easier to examine factual knowledge, it is possible to address this barrier as described in the section on assessment of research skills. How this assessment feeds back into a summative student grade and how this affects student compliance and engagement is an under-researched area.

Medical schools are also part of a higher education system in which students' progress intellectually from one level to the next on a structured degree programme on the *proviso* that they pass the assessment. There are strict assessment criteria linked to the university degree classification system and it is on these criteria that students focus. Therefore, if schools want the development of research skills and attributes to be taken seriously, they need to assess these skills; this ultimately requires considerable commitment from faculty.

Academic research staff

Often faculty are designated either as a teacher or as a researcher, although some universities afford staff both titles. For researchers, time away from research spent teaching is seen as wasted since it puts them at a disadvantage with their research peers; the main emphasis for their career progression being on research output. In the UK, the research assessment exercise (RAE) exercise or the new research excellence framework (REF) has focused solely on evaluating academic staff on their research activities, making those that are research active more reluctant to spend time on teaching activities. Clearly, it is a commitment for staff to supervise students participating in research projects since students have the potential to be viewed as a valuable resource (MacDougall & Riley 2010).

Clinical educators are in a similar situation. In many hospitals, teaching time for clinical academics is not valued. It is seen as too expensive to have high-earning clinicians spending valuable time teaching undergraduates. Much of the clinical skills training is now done in clinical skills teaching units to exact protocols. Consequently the time for bedside teaching and the opportunities to pick up or gain an understanding of clinical research, or how research informs practice, is limited.

From the perspective of teachers, schools may be concerned about faculty training and development, especially in the light of the comment from MacDougall and Riley in their study reporting recommendations for supervision that *'To supervise well needs some existing research/audit experience'* (MacDougall & Riley 2010). Attention is drawn to the course called 'Entering Research' at the University of Wisconsin (Balster et al. 2010). This course is taken as a staff development option. Although it was not created originally for medical teachers, it does provide a model to create a facilitator manual which allows staff to act as facilitators/mentors to help students develop skills in research and research-related attributes.

Remoteness of research and research faculty

One of the concerns raised in the report by Struthers and colleagues (Struthers et al. 2008) was the feeling that students could leave their university without being aware of the key areas of research within their respective schools and of the international research 'stars' that are part of their school. Some schools often address this by arranging inspirational talks by researchers or by inviting these researchers to guest lecture on their course. In many cases, participants in the Struthers study (Struthers et al. 2008) felt this type of seminar series to be unsatisfactory as content was often not delivered at a level that students can engage with. Several said that it should be embedded in the ethos of the staff that they interact with the students at a research level and others felt that it was up to individual faculty to engage with the students about their research. There is still a concern, however, that students are missing out on both the knowledge of local research and on the opportunity to become involved. It seems that schools are failing to communicate to the students the value of these research talks (Burgoyne et al. 2010).

Students

Students may not be aware of the relevance of research skills and related attributes in relation to their future careers. As they become more aware of their profession and the institutional priorities of service, education and research they assess their own career priorities and, without clear role models, may exclude research as an academic career at an early stage (Levine et al. 2011). In Burgoyne and colleagues' study on students' perspectives of undergraduate medical research, students were generally unaware of the research activities of their teachers and mentors, suggesting they did not view such individuals as research role models. (Burgoyne et al. 2010)

It would appear however, that students would like to be informed and more involved in research, this would enable them to understand what research is and that research skills and attributes are relevant to the routine practice of all doctors and not just those involved in full-time research (Burgoyne et al. 2010; Murdoch-Eaton et al. 2010). The core curriculum must ensure that relevant and appropriate research experience is gained by all graduates, so it would be helpful if research-related learning activities such as projects have explicit descriptors and learning outcomes (see Appendix 5 Case Study 6 for an example; Burgoyne et al. 2010; Murdoch-Eaton et al. 2010).

Another way to enthuse and encourage students is for them to recognise research role models amongst faculty (MacDougall & Riley 2010). Fostering a more formal linkage between students and the research environment can help to raise awareness and develop an interest in research within students. The undergraduates of today need to be trained for their careers as clinical researchers and academics of the future. Universities should encourage their successful researchers to describe their research to students at a level which they will understand and in a manner that inspires them.

Encouraging students to publish their student research projects is an important way of engaging students interest in research (Griffin & Hindocha 2011); however this will only be viewed as important by students if it is linked in some way to a perceived improved career progression. In the Struthers report (Struthers et al. 2008) interviewees felt that, although it is not possible for all students to publish research papers, if publications were advantageous to the individual student's career then it would encourage future students to engage in research.

National policy

While some of the barriers discussed above to encouraging the development of research skills and attributes can be circumvented at school or institutional level, some of the issues highlighted need to be resolved at national policy level. National policy makers have a responsibility in this area and they should seek to encourage the acquisition of research skills and the development of research-related attributes by:

- Increasing external funding for educational research
- Positively valuing, possibly through promotional or appraisal means, the time spent by senior academics in engaging students in research
- Improving the attractiveness of a research career to students; achieved in itself by frequent exposure and communication with research faculty and activities

Conclusions

Research skills and appropriate attributes towards research should be major learning outcomes of medical education. (World Federation for Medical Education, WFME 2007) Appropriate curriculum design and training sessions will help institutions achieve these aims without overburdening the curricula. Modern medical curricula should offer all students the opportunity to engage in independent research in the broadest sense to allow them to develop and refine their research capabilities.

There are some potential barriers to instituting and delivering these aims but these can be overcome or circumvented by careful planning and exploring alternative modes of delivery. If the appropriate research attributes form an important component of a well-rounded doctor's training, then research experience should add value to any future job application, providing an incentive to train the clinical scientists of the future.

The UK Medical Research Council responded to a Royal College of Physicians consultation on medical professionalism in 2005 with a powerful statement indicating that all medical professionals should seek to encourage research. *'Overall, a mark of professionalism for the future will be research awareness for the benefit of patients. Some medical professionals will actively participate in research but all should seek to encourage it and, where appropriate, to involve their patients actively in the medical research agenda, and implement the results of this research in their professional practice.'* (Cited in Evans et al. 2011).

In order to achieve this, every medical student must understand research methods and the benefits that research brings to their profession. This understanding can be greatly enhanced by encouraging the active participation of students in research activities.

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Appendix I

Case study 1

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Title of initiative:
Critical reading: The Journal Referee.

Description of initiative:
Critical reading of the literature and assessment of the significance of a piece of research is an important skill for all doctors and an essential component of the academic, as opposed to the professional, training of medical students. To foster the skills of critical reading we have developed an exercise entitled 'The Academic Journal Referee' which is a component of an SSC 'Pathology for Junior Doctors'. The exercise is primarily a formative assessment tool although it also contributes to the overall summative assessment of this SSC.

The student is asked to act as a referee for an academic journal. They are given a paper submitted to the journal (actually an already published paper) and asked to write a report to the editor commenting on the strengths and weaknesses. Time, usually two half days, is specifically set aside for the exercise. Suggested reading is 'Studying a study testing a test' by Riegelman.

As preparation for the exercise a seminar on critical scientific reading is delivered. Several points are highlighted particularly the need to read the paper in a systematic analytical way and that this is a different way of reading. Guidance is given on the optimum structure of the report which reflects the pattern of reading a scientific paper.

Which students are involved? (e.g. % of cohort, stage of training, means of selection):
Self-selected students from year 5. Usually 10–12 students.

Which graduate attributes are enhanced by this initiative?
Critical reading, analytical skills.

What resources were required and what difficulties were encountered/overcome?
A preparatory seminar was delivered.

The selection of suitable research papers is critical for the success of the exercise. It is essential to avoid papers with methodologies or vocabulary beyond the experience or understanding of the student. The student needs to understand the background to the research and the methodology used without substantial background reading otherwise it changes to an exercise of scientific comprehension rather than critical reading and analysis.

Impact of the initiative (if assessed) and/or student feedback:
In general the students prove to be excellent critical readers with an appropriate level of guidance. They report significant improvement in their critical reading and analytical skills and although we have no hard evidence, the students claim to find other pieces of work such as project or audit studies benefit from having completed this SSC.

Case study 2

Authors and affiliations:
Dr K Mattick, Peninsula Medical School (PMS)

Title of initiative:
Research in Action: Integrating Science with Clinical Practice

Description of initiative:
This is a fourth-year Special Study Unit (SSU) where students ''piggy back'' an active research group and experience the process of research. They have the opportunity to try out the techniques, analyse data and pose questions. Staff are given some guidance and examples on what is appropriate to give students to do. This involves three one-week blocks across the fourth year. Students are able to choose the type of research group they join; often there are three or four students with each research group. After the first contact session the students are asked to produce an overview of the research topic in the form of a BMJ critical review. This review is formatively marked, and is set to ensure the students have a good understanding of the field. In the second contact week the students are expected to analyse data generated by the research team, and use it to produce a research poster. This poster is summatively assessed and contributes a third of the overall score. The students present their posters at an internal PMS research in action poster day, but this is not part of the summative assessment. At the end of the third week the students are expected to produce a future work proposal, which should build on the data presented in the poster and state where the student would take to project in the next 12 months. The future work proposal is also summatively assessed and accounts for the remaining two-thirds of the overall mark. The mark contributes to the overall assessment of the SSU modules, of which this is one of three in the fourth year. Students must pass SSU module but can compensate marks over the 3 SSUs.

Which students are involved? (eg % of cohort, stage of training, means of selection):
All fourth year students

Which graduate attributes are enhanced by this initiative?
Ability to work in a team; awareness of an academic career path; an understanding of basic research methods; an understanding of ethics and governance of research; an enquiring mind; presentation skills; practical ability to do research; understanding data analysis.

What resources were required and what difficulties were encountered/overcome?
Training for supervisory staff.

Appendix 2

Case study 3

Authors and affiliations:
Simon C Riley, Director of Student Selected Components, Obstetrics and Gynaecology, University of Edinburgh, QMRI, 47 Little France Crescent, Edinburgh, EH16 4TJ (email: Simon.C.Riley@ed.ac.uk)

Title of initiative:
Student Selected Components in the Medical Curriculum.

Description of initiative:
Student Selected Components (SSCs) are a result of the guidance from the General Medical Council to restructure medical curricula to reduce content overload and at the same time provide students with opportunities for choice and depth of study. In the undergraduate programme in medicine at the University of Edinburgh the SSCs form just under 20% of the timetable and are the main research-teaching linkage. The SSCs are also important in defining this course by providing clear research opportunities to a participating student in a research rich environment. Furthermore, 30–35% of our medical students also take the opportunity to carry out an intercalated Honours degree, between second and third year, which incorporates a significant research project component. The purpose of the SSC programme is to permit students to progressively develop a broad spectrum of research skills (including an understanding of evidence based medicine, informatics, medical statistics, critical appraisal), in conjunction with professional skills (including communication, team-working, and life-long learning) on projects of the student's own choice. The SSC programme is fully integrated with the core curriculum, both in delivering core skills and in its assessment. Students carry out four separate research projects. In Year 1, students select from a wide choice a hospital-based projects and work in small groups, supervised by a member of staff. The project usually involves an appraisal of literature and a simple questionnaire to patients. In year 2, students perform two literature based projects in small groups, facilitated by a member of staff. The first is from a choice of topical medical issues and the second is organised by the students themselves, who, with support sign up their own staff facilitator. In year 4, students decide upon a topic or field of study and self select, again with support. They negotiate with and sign up to work with a supervisor for a 14 week research project.
The Year 4 project in particular is highly regarded by both students and staff as an excellent opportunity to perform some useful 'real' research. The project may take the form of an audit which can influence local care provision, a component of an ongoing larger research project, a small stand alone complete study, a preliminary or pilot study, or a systematic review, across the whole spectrum of medical specialties.
There seem to be several factors that make it work successfully:

(a) By this stage students have already developed a useful range of research skills which they bring to a project.
(b) By getting students to self select and sign up their own supervisors, they develop a real commitment and ownership of their project, and a partnership with their supervisor.
(c) It is viewed as a real opportunity by students for several reasons. These include being able to view a specialty for an extended period, which they may be considering as a potential career; to gain a range of useful skills and some independence; to enhance their CV in a range of ways, and even to 'do something useful'.
(d) Similarly it is viewed as an opportunity by supervisory staff to allow a motivated student to perform some useful research, and to encourage students interested in their own field of research and specialty.
(e) Students and supervisors are well supported, including medical statistics, library and ethical support, and the administrative and assessment burden is minimised.

The Student Selected Components provide an opportunity in medical curricula to provide curriculum time to allow students to perform a wide range of research projects and to progressively develop their research and professional skills, which are essential for their future success in careers across medicine.

Which students are involved? (e.g. % of cohort, stage of training, means of selection):
All students on the MBChB undergraduate programme.

Which graduate attributes are enhanced by this initiative?
Full range of research skills, together with allied professional personal skills.

Impact of the initiative (if assessed) and/or student feedback:
Overall very good feedback across the whole SSC programme.

Appendix 3

Case study 4

Authors and affiliations:
Dr J Aiton, School of Medicine, University of St Andrews.

Title of initiative:
Generic Scientific and Research Skills for Medicine – a Vertical Curriculum Strand.

Description of initiative:
Medical students from St. Andrews graduate after 3 years of study with a BSc Honours Degree in Medicine before completing their clinical training at the University of Manchester or a partner Medical School in Scotland. The curriculum is organised as a modular integrated systems-based course with a pedagogical approach that is designed to provide the scientific basis of the practice of medicine. The curriculum consists of a pre-honours year followed by 2 further years of Honours study. In the final semester of the Honours programme, every student completes a research dissertation which may be laboratory based, involve survey data collection, audit or an extensive literature review which addresses a research question.
In order to lay the groundwork for the honours dissertation, we have a devised a generic research skills programme running through the curriculum which provides students with the opportunity to acquire and develop the appropriate skill set required for their dissertation. The research skills are mapped to a matrix which covers all 3 years of the curriculum to ensure that the appropriate skills are addressed at appropriate points in the curriculum and integrated with other professional skills and teaching, such ethics, clinical skills, clinical medicine and portfolio work. Mapping of all the different elements in the curriculum is vital in identifying gaps in the programme of research skills teaching and reducing duplication. Initial student feedback indicates that students felt ill-prepared for the task of completing a dissertation. To address the perceived deficiency, scientific and generic skills teaching were introduced from the very outset of the degree. Figure A1 shows the over view of the distribution of the generic scientific and research skills located in each of our undergraduate modules. Within each module a detailed audit was conducted in order to identify the contribution of each element to our research skills matrix
In their first module (MD2001), new students are introduced to the concept of the scientific method and the importance of basing the practise of medicine on evidence derived from high quality research. Students must read a scientific paper and analyse its structure, the methods used present data and the importance of scientific referencing. Students gain practical experience of using the NHS Scotland e-library Knowledge Network to search the literature for key publications and full-text articles and compare the effectiveness of search tools such as PubMed, Ovid and Google Scholar.

(continued)

	MD2001	MD2002	MD3001	MD3002	MD4001	MD4002	MD4003
The scientific method in medicine							
The scientific method	+	+	+	+	+	++	
Understanding the scientific literature	+	+	++	++	++	++++	
Experimental design and interpretation	+	+	++	++	++	++++	
Evidence based medicine							
The role of evidence based medicine	+		++	+	++	+++	
Statistics and statistical analysis	+		++	+	+	++	
Critical appraisal of scientific papers	+	+	+	++	++	++++	
On-line literature searching	+	+	++	+	++	++++	
Writing and numeric skills							
Numerical Manipulation	+	++	+	+	+		
Structured scientific writing	+	++	++	++	++	++++	
Plagiarism	+	+	+	+	+	++	++
Referencing source material	+	+	++	+	+	++++	
Presentation skills							
Oral presentation	+	+	++	++	++	++++	++++
Poster design and presentation		++		++++			
Personal development							
Time and project management			+	++		++++	+
Peer teaching, learning and assessment	+	+	++	++	++	+	+++
Reflection on learning experiences	+	+	+	++	++	++++	
Clinical reasoning	+	+	+	+	++		++++

Figure A1. Matrix view of the teaching of scientific and research skills across the three years of the curriculum. The relative content is indicated by the number of + signs.

In the second semester of their pre-honours year (MD2002) students apply the research skills acquired in first semester to write a scientific report on a on a topic of their choice in the style of a British Medical Journal (BMJ) editorial. They are required to find and use the BMJ 'Instructions for authors' which gives them experience of writing in a style appropriate for publication.
In the Honours programme, the role that evidence based medicine plays in determining practice is considered in more detail (MD3001) with particular focus being placed on research study design, basic statistical concepts, literature searching and the use of an on-line citation management system (RefWorks). Students are asked to look more critically at the literature and use data they collect from an exercise laboratory experiment as the framework for writing a scientific paper. A selection of published articles on related experimental findings (body mass index and fitness measurement) are used to prompt students through a series of questions on study design, selection of control and experimental groups and the extrapolation of research study findings to population epidemiology. Students are also expected to use more sophisticated search strategies to identify key publications and access full text articles via University or NHS subscribed sites as detailed in the task below.
Example task:

Professor Jack L Feldman is a visiting professor of neurobiology from the University of California who will be giving a seminar in the School in early November. Feldman has been responsible for a number of significant discoveries underpinning our understanding of the mechanisms involved in respiratory rhythm generation. His research has contributed to our understanding of sleep apnoea, sudden infant death syndrome, Rett syndrome and congenital central hypoventilation syndrome (Ondine's curse). He has asked *'What mechanism(s) control the 500 million breaths we take during our allotted 80 years?'*
Search the literature to answer the following questions and store the references you collect in RefWorks

- *What is the name of the principal rhythm generator discovered by Feldman?*
- *What influential paper, published by Feldman's group in 1991, claimed to have identified the neurons responsible for respiratory rhythm generation?*
- *Feldman and Del Negro wrote a review entitled 'Looking for Inspiration' in 2006. What is the correct citation for this review?*
- *In a recent Nature Neuroscience publication, Feldman has commented on the work of Muriel Thoby-Brisson's group on rhythmic foetal breathing. What are the references to Feldman's article and Thoby-Brisson's review in the Journal of Applied Physiology in 2008?*

In third year (final undergraduate modules), activities focus on the students' analytical ability and critical thinking skills. Tasks include the interpretation of scientific data. This is another workbook based exercise where the students are given the edited introduction and methods to a paper, they are provided with a glossary of new terms and are given figures and figure legends.
They are then prompted by a series of questions to analyse the data and try to draw conclusions about the experimental data.
Semester two of year three sees all the students embarking on an Honours project. Most dissertations will be a critical review but some students (around 25% of the class of 150) chance to carry out original research in the laboratory or in the community.
This is known to be a challenging task for students at this early stage of their career. However, by developing the generic research skills early and reinforcing them throughout the course, we are giving the students the best possible opportunity to fulfil these objectives. There is simply not space in the curriculum to do everything. We do not, for example, formally teach a statistics course. Instead, we target more advanced statistical training for those who have an immediate need.
More recently, the School has been devising assessments using integrated questions which include both basic and clinical sciences as well as sections which test the students' abilities to interpret data, identify study design strengths and weaknesses and apply critical thinking. (examples are included in this Guide).

Bloom (1956) classified levels of intellectual behaviour in learning into three overlapping domains: the cognitive, psychomotor, and affective. Within the cognitive domain, he identified six levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. These domains and levels should be at the core of an approach that fosters critical thinking skills in undergraduate medical students. Instilling the attributes adjudged to be important in developing a research ethos is more difficult since they belong in the creative thinking domain exemplified by divergence and curiosity. By teaching critical thinking skills and providing students with opportunities to practice in the appropriate context, we hope develop the creative thinking skills that underpin the research attributes we are trying to foster. The research skills matrix provides a framework to ensure that there is an appropriate environment within which the required attributes can be developed.

Appendix 4

Case study 5

Authors and affiliations:
Dr J Aiton, School of Medicine, University of St Andrews

Title of initiative:
Assessment of Generic Scientific and Research Skills

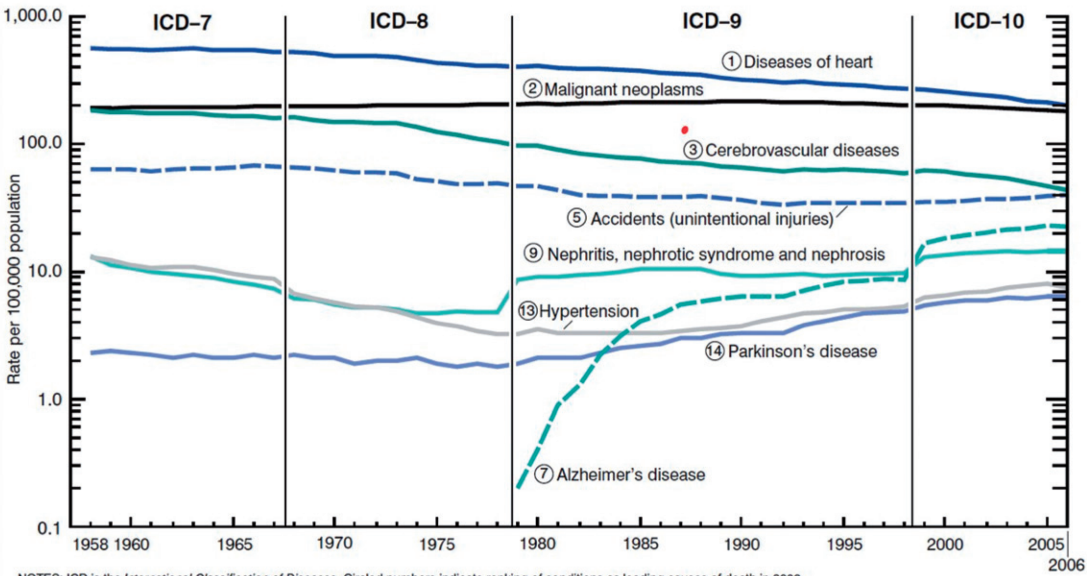
Description of initiative:

Question 1

Task	**Answer**	**Citation**
Some of our staff are currently working in Malawi. Which anti-malarial(s) does a recent Cochrane Review recommend to prevent them contracting malaria and why has this treatment been chosen?	Tovaquone-proguanil and doxycycline are the best tolerated. Mefloquine associated with adverse neuropsychiatric outcomes.	Jacquerioz FA, Croft AM. Drugs for preventing malaria in travellers. Cochrane Database of Systematic Reviews 2009, Issue 4. Art. No.: CD006491. DOI: 10.1002/14651858.CD006491.pub2
Clinical Queries in PubMed facilitates quick searches of the literature. Find a reference for a	Use of garlic cannot be recommended as	Simons, S, Wollersheim, Thien, T (2009). A systematic review on the influence of trial quality on the effect of garlic on blood pressure.

recent systematic review on the influence of trial quality on the effect of garlic on blood pressure. What is its main recommendation?	antihypertensive advice for hypertensive patients in daily practice.	Neth J Medicine, 67, 212 – 219.
A recent paper published in JAMA demonstrated positive benefits from exercise in older patients at risk of Alzheimer's disease When was this research conducted and what was the study design?	May 2004 – January 2007 Randomised controlled trial	Lautenschlager NT, Cox KL, Flicker L, Foster JK, van Bockxmeer FM, Xiao J, Greenop KR, Almeida OP. (2008) Effect of physical activity on cognitive function in older adults at risk for Alzheimer disease: a randomized trial. JAMA, 300, 1027-37.

Question 2



NOTES: ICD is the *International Classification of Diseases*. Circled numbers indicate ranking of conditions as leading causes of death in 2006.
Age-adjusted rates are per 100,000 U.S. standard population; see "Technical Notes."
SOURCE: CDC/NCHS, National Vital Statistics System, Mortality Statistics Branch.

Figure 6. Age-adjusted death rates for selected leading causes of death: United States, 1958–2006

This graph was taken from the 2009 report on the National Vital Statistics published by the US government. The data shows the age adjusted death rates for selected leading causes of death from 1958 to 1996. Please answer the following questions

a) What type of scale is used to plot the data on the y-axis of the graph?
Logarithmic scale
b) Why has this scale been used?
To allow a wide range of numerical data to be plotted on the same graph.
c) Why does interpreting this type of scale require care?
Since the scale increases logarithmically, relatively small changes in the graph can equate to large numerical changes in the rate of death
d) The data are presented using different ICD categories. What is ICD-10?
The International Statistical Classification of Diseases and Related Health Problems, 10th Revision (known as "ICD-10") is a medical classification for the coding of diseases, signs and symptoms, abnormal findings, complaints, social circumstances and external causes of injury or diseases
e) Who is responsible for the ICD codes?
World Health Organisation- the ICD codes are revised periodically to reflect new developments in medicine
f) Why are ICD codes used?
They are used to classify diseases and other health problems recorded on many types of health records including death certificates and health records. They also provide the basis for the compilation of national mortality and morbidity statistics.
g) The data plotted represent the age-adjusted death rates for different years. What is the age -adjusted death rate and why is it used to display these data?
The age-standardised death rate is a weighted average of the age-specific mortality rates per 100 000 persons, where the weights are the proportions of persons in the corresponding age groups of the WHO standard population. Two populations with the same age-specific mortality rates for a particular cause of death will have different overall death rates if the age distributions of their populations are different. Age-standardised mortality rates adjust for differences in the age distribution of the population by applying the observed age-specific mortality rates for each population to a standard population.
h) Would you say there has been a substantial change in the death rate due to heart disease? Give your reason(s).
Yes – the death rate has dropped from 600 per 1000,000 to 100 per 100,000 over the last 50 years
i) How much Alzheimer's disease increased between 1979 and 2006?
From 0.2 per 100,000 to 20 per 100,000 i.e. 100 fold increase
j) Is there a relationship between the death rate for hypertension and that for heart disease?

(continued)

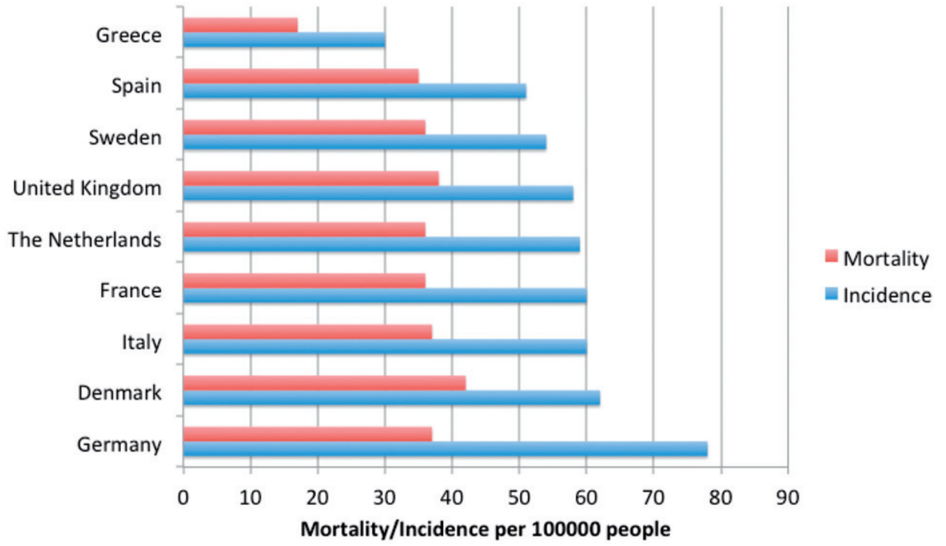


Figure A2. Colorectal cancer incidence in males in the European Union in 1996. Data were collected from EUCAN, a service that provides data on the incidence and mortality of 24 key cancers in 15 member states of the European Union.

Initially the death rate for both diseases showed a downward trend until the 1980's at which point the death rate from cardiovascular disease continued to fall but the death rate from hypertension started to increase. This increase in deaths from hypertension continues to show an increasing trend

Question 3

Table 1. Dietary patterns associated with participating countries.

Country	**Foods consumed at ≥ 150% mean overall intake worldwide**
Italy	Vegetables, fruits, cereal products, vegetable oils, sauces
Greece	Vegetables, legumes, vegetable oils
Spain	Vegetables, fruits, legumes, vegetable oils, milk, eggs, fresh meat, fish
France	Sugars, butter, dairy products
Germany	Butter, processed meat, coffee, juices
The Netherlands	Potatoes, margarines, dairy products, processed meat, tea, coffee
United Kingdom	Potatoes, cakes, sugar, margarine, butter, tea, soft drinks
Denmark	Sugars, margarines, tea, coffee, soft drinks, alcohol
Sweden	Potatoes, cakes, sugars, margarine, dairy products, coffee, soft drinks

a) Define incidence

Incidence measures the rate of occurrence of new cases of a disease or condition. Incidence is calculated as the number of new cases of a disease or condition in a specified time period (usually a year) divided by the size of the population under consideration who are initially disease free.

b) Analyse the data presented in Figure A2

Figure 1 shows the incidence and mortality data for colorectal cancer in males in in 15 member states of the European Union for 1996. The data shows that the incidence varies by a factor of approximately 2 with Germany being the highest (70 per 100000) and Greece being the lowest (30 per 100000). Mortality data shows a similar variation from Germany to Greece and largely tracks the changes in incidence. Of all the countries reported, Denmark seems to have a higher mortality from colorectal cancer than might be expected on the basis of the incidence data.

c) What conclusions, if any, can be drawn from the data presented in Figure A2 in the light of the information presented in Table 2?

Whilst there is some evidence to suggest that a diet that is higher than average in vegetables, legumes, vegetable oils (Greece) is protective against colorectal cancer other countries with higher than average consumption of these products fare less well. There is weak but suggestive evidence that diets rich in dairy products and/or processed food predispose to colorectal cancer. An alternative interpretation of these data might lie in the fact that some European counties have more extensive screening programmes for colorectal cancer which result in early detection and diagnosis. This would not only increase the incidence data but might also lead to more accurate reporting of cause of death (see the data from Germany)

d) Bile is essential for the digestion and absorption of lipids and is stored in the gall bladder. What is bile, why it essential for lipid digestion and what mechanisms are involved in its release from the gall bladder?

Bile
Bile salts (50%)
Bile pigments (e.g. bilirubin) (2%)
Cholesterol (4%)
Phospholipids (40%)

Bile salts emulsify lipids to prepare them for digestion and solubilise the products of digestion into 'packets' called micelles. Chyme in the small intestine triggers CCK release from the I cells of the duodenal and jejunal mucosa in response to the presence of monoglycerides, fatty acids, small peptides and amino acids. CCK stimulates gall bladder contraction and stimulates relaxation of the Sphincter of Oddi
In addition to diet, genetic factors can also play a role in predisposing to colorectal cancer. About 25% of cases have a family history. Familial Adenomatous Polyposis (FAP) is one of two major familial colorectal cancer syndromes.
e) What is the predominant phenotype of FAP and how does this relate to the pre-disposition to cancer?
Large number of polyps. Low mutation rate but high chance at least one will progress to tumour.
f) What is the gene which is disrupted in these patients and what type of mutation is most frequently observed?
Adenomatous polyposis coli (APC). Nonsense/Frameshift.
g) One of the properties of the gene product is to bind to microtubules. How do defects in this property contribute to disease?
If APC does not bind to tubules chromosomes cannot segregate properly at mitosis, resulting in gain/loss of chromosomes and promotion of tumour genesis.

Appendix 5

Case study 6

Authors and affiliations:
Professor Lindsey Kent, School of Medicine, University of St Andrews

Title of initiative:
Research project learning outcomes

Description of initiative:
Specific learning objectives include:

- Develop an understanding of scientific methods, including technical and ethical principles used when designing experiments
- Develop the ability to use resources in a systematic and organised fashion.
- Develop an inquisitive and questioning attitude and apply rational thought processes.
- Be competent in the use of literature searching using online methods.
- Understand the structure and organisation of a scientific paper.
- Be able to formulate a work plan in order to complete a task at an appropriate level in a defined time frame.
- Prepare a dissertation on a selected advanced topic demonstrating critical thinking, analysis and understanding of the topic.
- Summarise the findings of the dissertation topic and present them using a PowerPoint presentation.
- Develop reflective practice using a portfolio entry for a significant learning event