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Review Article

Integration of Health Informatics in Undergraduate Medical Educational Curricula - A Systematic Review

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Abstract

Objective: To systematically review student utilization of medical informatics and its integration in the undergraduate medical education system.

Introduction: The need for medical informatics integration in curricula has been suggested as essential given the expansion of technology into health care. The structure of such instruction will need to complement current health care practices while enhancing patient outcomes. Attempts at integrating modules and electives have been carried by various institutions. However, no compilation of the efforts or their value has been reported for the purpose of enhancing current curricula.

Methods: Five databases were used (PubMed/OVID, CINAHL, Cochrane Library, Embase, and Web of Science). Inclusion criteria included articles published between 1990 and June 2021. MeSH terms and key words (available in Appendix A) in titles and abstracts included health informatics, clinical informatics, informatics training, medical student, medical school, undergraduate medical education (UME), pre-clerkship education, clinical clerkship, clinical education, clinical apprenticeship, or foundational science course/curricula. The review yielded evidence of 20 peer reviewed and relevant articles.

Results: Four themes were identified: (A) Informatics education in medical schools, (B) Medical student ability to utilize medical informatics/technology, (C) Medical student interactions with electronic health records, (D) Adoption of informatics in medical students' assessment. However, no description of a formalized curriculum, whether longitudinal or otherwise, was noted.

Conclusion: Efforts to integrate informatics in medical school curricula have been limited and unaligned. A prospective focus may require ensuring the integration of formal objectives that are devised by a national licensing body.

Keywords: *Curriculum; Informatics; Medical Education; Medical Records; Medical Students; Systematic Review*

Introduction

Medical informatics is a domain of information sciences where engineering and technology in health and medicine intersect with research, education, and clinical practice [1]. The idea that medical schools should integrate medical informatics in their curricula is not

new. A panel on the General Professional Education of the Physician in 1984, a sub-group of the Association of American Medical Colleges (AAMC), specifically identified medical informatics as an area in which new educational opportunities needed to be developed so that physicians would be better prepared for the practice of medicine [2]. A study in 1998 regarding medical informatics curriculum concluded that a definitive curriculum for medical schools does not exist, but institutions were developing objectives and had begun to reach a consensus on several points [2]. These points were gathered by each school submitting their own objectives regarding medical informatics to an online survey. And it was found that the collected objectives mirrored those stated in the AAMC draft of objectives from the Medical Informatics Advisory Panel. The Medical Informatics Panel identified five roles with learning objectives relevant to each [3].

That same year, the AAMC initiated the Medical School Objectives Project (MSOP) to identify the relevance of medical informatics to the practicing physician and proposed thirty program-level learning objectives to be added to the medical school curriculum, particularly the ability to utilize databases to retrieve and manage biomedical information for clinical decision making [3]. In 2007, the impact of the MSOP guidelines was measured through a survey of 70 medical schools in the United States and Canada with few reporting set aims and fewer formally assessing competencies. The report concluded that "some progress has been made but much more needs to be accomplished" [4]. The need for medical informatics curricula is essential given the expansion of medical technology and the evolving field in medicine. The necessity of medical informatics within training dictates that it be structured to complement current health care practices while enhancing patient outcomes.

Objective of the Study

This study's objective was to systematically assess peer-reviewed publications for the extent of integration and utilization of health-related informatics in US medical schools across both educational and clinical platforms.

Methods

Five databases were used for the comprehensive publication search. These databases included PubMed/OVID, CINAHL, Cochrane Library, Embase, and Web of Science. Inclusion criteria included articles published between 1990 and June 2021, published in English and pertaining to medical schools in the United States. The review was aligned with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement [5]. Detailed study inclusion and exclusion criteria are available for review in figure 1. MeSH terms and key words (available in Appendix A) in titles and abstracts included health informatics, clinical informatics, informatics training, medical student, medical school, undergraduate medical education (UME), pre-clerkship education, clinical clerkship, clinical education, clinical apprenticeship, or foundational science course/curricula. All references were uploaded to evidence distilling software. Once all articles were uploaded, peer-reviewed journal articles were reviewed while excluding any duplicates.

The investigators initiated a two-phase review process. In the first phase, 1142 articles were identified, and two authors (ME, CB) independently screened the titles and abstracts for inclusion or exclusion (available in table 1). The second phase included a full-text assessment. Discrepancies in the study selection process included consensus with arbitration by a third author (DZ) as needed. Once fully screened, the included journal articles were organized under the above stated objectives using a thought map to organize the data. A meta-analysis was not considered due to the heterogeneity of the studies.

Results

The MeSH term search identified 1896 potential records, with the final number eligible for inclusion in the systematic review being 20 peer-reviewed articles. Four themes were identified: (A) Informatics education in medical schools, (B) Medical student ability to utilize medical informatics/technology, (C) Medical student interactions with electronic health records, (D) Adoption of informatics in medical students' assessment.

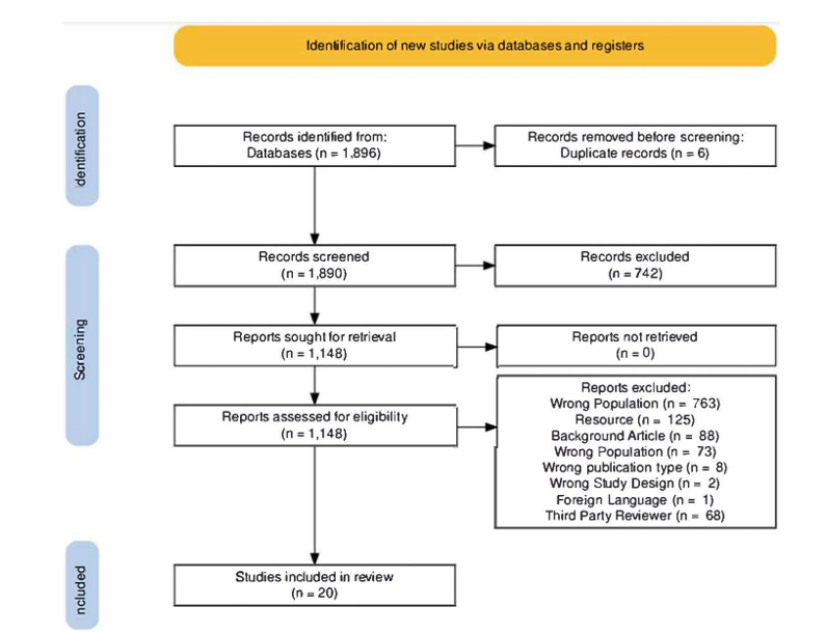

Figure 1: *PRISMA flowchart for medical informatics literature.*

Criteria	Inclusion	Exclusion
Population Intervention	Medical students, medical school educators, medical school curriculum, Undergraduate medical education	Non-medical students
Comparison	Implementation, application, and result of medical informatics in undergraduate medical education	Any informatics not involving undergraduate medical education
Primary Outcomes	Integration, curriculum develop, and utilization of medical informatics in medical education and clinical skills	N/A
Types of study design	Systemic reviews, survey, cross-sectional, trials, cohort, longitudinal, literature review, controlled trials, case report, meta-analysis	N/A
Setting	Medical Schools in the United States	Non-United States
Years of publication	Articles published between 1990-2021	Articles published before 1990
Publication type	Published primary studies	
Databases	PubMed, CINAHL Search Strategies, Cochrane Library, Embase Search Strategies, and Web of Science	N/A
Language	English	Non-English

Table 1: *Study inclusion and exclusion criteria.*

Informatics education attempts in medical school: Defining how medical informatics have been taught in medical schools is vital for potential curricular updates. In 2007, The University of Arizona College of Medicine in Phoenix established a new Biomedical Informatics Department (BMI) which incorporated 45 hours of required sequenced and integrated instruction with BMI topics including an overview of BMI, privacy and security issues, and the use of online and handheld clinical decision support calculators and tools. They evaluated the effectiveness of this new curriculum via optional student evaluations using 16 first-year students and 17 second-year students. A bimodal distribution regarding the perceived value of such education was noted. This also included a pre- and post-test analysis of 25 students who completed the curriculum and identified significant improvement across comfort, understanding, and use of BMI tools and concepts. When comparing to another cohort of 32 students from another campus (Tucson, AZ) who did not complete the BMI curriculum, the Phoenix group had statistically significant differences from the standpoint of better comprehension of BMI definitions, relevance, barriers, mobile decision support, tools and techniques [6].

The University of Texas Health Science Center at San Antonio implemented two informatics focused trials between 1997-2000. The first trial (1997-1998) involved an intervention group that had focused student tutelage on how to search for medical evidence and how to appraise evidence in the clinical setting. The control group was not offered the focused education. Two-hundred third year medical students participated in the trial with no statistically significant difference noted relative to changes in self-reported frequency of literature searches (20% and 17%, respectively), satisfaction with quality of search output and results (32% and 28%, respectively), and satisfaction with the speed of searching (24% and 17%, respectively). In a second trial (1999-2000), the intervention group was offered specialized website access focused on automated searches for educational and medical evidence. The study was completed by 157 students where 84 students utilized the customized Internet browser, but no statistically significant differences in self-reported habits were noted between groups. However, when comparing the two trials, the frequency and satisfaction with the searches increased significantly [7].

A report from 2004 attempted to identify learning objectives, teaching innovations, and student outcomes for teaching medical informatics (MI) in medical schools that participated in the Undergraduate Medical Education for the 21st century (UME-21) curriculum project. Five categories for MI literacy had been adapted from the Medical School Objectives Project (MSOP). These categories were: Role of the Lifelong Learner (accessing, evaluating, and using information and databases), Role of Clinician (obtaining patient information, using decision support), Role of Educator/Learner/Communicator (accessing information for patient education, student-teacher communication, studying Web-based cases, making presentations, accessing on-line course information), Role of Researcher/Evaluator (documenting patient encounters), and Role of Manager (using drug formularies and clinical guidelines). Graduating medical students from UME-21 partner schools reported high levels of involvement with many of the MI skills tracked in the study. For most study categories, the indicators increased from the 1999 cohort (seniors untrained in the UME-21 curriculum) to 2001 cohort (majority of seniors trained for 2 years of UME-21). The 2001 vs 1999 survey suggested that a high percentage of graduates from the UME-21 schools judged that they regularly used the Internet to obtain information for care of their patients (97% vs 91%), were adequately exposed to searches using medical information databases (94% vs 94%), used practice guidelines established by national or managed care organizations (93% vs 88%), and used a computer-based clinical record system (90% vs 78%). Overall, the data showed increases in the levels of educational experiences reported by medical schools over the two-year study period [8].

As noted, limited studies report the attempts and outcomes of integration of informatics within medical school curricula with objectives, training methodology, and implementation modalities varying across publications. Overall, the medical schools that did attempt to include medical informatics in medical training demonstrated a positive outcome in regard to their knowledge of information sciences.

Adoption of informatics in medical students' assessment: The assessment of medical student performance when integrating informatics into the medical school curriculum is vital as it helps determine the benefit, value, and impact of such a training. A study completed at Case Western Reserve University assessed the self-perceived skills of 1st and 2nd year medical students based on levels of achievement

in the AAMC's five domains of medical informatics of life-long learner, educator/communicator, clinician, researcher, and manager [9]. To set a baseline, the information was gathered from two classes who did not have medical informatics also integrated in their curriculum with results suggesting lack of confidence in the ability to apply medical informatics while providing care.[9] This study helped delineate the need for formal medical informatics training to ensure medical students gain skills needed for effective and efficient clinical performance.

In 1998, the AAMC initiated the MSOP to identify the relevance of medical informatics to the physician and proposed the five core objectives listed earlier to be added to the medical school curriculum. In 2007, the impact of the MSOP guidelines was measured through a survey of 70 medical schools in the United States and Canada. The study findings suggested that some progress has been made, as a limited number of medical schools had incorporated medical informatics concepts within their curricula, much more was still needed to ensure that graduating physicians will be able to efficiently and effectively use the health information technology [10].

In 2011, the Rosalind Franklin University of Medicine and Science, researched the impact of using informatics tools, such as a diagnostic reminder system, on student clinical reasoning while practicing on simulated case studies. This study demonstrated the positive impact of incorporating informatics into clinical training and the improvement in diagnostic accuracy. The study was conducted with fourth year medical students who received a 2-hour training session on the overview of the informatics system, specifically the Isabel PRO system, general principles for entering a search query, and how to interpret query results. The subjects then participated in a multi-station simulated patient exercise designed to assess diagnostic accuracy [11]. This study evaluated students' differential diagnosis, first those without the PRO system, second those who could use PRO system during the simulated case, and then those who used the system after the case. Paired t-testing demonstrated significant improvement ($p < 0.05$) in diagnostic accuracy after implementing the PRO system [11].

One of the primary objectives in medical education is to deliver up to date education and train students with the best tools and resources available. Additionally, providing medical students with how to best use specific informatic tools within clinical situations, 'gold standard' examples, was a critical and essential learning methodology. Because these tools improve clinical results and patient safety, the AAMC suggested formally incorporating informatics tools into medical curricula [4]. Even back in 2006, up to 81% of surveyed medical students and residents agreed that "teaching of technology skills should be part of medical curriculum" [12]. A contemporary study noted that 92% of students believed that healthcare related technology should be taught specifically in medical school [13].

Medical student ability to utilize medical informatics/technology: Understanding how medical students utilize MI and technology in real-life clinical applications for their education and training is necessary. One study evaluated undergraduate medical students relative to how well prepared they were for the transition to residency. Anderson et. al assessed this by examining how students "efficiently used electronic tools to locate high-quality evidence among available resources and how to rapidly and critically appraise literature to immediately impact clinical practice at the point-of-care" [14]. The setting for the study was based on a fourth-year capstone course in evidence-based medicine (EBM). This course required students to access high-quality publications using electronic resources and find up-to-date evidence-based literature, to utilize applications permitting for evidence-based decisions in clinical settings, and to evaluate meta-analyses and guidelines for patient care. Of the 161 participants where 71% had gone to match into specialties, student average knowledge assessment score significantly improved compared to baseline (47% vs. 68% correct on pre- vs. post-assessments, $p < 0.001$). These gains in knowledge were significant for ability to access literature and interpret meta-analyses ($p < 0.001$), independent of gender, year, or specialty.

Jacobs., *et al*. in 2017 looked at medical students' attitudes towards using health information technology (HIT) from the perceived usefulness and ease of use standpoints [15]. A 72-item survey was distributed to students at Nova Southeastern University College of Osteopathic Medicine during their UME, from the first year to graduation. Students were assessed regarding prior technology experience with a response rate of 61%. "Only 34 respondents (5.6%) reported that their school had an established approach for students learning HIT, and only 54 (9%) reported they had been instructed on the use of EHRs in medical school". Similarly, Krause surveyed first

and second-year medical students at Case Western Reserve University relative to their perceived levels of achievement in the five areas of medical informatics: lifelong learner, clinician, educator, researcher, and manager. With a response rate of 45%, the 128 student respondents rated their perceived level of achievement highest in the use of online resources and use of software to make graphs and prepare presentations. However, the ability to use clinical information systems for accessing databases were labelled as the lowest competencies. The students demonstrated interest for more formal education in these areas [9].

As the use of health informatics expanded into developing and improving clinical skills, the resultant transformation of medical education became a focus of various studies. Kalet looked at 162 second year medical students during the introductory course to bedside diagnosis with the implementation of three different approaches to using health information technology to teach abdominal exams [16]. The students were randomly assigned (1:1:1) to Watch, Drag, or Click versions of the abdominal exam module. Those in the Watch group were provided only with the abdominal examination computer video with the simple stop-and-go functionality. Those in the Drag group were able to click and drag tools in motions simulating actual performance of the task while those in the Click group used the mouse to trigger demarcated animated demonstrations. A pretest addressed baseline student knowledge, spatial ability, and prior experience with abdominal exams, whereas a posttest included demonstrations of the abdominal exam on a standardized patient and a structured note writing of the findings. Students in the Click group (65%) exhibited better physical exam skills performance than those in the Drag (56%) or Watch groups (58%). They also found that more students in the Click (89.8%) and Drag (92.3%) groups correctly diagnosed the standardized patient (SP) as having specific medical conditions than students in the Watch group (81.0%). Active engagement using computer assisted instruction had been previously assessed by Romanov., *et al*. where they demonstrated that embedding video clips in modules improved the learning outcomes [17]. Of the 121 second-year medical student involved, those that watched the videos were more active in discussion forums and achieved better course grades. Thus, the Kalet and Romanov studies suggest that integrating various forms of computer informatics in medical education may improve medical student knowledge and clinical skills.

Another study looked at the engagement of students and their interest in the use of case logging aids. The Edward Via College of Osteopathic Medicine (VCOM) devised an application to educate users on improved ICD-10 coding, for billing both diagnostic and procedural codes used in the clinical setting. The 540 third-year medical students logged their clinical experiences across various rotations and experiences with medical informatics playing a role in expanding a student's knowledgebase and experience [18].

Medical student interactions with electronic health records: The use of electronic medical records (EMR) by medical students is becoming more widespread with value attributed to their contributions. Thus, it is critical to train students to reliably and confidently contribute to the healthcare team activities. Attitudes towards confidentiality within the electronic health records (EHR) system was assessed in first year medical students at Vanderbilt University [19]. The students were given introductory biomedical informatics lectures that consisted of two half-hour sessions covering general concerns related to patient confidentiality, computerized records, and outlined specific policies. Students were thereafter queried (response rate of 94%, 97 of 103 enrolled) on their handling of various situations such as if a fellow student sold specific patient information to the media, whether they would respond differently if the student had sold a password to enter the system, and whether sensitive medical records such as those of prominent persons should be given extra security measures.

Currently no EMR-related competencies are required in Accreditation Council for Graduate Medical Education or in the United Stated Medical Licensing Examination. Few medical schools have integrated teaching effective use electronic health records into their curricula, and many do not have explicit processes for assessing medical informatics competencies. Alpert Medical School of Brown University developed a longitudinal medical informatics curriculum focusing on EHR in the clinical setting. This was achieved by educating third year medical students on "Effective Communication with Electronic Medical Records" and facilitating simulated patient encounters with the use of EHR. Outcomes were assessed through direct observation of the student's EHR use and communication skills and self-reflection of students [20]. A study looking at medical student utilization of EHR in the clinical setting during the 2015- 2016 academic year looked at

49 third-year medical students who spent 4.42 hours daily in EHR software while rotating on the internal medicine service in Madison, WI. It assessed the importance of EHR as an educational resource for students while engaging them in patient care. The study suggested that students primarily focused upon chart review and less on documentation and order entry, suggesting that higher engagement may not correlate with efficiency [21]. Moreover, the study concluded that a structured curriculum for proper use of EHR may optimize student time and focus their efforts appropriately.

Ellaway reported that "simply providing didactic based instruction on HER use does not lead students to transfer their knowledge to practice suggesting that EHR use is better learned through direct hands-on practice" [22]. This correlated with Stevens., *et al*.'s study that investigated medical student interest in EHR documentation [23]. This was accomplished by permitting medical student note writing and subsequent integration into the billable encounters in August 2018. A statistically significant increase was noted in student authored notes from a standpoint of content and relevance while enhancing their engagement and learning.

However, another study looked at the perpetuation of redundancy (i.e. copying and pasting) in medical student notes in EMRs. Looking at 94 medical students' notes from Vanderbilt University, including H&Ps and progress notes, they found that the H&Ps had approximately 35 to 40% redundancy in physical exam findings, assessments, and plans. Similarly, nearly 80% redundancy was noted for physical exams and almost 60% for assessment/plans. When analyzing for redundancy in the assessment/plan section based on USMLE Step II CK percentiles, the lowest third of scores had a cluster of higher redundancy. Additionally, this redundancy was significantly proportionately higher in the lowest third than in the upper third (67% vs 38%) [24]. A prospective, controlled study from March of 2003 to April 2004 surveyed 143 medical students from Johns Hopkins University School of Medicine at the conclusion and start of the rotations based on electronic and paper order entry using three teaching hospitals. Hospital A used computerized provider order entry (CPOE), Hospital B used paper orders until November 2003 and switched to CPOE until April 2004, and Hospital C used only paper orders. Ninety-five percent of students believed that placing orders helps students learn what tests and treatments patients need. Students at hospitals using CPOE reported placing significantly fewer of their patients' follow-up orders compared to students at hospitals using paper orders. This was due to increased time spent by residents reviewing computer orders compared to written ones (25% vs. 50%, $p < 0.01$) [25]. As this has been recognized as a concern, focus by institutions included augmenting EHR education to improve both medical student engagement as well as identify ways to optimize physician documentation processes. To better train their students and enhance their abilities, the University of Minnesota implemented a new course within their curriculum, Epic 101, across six institutions that use HER [26]. The standardized training permitted for effective preparedness of more than 443 students who successfully passed the accompanying assessment and ultimately resulted in the replacement of the multiple hospital specific training setups.

As health care information technology is vastly and rapidly changing, it is vital to keep pace with the new and improving medical technology that students may have exposure to. This necessitates the structured training and developed competencies in EHR use that permit for student success. As such, education in optimal EHR use is necessary before graduation as the focus thereafter needs to be on patient care.

Discussion

Medical schools have attempted the integration of informatics using variable components of the suggested 1998 AAMC objectives. However, there has been no consistent methodology for how the UME applied such recommendations within the institutions as some selectively adopted subsets and overlooked the rest. Reasons for such variability remain unclear; however, this may stem from the lack of updated recommendations. The peer-reviewed literature available to date does not suggest the availability of formalized curricula addressing informatics in healthcare that are aligned with current healthcare and medical student education needs. This is especially evident in the lack of recent publications focusing on the implications of integration of EHR into patient care following the implementation

of the 2009 Health Information Technology for Economic and Clinical Health (HITECH) Act which promoted the adoption and meaningful use of health information technology.

Similarly, the paucity of focused education on informatics and structured utilization of technologies, such as the EHR (accessing clinical information), were reflected in absence of either established or formalized curricula in certain programs, as identified by both Jones and Jacobs [15,27]. This was evident in the reported lack of comfort of medical students entering the clinical environment and needing to access to EHR. The relationship between provider, patient and computer can be optimized with implementation of focused education that integrates medical informatics and EHR courses in the medical curriculum.

When assessing the effect of adoption of informatics in medical school assessments, marked impact has been noted in the acquisition of information and formal assessment arenas. Anderson's assessment of the outcomes of informatics on a capstone class, from the access to data, literature appraisal, and metanalysis interpretation standpoints, suggested significant positive effects especially that such skills are critical to overall physician success [14]. This demonstrates the notable potential of targeted medical informatics curricula on the development of upcoming physicians.

Limitation of the Study

The limitations of this study include the use of a compilation of non-uniform study designs and types. This is partly due to the small number of references available to review. Similarly, the assessment is qualitative in nature and thus objective appraisal may not be as plausible. From a topic standpoint, the variability across the reviewed articles does not permit for adequate comparison to develop recommendations supporting a specific methodology for standardization of curricula in US medical education, except the uniform need for formal integration in the curricula nationally. The strengths of the study includes the number of manuscripts assessed and included, methodology used in the review, as well as the peer-reviewed nature of the studies assessed.

Conclusion

Despite marked attempts at integration of informatics in UME, the data suggests that efforts may have been unaligned - possibly due to the lack of well-defined objectives. Given the dates of publication of peer-reviewed manuscripts relative to the recent extensive integration of EHR into the healthcare landscape, the current data available may not be representative of what is currently occurring in the UME world. Future direction will require guidance by studies focusing on the evolving state of informatics across the nation, while ensuring the integration of formal objectives that are devised by a national licensing body.

Presentations

The findings of our study were accepted for presentation at The Central Association of Obstetrics and Gynecology (CAOG) Annual Meeting.

Acknowledgement

We would like to thank Margaret Hoogland for her help with the literary search.

Appendix

Appendix A: Search Strategies

PubMed Search Strategies

(health informatics[all fields] OR health informatic[all fields] OR clinical informatics[all fields] OR informatics training[all fields] OR medical informatics[all fields])) OR (health informatics[mesh] OR health informatic[mesh] OR clinical informatics[mesh] OR informatics training[mesh] OR medical informatics[mesh])) 86143

medical student[all fields] OR medical student[mesh] OR medical school[all fields] OR medical school[mesh] OR undergraduate medical education[all fields] OR undergraduate medical education[mesh] OR pre-clerkship education[all fields] OR pre-clerkship education[mesh] OR preclerkship education[all fields] OR preclerkship education[mesh] OR pre clerkship education[all fields] OR pre clerkship education[mesh] OR clinical clerkship[all fields] OR clinical clerkship[mesh] clinical education[mesh] OR clinical education[all fields] OR clinical apprenticeship[mesh] OR clinical apprenticeship[all fields] OR foundational science course[mesh] OR foundational science course[all fields] 1242105

(health informatics[all fields] OR health informatic[all fields] OR clinical informatics[all fields] OR informatics training[all fields] OR medical informatics[all fields])) OR (health informatics[mesh] OR health informatic[mesh] OR clinical informatics[mesh] OR informatics training[mesh] OR medical informatics[mesh]) AND (medical student[all fields] OR medical student[mesh] OR medical school[all fields] OR medical school[mesh] OR undergraduate medical education[all fields] OR undergraduate medical education[mesh] OR pre-clerkship education[all fields] OR pre-clerkship education[mesh] OR preclerkship education[all fields] OR preclerkship education[mesh] OR pre clerkship education[all fields] OR pre clerkship education[mesh] OR clinical clerkship[all fields] OR clinical clerkship[mesh] clinical education[mesh] OR clinical education[all fields] OR clinical apprenticeship[mesh] OR clinical apprenticeship[all fields] OR foundational science course[mesh] OR foundational science course[all fields]) 7180

(health informatics[Title/Abstract] OR health informatics[Title/Abstract] OR clinical informatics[Title/Abstract] OR informatics training[Title/Abstract] OR medical informatics)[Title/Abstract]) 5642

(health informatics[Title/Abstract] OR health informatics[Title/Abstract] OR clinical informatics[Title/Abstract] OR informatics training[Title/Abstract] OR medical informatics)[Title/Abstract]) AND (medical student[all fields] OR medical student[mesh] OR medical school[all fields] OR medical school[mesh] OR undergraduate medical education[all fields] OR undergraduate medical education[mesh] OR pre-clerkship education[all fields] OR pre-clerkship education[mesh] OR preclerkship education[all fields] OR preclerkship education[mesh] OR pre clerkship education[all fields] OR pre clerkship education[mesh] OR clinical clerkship[all fields] OR clinical clerkship[mesh] clinical education[mesh] OR clinical education[all fields] OR clinical apprenticeship[mesh] OR clinical apprenticeship[all fields] OR foundational science course[mesh] OR foundational science course[all fields]) 474

CINAHL Search Strategies

MH “Schools, Medical” OR MH “Students, Medical” OR medical students OR medical school OR undergraduate medical education OR pre-clerkship education OR pre clerkship education OR preclerkship education OR clinical clerkship OR clinical education OR clinical apprenticeships OR foundational science courses OR foundational sciences curricula OR basic science courses OR basic science curricula 70068

TI (health informatics OR medical informatics OR clinical informatics OR medical informatics OR informatics training) OR AB (health informatics OR medical informatics OR clinical informatics OR medical informatics OR informatics training) 6114

(MH “Schools, Medical” OR MH “Students, Medical” OR medical students OR medical school OR undergraduate medical education OR pre-clerkship education OR pre clerkship education OR preclerkship education OR clinical clerkship OR clinical education OR clinical apprenticeships OR foundational science courses OR foundational sciences curricula OR basic science courses OR basic science curricula) AND (TI (health informatics OR medical informatics OR clinical informatics OR medical informatics OR informatics training) OR AB (health informatics OR medical informatics OR clinical informatics OR medical informatics OR informatics training)) 224

Cochrane Library (Wiley)

#1 MeSH descriptor: [Students, Medical] explode all trees 1134

#2 MeSH descriptor: [Schools, Medical] explode all trees 74

#3 MeSH descriptor: [Education, Medical, Undergraduate] explode all trees 834

#4 MeSH descriptor: [Clinical Clerkship] explode all trees 168

#5 MeSH descriptor: [Medical Informatics] explode all trees 9218

#6 (medical students OR medical schools OR undergraduate medical education OR #1 OR #2 OR #3 OR #4 OR foundational sciences course OR basic science course OR clinical clerkship OR clinical education OR Clinical apprenticeship OR foundational science curricula OR basic science curricula) 68094

#7 (health informatics OR medical informatics OR clinical informatics OR informatics training):ti,ab,kw 558

#8 (health informatics OR medical informatics OR clinical informatics OR informatics training):ti 32

#9 (health informatics OR medical informatics OR clinical informatics OR informatics training):ab 249

#10 #8 OR #9 268

#11 #10 AND #6 59

Embase Search Strategies

1 'health informatics'/exp OR 'health informatics' OR 'clinical informatics'/exp OR 'clinical informatics' OR 'medical informatics'/exp OR 'medical informatics' OR 'informatics training' 86143

2 'medical student' OR 'medical school' OR 'undergraduate medical education' OR 'pre-clerkship education' OR 'preclerkship education' OR 'pre clerkship education' OR 'clinical clerkship' OR 'clinical education' OR 'clinical apprenticeship' OR 'foundational science course' OR 'foundational science curricula' OR 'basic science course' OR 'basic science curricula' 1242105

3 ('health informatics'/exp OR 'health informatics' OR 'clinical informatics'/exp OR 'clinical informatics' OR 'medical informatics'/exp OR 'medical informatics' OR 'informatics training') AND ('medical student' OR 'medical school' OR 'undergraduate medical education' OR 'pre-clerkship education' OR 'preclerkship education' OR 'pre clerkship education' OR 'clinical clerkship' OR 'clinical education' OR 'clinical apprenticeship' OR 'foundational science course' OR 'foundational science curricula' OR 'basic science course' OR 'basic science curricula') 7180

4 'health informatics':ti,ab OR 'clinical informatics':ti,ab OR 'medical informatics':ti,ab OR 'informatics training':ti,ab 5642

5 ('medical student' OR 'medical school' OR 'undergraduate medical education' OR 'pre-clerkship education' OR 'preclerkship education' OR 'pre clerkship education' OR 'clinical clerkship' OR 'clinical education' OR 'clinical apprenticeship' OR 'foundational science course' OR 'foundational science curricula' OR 'basic science course' OR 'basic science curricula') AND ('health informatics':ti,ab OR 'clinical informatics':ti,ab OR 'medical informatics':ti,ab OR 'informatics training':ti,ab) 691

6 ('medical student' OR 'medical school' OR 'undergraduate medical education' OR 'pre-clerkship education' OR 'preclerkship education' OR 'pre clerkship education' OR 'clinical clerkship' OR 'clinical education' OR 'clinical apprenticeship' OR 'foundational science

course' OR 'foundational science curricula' OR 'basic science course' OR 'basic science curricula') AND ('health informatics':ti,ab OR 'clinical informatics':ti,ab OR 'medical informatics':ti,ab OR 'informatics training':ti,ab) 474

Web of Science Core Collection Search Strategies

1 health informatics OR medical informatics OR clinical informatics OR medical informatics OR informatics training (Title) or preclerkship education OR pre clerkship education OR preclerkship education OR clinical clerkship OR clinical education OR clinical apprenticeships OR foundational sciences courses OR foundational sciences curricula OR basic science courses OR basic science curricula (Title) 7,778

2 health informatics OR medical informatics OR clinical informatics OR medical informatics OR informatics training (Title) or preclerkship education OR pre clerkship education OR preclerkship education OR clinical clerkship OR clinical education OR clinical apprenticeships OR foundational sciences courses OR foundational sciences curricula OR basic science courses OR basic science curricula (Title) and medical students OR medical schools OR undergraduate medical education (All Fields) 4,146

3 health informatics OR medical informatics OR clinical informatics OR medical informatics OR informatics training (Title) or preclerkship education OR pre clerkship education OR preclerkship education OR clinical clerkship OR clinical education OR clinical apprenticeships OR foundational sciences courses OR foundational sciences curricula OR basic science courses OR basic science curricula (Title) and medical students OR medical schools OR undergraduate medical education (Topic) 3,768

4 health informatics OR medical informatics OR clinical informatics OR medical informatics OR informatics training (Title) or preclerkship education OR pre clerkship education OR preclerkship education OR clinical clerkship OR clinical education OR clinical apprenticeships OR foundational sciences courses OR foundational sciences curricula OR basic science courses OR basic science curricula (Title) and medical students OR medical schools OR undergraduate medical education (Topic) and Articles (Document Types) 1,857

5 health informatics OR medical informatics OR clinical informatics OR medical informatics OR informatics training (Title) or preclerkship education OR pre clerkship education OR preclerkship education OR clinical clerkship OR clinical education OR clinical apprenticeships OR foundational sciences courses OR foundational sciences curricula OR basic science courses OR basic science curricula (Title) and medical students OR medical schools OR undergraduate medical education (Topic) and Articles (Document Types) and USA (Countries/Regions) 958.

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