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Research and Education

Twenty Five Years of Medical Informatics Education at Heidelberg/Heilbronn: Discussion of a Specialized Curriculum for Medical Informatics

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Abstract: The specialized university curriculum for medical informatics (MI) at the University of Heidelberg/School of Technology Heilbronn is one of the oldest educational approaches in the field of medical informatics, and has been successful for 25 years with about 1,000 *graduates (Diplom-Informatikerin der Medizin or Diplom-Informatiker der Medizin)*. It belongs to the category of dedicated master's programs for medical informatics and is based on the concept of medical informatics as a medical discipline in its own right. The curriculum is oriented towards the total spectrum of medical informatics ranging from health care economics, biosignal and medical image processing, medical documentation, to information and knowledge processing in medicine. It is a 4.5-year program with strong emphasis on the methodological foundations of medical informatics and on practical education in a number of specific laboratories. Thirty-five students are admitted each semester, and in total about 440 students are enrolled. The faculty consists of 17 full-time members and about 25 part-time lecturers. We report on characteristics, structure and contents of the new 5th version of the curriculum and discuss the features of a specialized curriculum for medical informatics with respect to the challenges for medical informatics in the 21st century.

Keywords: Medical informatics, health informatics, curriculum, education, training.

1. Introduction

In 1991, the International Medical Informatics Association, Working Group 1: Education (IMIA, WG1), suggested a classification of programs for medical informatics which lead to a university degree, certificate or diploma. The curriculum for medical informatics at the University of Heidelberg/School of Technology Heilbronn belongs to the category of dedicated master's programs for medical informatics, a synopsis of which was subject of the IMIA WG1 working conference in Heidelberg/Heilbronn in 1992 [1] on the occasion of the 20th anniversary of the Heidelberg/Heilbronn curriculum. The experience gained in this approach [2] has influenced curriculum recommendations in the field of medical informatics issued by the German Association for Medical Informatics, Biometry and Epidemiology (GMDS) [3]. In particular, it has influenced the revised 5th version of the curriculum, which is described here, and which has been coordinated by the authors. The start of this new version of the curriculum coincides with the 25th anniversary of the program and an ongoing intensive discussion with respect to a systematization of medical informatics and the challenges for medical informatics in the 21st century [4-7].

2. General Characteristics

2.1 Students-Education-Graduates

The course, founded in 1972, is run jointly by the University of Heidelberg and the School of Technology Heilbronn, the Medical Faculty Heidelberg being responsible for the medical education part and the Department of Medical Informatics Heilbronn for the informatics part. Responsibilities for

Students	Education	Graduates
Number of students enrolled : 440 students accepted/semester : 35 applicants/semester : 70 - 400	Number of semesters : 9 Number of weeks/sem. : 16 Total number of teaching hours : 2,700 Staff: 17 full, 25 part-time	Degree : *Diplom Informatiker(in) der Medizin* Number of graduates : 1,000 with doctor's degree: > 90 Job opportunities : good

Fig. 1. Features of the curriculum for Medical Informatics at Heidelberg/Heilbronn

specific medical informatics subjects have been established both in Heidelberg and in Heilbronn.

Graduates are awarded the title *Diplom-Informatikerin der Medizin* or *Diplom-Informatiker der Medizin (Dipl.-Inform. Med.)* by the Medical Faculty of the University of Heidelberg. The degree is comparable to a Master of Science degree. Graduates can achieve a Ph.D. as *Doctor Scientiarum Humanarum (Dr. sc. hum.)* at the University of Heidelberg. A post-graduate *Certificate ‚Medical Informatics'* [8] can be obtained from the German Association for Informatics (GI) and GMDS after five years of professional qualification in the field of medical informatics.

The intended program length is 4.5 years, comprising 8 study semesters (16 weeks per semester) and one semester for the diploma thesis. The *effective* length of the studies is currently about 6 years due to the complexity of the program. However, one of the goals of the last curriculum revision is to solve this problem.

The faculty consists of 17 full-time lecturers from the Department of Medical Informatics and other departments of the School of Technology Heilbronn and from the Medical Faculty of the University of Heidelberg. About 25 part-time lecturers come from the University of Heidelberg, neighboring teaching hospitals, scientific research centers, and the computer industry.

General characteristics and features of the curriculum are shown in Fig. 1.

2.2 Program Philosophy, Objectives and Focus

The curriculum philosophy is based on the concept that medical informatics is a scientific medical discipline in its own right, as is argued in detail in [9]. This philosophy entails that the program is oriented towards the *total* spectrum of medical informatics ranging from health care economics, biosignal and medical image processing, medical documentation, to information and knowledge processing in medicine. Furthermore, medical informatics is an integral part from the beginning of the studies, with a close contact to medical practice.

The objectives of the curriculum are to provide methodological foundations for medical informatics, and the methods for medical informatics themselves, to prepare graduates for careers in medical informatics in academic, hospital or industrial settings. Graduates of the program must be able to apply methods and tools of medical informatics, and to participate in research and methodological development in the field of medical informatics. The field of work assigned to them is diversified, as shown in an inquiry among graduates [2] (Fig. 2).

The Heidelberg/Heilbronn medical informatics curriculum is an *informatics-related* approach to medical informatics ([3], p 64). Graduates

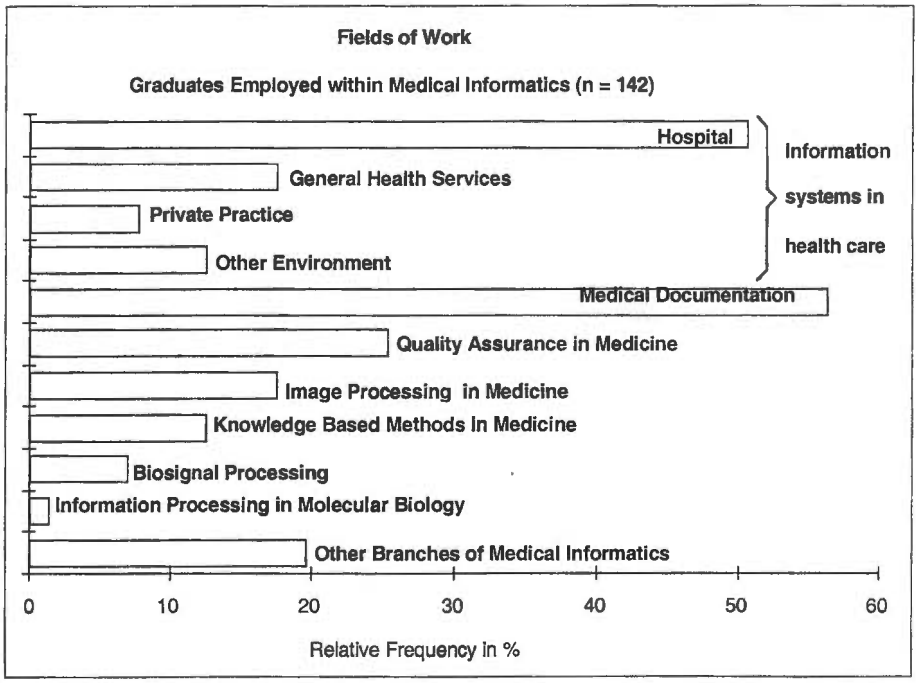

Fig. 2. Fields of work of graduates employed within medical informatics (n=142). Graduates were asked to indicate subsections of medical informatics, to which their activities are assigned. Only those fields were to be indicated which, on average, take at least 10% of their working hours. Response options were given; multiple responses were allowed [2].

should have better professional chances in medical informatics than informatics graduates (and, also, physicians). On the other hand, they should also be able to compete with informatics graduates for informatics positions outside medicine and health care.

2.3 Evolution of the Curriculum

Since its beginning and up to its current 5th version, the Heidelberg/Heilbronn medical informatics curriculum focussed on an informatics-related approach to medical informatics. However, the 5th version introduced some important changes in the structure of the program.

Although there are still many courses in „standard informatics", especially for software engineering [10], as well as courses in the fundamentals of medicine and other fields such as medical biometry [11], one major change in the 5th version of the curriculum is the introduction of a sequence of courses devoted to medical informatics (Fig. 3). As discussed in [9] and [12], with respect to the 3rd and 4th versions of the curriculum, we are again moving one step to medical informatics as being a discipline not just based on methods and tools of informatics applied to medicine and health care.

This movement was an important factor in redesigning the program. The more medical informatics is becoming a recognised discipline of its own [13,14] with distinctive fields, the more this has to be reflected and even promoted in the structure and content of medical informatics programs.

The evolution of the curriculum has been strongly influenced by the results of the five IMIA WG1 conferences in Lyon (1974), Chamonix (1983), Victoria (1989), Prague (1990), and Heidelberg/Heilbronn (1992), which are the predecessors of the conference in Newcastle (1997), and curriculum recommendations from various organizations (Fig. 3). On the other hand, the Heidelberg/Heilbronn curriculum MI itself has influenced recommendations, e.g. for granting a certificate in medical informatics for qualified professionals, and the GMDS recommendations for education and training in MI [3].

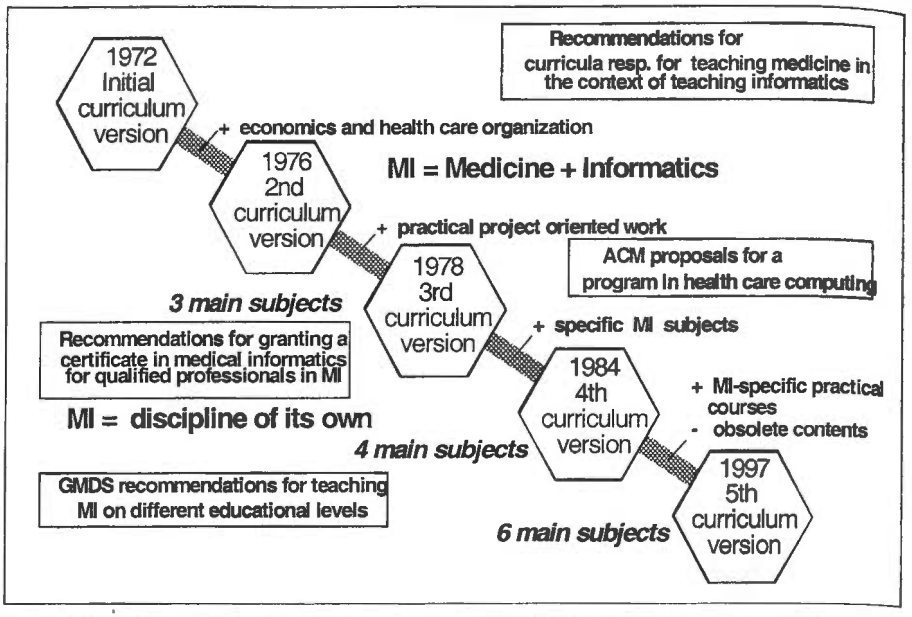

Fig. 3. Evolution of the curriculum MI Heidelberg/Heilbronn over 25 years comprising four curriculum revisions.

2.4 Curriculum Revision

Triggers for the revision (Fig. 4) of the 4th curriculum version [15] which led to the current version of the program were: known weaknesses of the organization of the 4th version, feedback from the graduates [2], the intensive ongoing discussion on the systematization of medical informatics [4,5,16], the increasing breadth of medical informatics [6,7], the international status of education in medical

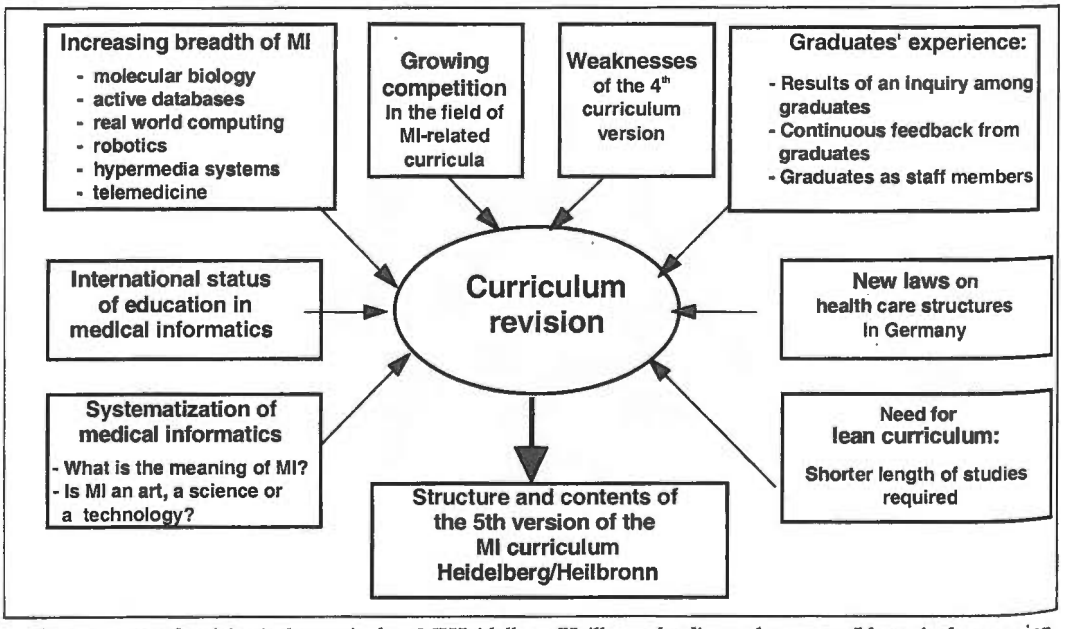

Fig. 4. Process of revision in the curriculum MI Heidelberg/Heilbronn leading to the current 5th curriculum version.

informatics [1,17,18], the growing competition in the field of MI-related curricula, new laws on health-care structures in Germany, and the above-mentioned requirement to reduce the length of studies.

Furthermore, besides the need to cover many new application fields of medical informatics, the evolution of the discipline of medical informatics (discussed at the IMIA-conference 1992 in Heidelberg/Heilbronn) was of special importance: This evolution is characterized by the paradigm shift from medical informatics primarily meaning the application of general methods of informatics to medicine, to being conceived as a discipline comprising the development of specific methods and tools of its own for handling problems in medicine and health care.

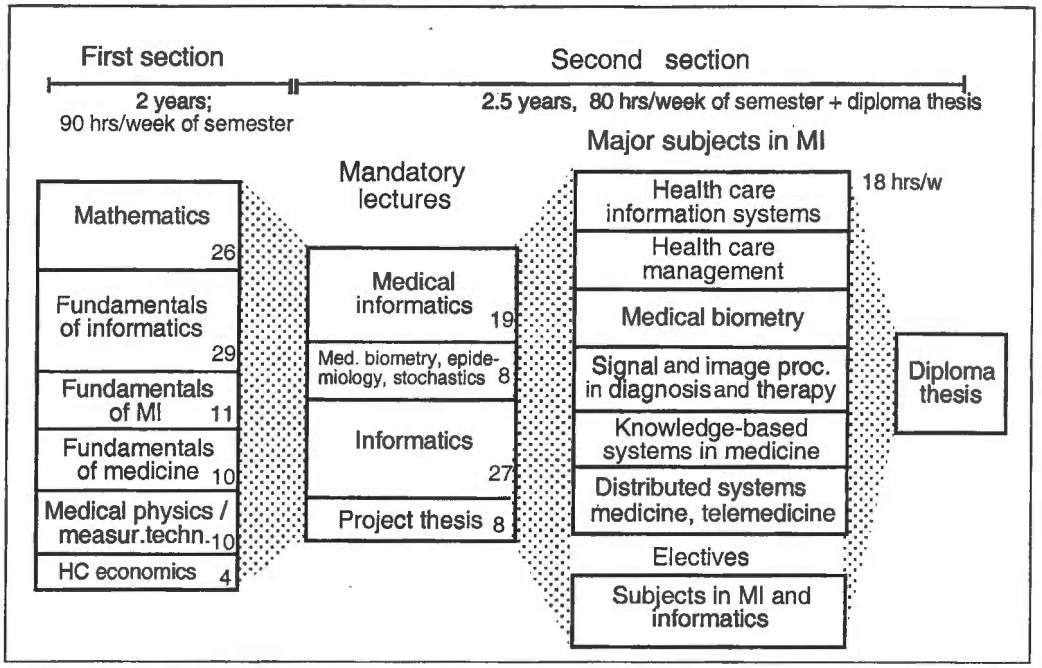

Fig. 5. Overview of the curriculum MI Heidelberg/Heilbronn (current 5th version), its subdivision into first and second sections, and the major subjects. The numbers in the boxes indicate the number of hours/week of semester. One hour/week of semester means one teaching hour every week of a semester. One semester comprises 16 weeks. Thus, one hour/week of semester means a total of 16 teaching hours.

3. Program Structure and Contents

3.1 Program Structure

The integration of medical informatics into the curriculum described above is reflected by the curriculum structure (Fig. 5). The first section covers fundamentals, especially of informatics and medical informatics, as well as fundamentals of mathematics, medical physics, electrical measurement techniques, medicine, and health economics. The second section comprises mandatory lectures in medical informatics, in informatics, and in medical biometry, epidemiology and stochastics, and six major subjects in medical informatics.

The major subjects are:

1. Health care information systems:
   Design, implementation and application of database systems in health care; selected topics of information systems of health care, especially of hospital information systems.
2. Health care management:
   Functional description of hospital information systems, especially of application systems for hospital administration and for patient management.
3. Medical biometry:
   Advanced methods of medical biometry and epidemiology; models in biometry; planning, conducting and analyzing clinical studies.
4. Signal and image processing in diagnosis and therapy:
   Recording, storage and analysis of signals and images in medicine (e.g., ECG, EEG, X-ray, CT and MR images); development and application of methods of pattern recognition for decision support in diagnosis and therapy planning [19].
5. Knowledge-based systems in medicine:
   Advanced methods and tools for knowledge-based decision support in diagnosis and therapy; structuring and modeling of medical knowledge and of decision processes in diagnosis and therapy; integration of decision support systems in hospital information systems.
6. Distributed systems in medicine, telemedicine:
   Foundations for distributed systems in health care; interoperability of and information exchange between application systems of a regional health care system; features of remote access to external data and knowledge sources, applications of telemedicine, virtual reality in medicine.

3.2 Curriculum Contents

3.2.1 Mathematical Foundations and Electrical Measurement Techniques

Courses in mathematics (Table 1) are specific for informatics and medical informatics, especially with respect to discrete mathematics and numeric mathematics needed by various methods in the spectrum of medical informatics. Similarly, the foundations of electrical measurement techniques, including medical physics, cover topics specific for medical informatics.

Table 1. Courses in mathematical foundations and electrical measurement techniques in the curriculum MI Heidelberg/Heilbronn (current 5th version). The number of hours/week of semester is indicated in parentheses.

Education part	Course/lecture/practical course
Mathematics	-Mathematics for informatics: lectures (18) and exercises (8)
Electrical measurement techniques	-Medical physics (3) incl. exercises -Electrical measurement techniques (7) incl. practical course

3.2.2 Courses in Medicine and Medical Informatics

The *medical* education part (Table 2) concentrates on fundamentals of human medicine (anatomy, physiology, biochemistry) and basic knowledge of medical disciplines (internal medicine, surgery, etc.).

The education in *medical informatics* (Table 2) in the first curriculum section comprises introductory courses for e.g., fundamentals of the health care system, medical documentation, medical methodology, fundamentals of information systems in health care, and fundamentals of bioelectrical systems. They are the basis for the corresponding advanced courses in the second section, and also for the major subjects.

Of special importance is the practical course *information systems in health care,* which reflects the strong emphasis on analytical methods in the professional spectrum of medical informaticians. In a larger project, usually focusing on analyzing and evaluating parts of the information system of a health care institution, students are introduced to teamwork, project management and interaction with health care professionals, and the practice of methods and tools for managing health care information systems.

3.2.3 Courses in Informatics

According to the curriculum philosophy, courses in informatics are typically oriented towards the application area medicine and health care. Within the framework of theoretical, practical and technical informatics, most emphasis is given to practical informatics (Table 3).

The software laboratory education with a set of practical courses in *programming in the small, programming in the large*, and *programming in the many* in a software laboratory environment aims at project-oriented team-organized practical software development training with software management, application of methods and tools, and project library [10]. It can be regarded as a continuation of the practical course *information systems in health care* described above. The philosophy of the software education is to conceive a software system not primarily as a collection of programs, but as a solution of problems which requires high personnel capabilities, especially with respect to analytical tasks, and adequate familiarity with the methods and tools of *software engineering, data engineering* and *knowledge engineering* approaches to improve software productivity. In this context, software paradigms like *the re-use* of components from an object-oriented hierarchy of classes, *prototyping* systems to reduce the application risk, *semantic data modeling* to capture more meaning of the area of discourse, and *formal specification* of software requirements to describe program semantics and apply automatic transformation procedures, play an important role.

3.2.4 Course in Health Care Economics

A course *health care economics* is offered in the first curriculum section as a foundation for the advanced topics in the corresponding major subject in the second curriculum section, reflecting the growing importance of this area within medical informatics (Table 4).

3.2.5 Courses in Medical Biometry, Epidemiology and Stochastics

Courses in medical biometry, epidemiology and stochastics (Table 5) are mandatory in the second curriculum section [11]. The course *stochastics* provides the fundamentals of probability theory and statistics. The course *fundamentals of medical biometry and epidemiology* covers design and analysis of clinical and epidemiological studies.

Table 2. Courses in medicine and medical informatics in the curriculum MI Heidelberg/Heilbronn (current 5th version). The number of hours/week of semester is indicated in parentheses.

Education part	Course/lecture/practical course
Medicine	- Fundamentals of human medicine and basic knowledge of medical disciplines (9) - Practical course *health care institutions* (1)
Medical informatics (first curriculum section)	- Introduction to medical informatics (1) - Medical methodology (2) - Fundamentals of bioelectrical systems (2) - Structure of the health care system (1) - Fundamentals of medical documentation (2) - Fundamentals of information systems in health care (1) - Practical course *MI in health care institutions* (1)
Medical informatics (second curriculum section)	- Information systems in health care, especially hospital information systems (4) - Practical course *information systems in health care* (6) - Knowledge-based decision support for diagnosis and therapy (2) - Medical documentation (2) - Medical image processing (2) - Medical signal processing (2)

Table 3. Courses in informatics in the curriculum MI Heidelberg/Heilbronn (current 5th version). The number of hours/week of semester is indicated in parentheses.

Theoretical Informatics	Practical Informatics	Technical Informatics
- Introduction to logic (1) - Theoretical informatics (5) - Compiler construction (2) - Coding theory and cryptography (2)	- Fundamentals (8) - Algorithms and data structures (4) - Software development (6) - Practical courses in software development (5) - Systems programming (3) - Database and information systems (4) - Knowledge-based systems (2) - Real time systems incl. practical course (4)	- Fundamentals incl. practical course (5) - Computer architectures (3) - Data transmission and computer networks (2) - Distributed systems and communication (2)

3.2.6 Courses in the Major Subjects

The students have to choose from one of the six major subjects (Table 6), comprising lectures with a volume of 6 hours per week plus a practical course/ seminar.

Additional elective courses (10 hours/week of semester) have to be chosen in accordance with the major subject courses. Furthermore, two seminars (each 1 hour/week of semester), one in the first and one in the second section of the course, and a project thesis (8 hours/week of semester) in the second section of the course are mandatory.

3.3 Program Technology

A central educational aim is not only to provide basic principles and discuss or simulate them, but to achieve practical, project-based and application-oriented education in small instructional groups (normally less than 35 students). For this purpose, there are several laboratories specifically for the education in medical informatics (Fig. 6).

The computer equipment comprises a multi-level supply concept:

1. Windows-based personal computers, Apple Macintosh systems, and UNIX-based workstations locally networked in pools for the practical education in software development, information systems, knowledge-based systems, and hypermedia.
2. Specialized laboratory computers, e.g., for biosignal and image processing and for sensor-based computing.
3. Client/server architectures including database servers, communication servers and computing servers in Heilbronn, in the university computer center in Heidelberg, and in the hospital computer center in Heidelberg.

A variety of upper and lower CASE tools supporting methods of software development, and systems which cover the entire software life cycle are available; the students are offered a number of programming languages, such as Ada, C, C++, Java, Lisp, Prolog, Smalltalk, etc.

Furthermore, database systems and expert system shells for different ways of knowledge acquisition, knowledge representation (rules, productions, frames, etc.) and knowledge processing (forward chaining, backward chaining, etc.) are available.

Finally, various tools packages for computer graphics, the management of time-oriented data, user interface design and generation, image processing, parser generation, version control, authoring tutorial systems, etc., are offered to the students.

Table 4. Course in health care economics in the curriculum of medical informatics at Heidelberg/ Heilbronn (current 5th version). The number of hours/week of semester is indicated in parentheses.

Education part	*Course/lecture/practical course*
Foundations of health care economics	- Health care economics (4) incl. exercises

Table 5. Courses in medical biometry, epidemiology and stochastics in the curriculum MI Heidelberg/Heilbronn (current 5th version). The number of hours/week of semester is indicated in parentheses.

Education part	*Course/lecture/practical course*
Stochastics	- Stochastics (4) incl. exercises
Medical biometry and epidemiology	- Fundamentals of medical biometry and epidemiology (4) incl. exercises

4. Discussion

The Heidelberg/Heilbronn curriculum for medical informatics is an informatics-related approach, but nevertheless intends to provide the students with a sound basic medical background in order to be able to understand and evaluate medical problems to be solved.

In contrast to most of the dedicated programs [18] dealing explicitly with health informatics (e.g. the health information science program at the University of Victoria, [20]) the Heidelberg/Heilbronn medical informatics curriculum comprises both mandatory lectures on information processing in health care *and* mandatory lectures related to medical informatics in its narrower meaning including the biomedical engineering field. Even in the major subjects a student has both options, as outlined above. We have positive experience with teaching medical informatics, comprising the whole domain of processing data, information and knowledge in medicine and health care to provide our graduates with a

Table 6. Courses in the major subjects in the curriculum MI Heidelberg/Heilbronn (current 5th version). The number of hours/week of semester is indicated in parentheses.

Major subject	*Course/lecture/practical course*
Health care information systems	- Database systems in health care (2) - Health care information systems (2) - Practical course *database and information systems in health care* (2)
Health care management	- Hospital informatics (4) - Seminar *hospital informatics* (2)
Medical biometry	- Medical biometry and epidemiology (advanced course) (2) - Models in biometry (2) - Practical course *medical biometry* (2)
Signal and image processing in diagnosis and therapy	- Medical signal processing (advanced course) (2) - Medical image processing (advanced course) (2) - Practical course *medical signal and image processing* (2)
Knowledge-based systems in medicine	- Knowledge-based decision support in diagnosis and therapy (4) - PC *knowledge-based decision support in diagnosis and therapy* (2)
Telemedicine	- Distributed systems in medicine.(4) - Practical course *distributed systems in medicine* (2)

broad background in medical informatics. However, the growing breadth of medical informatics as described in [7] makes it increasingly difficult to cover the whole spectrum in one curriculum.

One of the highlights of the health information science program at the University of Victoria is its co-operative education, i.e. its integration of academic studies on campus with related work experience in industry, business and government ([20], pp. 270-271). In our program we chose a different approach, based on a sequence of practicals in health care institutions. In each of the first 3 years of study the students have to participate in one practical course:

- 1st year: a practical course on health care institutions (1 week),
- 2nd year: a practical course on medical informatics in health care institutions (1 week), and
- 3rd year: a practical course on information systems in health care (6 hours per week during 1 semester).

The aim of these courses is for students to become acquainted with health care institutions, to learn how to interact with health care professionals, and, how to analyse and evaluate health care information systems. Finally, these courses should stimulate the students for their future work as medical informaticians.

For the 5th version of the Heidelberg/Heilbronn curriculum on medical informatics we hope to have reflected the evolution of medical informatics as a separate discipline, moving one step further towards teaching medical informatics, and not just medicine and informatics.

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Because so many persons participate in the Heidelberg/Heilbronn medical informatics curriculum, it is impossible to mention all contributors individually. We acknowledge the contributions from the lecturers of the curriculum, especially from the Heidelberg Medical Faculty and from the Heilbronn Medical Informatics Department. Last but not least, we acknowledge the contributions made by our students and graduates.

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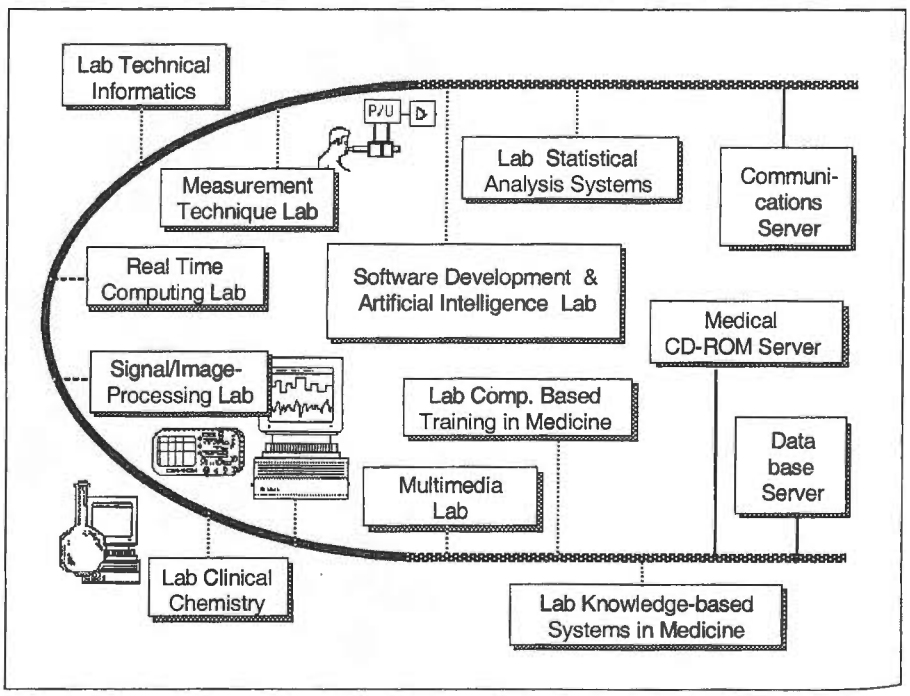

Fig. 6. Laboratories specifically for the education in medical informatics at Heidelberg and Heilbronn interconnected by local and global area networks.

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