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Special_Issue_Teaching_and_Training_Future_Health_Informaticians: Managing the transition from tradition to innovation of the Heidelberg/Heilbronn Medical Informatics Master's Program

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Conflict of Interest: The authors declare that they have no conflict of interest.

Abstract:
Background: To keep pace with the developments in the medical informatics field, the curriculum of the Heidelberg/Heilbronn Medical Informatics Master of Science program is continuously updated. In its latest revision we restructured our program to allow more flexibility to accommodate updates and include current topics and to enable students' choices.
Objectives: To present our new concepts for graduate medical informatics education, share our experiences, and provide insights into the perception of these concepts by advanced students and graduates.
Methods: Our new curriculum consists of three core components: Areas of Concentration that bundle elective courses in an important domain of medical informatics, a large catalog of elective courses, introductory/alignment courses for students without a bachelor's degree in medical informatics. We conducted an online survey of graduates and students with at least 75 credits to assess their opinion on the program's effectiveness and attractiveness.
Results: Mandatory courses include clinical medicine, project management, research, and practical training in biomedical informatics. Five areas of concentration bundle elective courses for 30 credits to provide a solid foundation in an important domain in medical informatics. These are bioinformatics, data science, computer-aided diagnosis and therapy systems, information management, and software engineering in medicine. The catalog of electives offers a total of 67 courses. About 75% of them are assigned to more than one area of concentration. Our survey demonstrates that the participants highly appreciate the flexibility of the electives and the opportunity to develop an area of expertise.
Conclusion: Offering a high degree of flexibility to our students has motivated them to join our program and resulted in a high level of student satisfaction. By designing the curriculum with areas of concentration and providing an infrastructure that permits courses on emerging topics to be added easily to the curriculum, we were able to meet our students' expectations.

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Submission to the Special Issue *Teaching and Training Future Health Informaticians*

Managing the Transition from Tradition to Innovation for the Heidelberg/Heilbronn Medical Informatics Master of Science Program

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Conclusion: Offering a high degree of flexibility to our students has motivated them to join our program and resulted in a high level of student satisfaction. By designing the curriculum with areas of concentration and providing an infrastructure that permits courses on emerging topics to be added easily to the curriculum, we were able to meet our students' expectations.

Keywords

Education, medical informatics, professional training, Master of Science program, curriculum, strategies for health IT training, workforce

Introduction

Our Medical Informatics program was founded in 1972 as a joint program by the University of Heidelberg and the Heilbronn University of Applied Sciences as one of the first medical informatics programs in the world [1,2] and combined the strengths of Heidelberg in medical research and patient care with the technical expertise of Heilbronn. Our program offers a computer science-based approach to medical informatics and has graduated approximately 2,000 medical informaticians to date.

There are a variety of definitions for the terms *biomedical informatics*, *medical informatics*, and *health informatics* [3,4]. In this article, we consider the terms to be interchangeable as others have done in publications on biomedical and health informatics education[5]. In our program, we use the term *medical informatics* because it is a literal translation of its official name in the German language. The program is compliant with the informatics program recommendations of the German Society for Informatics and has a special application focus and at least 50% computer science-specific courses. The program has traditionally offered very broad topics including software engineering in medicine, information systems, e-health solutions, and medical signal and image processing. To ensure that our education supports a wide range of job descriptions, we evaluated the program with a survey of its graduates and the results were published[6,7]. Originally, the program was designed as a 4 1/2 -year program with diploma degree. It was transformed into a bachelor's program in 2007 and a consecutive master's program starting in 2010.

To keep pace with the developments in the field of medical informatics, the curriculum is continuously updated [8-11] and is currently in its 8th revision. One of the driving forces behind the revision of the master's program was the rapid emergence of new topics in the field such as data science, which gained in importance in recent years[12-14]. A new revision always requires significant educational and administrative effort. Any revision must be approved by the councils of the two universities, which fortunately developed a well synchronized process. However, to reduce overall

effort and to incorporate new topics, a flexible solution was needed. In addition, we had seen a constant demand from students for more flexibility and choice based to the professional orientation they wish to pursue after graduation. Therefore, with the 8th revision of our program, we restructured our master's program completely to allow more flexibility for current topics and allow students more choices.

Objectives

The aim of our paper is to present our new concepts for graduate medical informatics education and to share our experiences. We complement this theoretical perspective with insights into the perceived appeal of, satisfaction with, and manageability of the program from the students' perspective based on a survey conducted among advanced students and graduates who were exposed to the new curriculum.

Background and Methods

Concepts and Quality Control of the medical informatics master's program

The medical informatics master's program is a two-year program with 120 credits over four semesters compliant with the European Credit Transfer and Accumulation System (ECTS). Each semester, 30 credits can be obtained. Fifteen students are admitted each semester.

The University of Heidelberg is accredited by an agency approved by the German Accreditation Council. The university established a comprehensive quality management process for its degree programs and uses a variety of methods like surveys among students and alumni, self-reporting, and external reviews at least every five years. Additionally, the educational experience for each course is evaluated by the students every two years. Stakeholders in a committee comprised of professors, academic staff, and students meets once a semester to discuss problems in the curriculum or its

implementation. If required, revisions of the program are based on the information received from all above sources.

Concepts for the 8th (and latest) revision of the medical informatics master's program

The latest concept was developed based on the identified need for a flexible curriculum. Specifically, three main drivers were identified by analyzing the results of Heidelberg University's quality measurements: 1) The rapid emergence of new topics in the field of medical informatics that must be incorporated into the curriculum seamlessly and without heavy administrative effort; 2) Students' expressed desire for course choice and individual study programs; 3) The need to attract a wider variety of students, including students from related disciplines (e.g. computer science).

The program consists of two parts, one of which is compulsory and the other elective in nature. The compulsory part of the program consists of courses that provide 50% of the credits in the first semester and a master's thesis (Fig. 1, blue modules). The program's flexibility is based on three core components: 1) A large catalog of elective courses; 2) Areas of concentration that bundle elective courses in an important subject of medical informatics (Figure 1, green modules); 3) Introductory a*lignment courses* for students who do not hold a Bachelor's degree in medical informatics but in another field (Figure 1, module M3).

Catalog of electives

The current catalog of electives contains more than 60 courses (Appendix 1 Table 1). Each course is offered once a year. The catalog is an appendix to the Master's curriculum and can be modified before each semester with little administrative effort unlike a curriculum revision which must be reviewed and passed by the councils of two universities. Moving the modifications to the catalog, allows new topics to be added quickly and topics that are no longer in demand to be removed (driver

1). The electives belong to one or more areas of concentration (Appendix 1 Table 1, column AoC) and can be selected by the students assuming they meet the constraints imposed by the areas of concentration (driver 2).

Areas of Concentration

To ensure a degree of coherence in the courses selected by students, we introduced the concept of areas of concentration (Figure 1, green modules). Five areas bundle elective courses of 30 credits to provide students with a solid foundation in one important domain of medical informatics. The areas of concentration are *bioinformatics*, *data science*, *computer-aided diagnosis and therapy systems*, *information management in medicine*, and *software engineering in medicine*. Over the course of their studies, students must complete at least one area of concentration by successfully completing all courses belonging to that area (Appendix 1 Table 1, column AoC).

Each area of concentration consists of three specific core subjects (area qualification) and a practical training experience, which together account for 15 credits (Appendix 1 Table 1, area printed in bold). The area qualification courses provide the core knowledge in the respective area, while the practical training ensures that the knowledge translates into applied competencies. The remaining 15 credits can be selected from the remaining electives indexed with the area of concentration.

The remaining 45 credits (Figure 1, grey modules) can be selected either in a way that the student completes a second area of concentration or freely according to individual's interests.

Introduction/Alignment courses

For students without a bachelor's degree in medical informatics (driver 3), we offer 15 credits of introduction/*alignment courses* (Fig. 1, M3), which we carefully selected from the courses of our bachelor's program. Students with a bachelor's degree in general or non-medical computer science

can acquire missing knowledge in the field of medicine. Students with a bachelor's degree in medical engineering can acquire missing informatics and software engineering skills. Students with a medical informatics background may choose from any of the elective courses from the master's program's catalog of the master's program for this module.

Survey of advanced students and graduates

To evaluate the concepts of the new master's program, we conducted a survey among advanced students and alumni who were exposed to the latest curriculum. We designed the questionnaire to assess the experience of students and thus judge the attractiveness of the program to prospective future students. We also aimed to understand the perception by current students and graduates of the distinctive components of the program.

Study population and survey implementation

All alumni (exposed to the new curriculum) and advanced students of the new curriculum who had completed at least 75 credits were invited via email to participate in the online survey (n=53). We provided a link to the survey and sent a reminder once. Students with 75 credits and more were selected because they already completed most of the coursework required.

Ethical Approval

The survey was presented to the ethics committee of Heilbronn University of Applied Sciences and conducted in accordance with the Declaration of Helsinki. It was implemented with the online survey tool SoSci (SoSci Survey GmbH, Munich, Germany).

Survey construction

The survey included four sections, each composed by a series of questions (cf. Appendix 2 for the translated version).

1. Demographics

General information about the participants' prior education and their career interests. Due to the relatively small size of the target group, it was not feasible to inquire about demographic details such as age, gender, or their highest degree attained to ensure anonymity. Consequently, it is not possible to distinguish between alumni and current students.

2. Knowledge of the program

A priori knowledge about the program's concept and the influence of its components such as the areas of concentration, electives, and *introduction/alignment courses* on choosing our master's program.

3. Perception of program flexibility and course quality

Perception of the program's flexibility, the areas of concentration, and special courses. Additionally, we inquired about the acceptance of the *introduction/alignment courses*, the perceived variety of areas of concentration, and the quality of a special research-related course.

4. General evaluation

General evaluation of the program and students' overall satisfaction.

We used 4-point Likert-Scales for single choice questions and a 5-point scale when a neutral response was appropriate. For analysis, we counted the responses at the different response levels did not subject them to further descriptive statistics. We provided a free text comment option for 12 questions. We used the free text comments qualitatively to supplement the findings obtained from the quantitative data.

Results

Curriculum

Compulsory Courses

The following courses were required for all students (compulsory courses): *clinical medicine* (6 credits), *research in biomedical informatics* (2 credits), *practical training in biomedical informatics* (4 credits), and *project management* (3 credits).

In the *practical training in biomedical informatics*, the students collaborated in small groups of three or four to conduct a systematic review on a current topic in medical informatics. The objective of the course is to have students from diverse backgrounds (due to the nature of their bachelor's degree) contribute collectively to a medical informatics topic. The first version of a resulting manuscripts is distributed among the students in the other groups and the two supervisors for peer review. The final results are presented and discussed with all students and faculty to facilitate critical thinking and team building among the new students in the program.

Introduction/Alignment Courses

We offer *introduction/alignment courses* for the following topics: Software engineering, programming, data bases, statistics, medicine (basics), medical documentation (basics), information systems in healthcare (basics), health care management, medical image processing (basics), medical signal processing (basics), process management in healthcare, interoperability and processes.

Compulsory Courses in the Area of Concentration

To complete an area of concentration qualification, the students must pass the associated core subjects listed at the beginning of Table 1 (Appendix 1), one applied/hands on course from the area of concentration, and additional electives worth 15 credits. The practical training in the data science area is divided into two smaller applied training pieces. One of them is carried out jointly with medical students where students attempt to solve an applied clinical informatics task in an interdisciplinary

fashion over the course of a semester. We consider the experience of working in a multidisciplinary team an important skill to be acquired in our medical informatics education[15].

Catalog of Electives

The current catalog of electives includes 67 subjects, most of them worth three credits, 14 courses are worth six credits (see Appendix 1, Table 1). The credit point increments were standardized to multiples of three to obtain high flexibility when combining electives. Approximately 75% of the courses are assigned to more than one area of concentration. The courses *ethics* and *personnel law and management* are included in all five areas. There are 18 courses dedicated to one area of concentration only. One example for this are the *Frank – van Swieten Lectures*, an international course delivered jointly with other universities[16]. All students learn the topic of *strategic management of information systems* based on the standard textbook for this topic[17] and visit a department in their local university hospital to analyze its information systems and processes. Subsequently, they model their observations according to the methods that were taught. At the end of June, all students gather for three days at the site of one of the participating universities. During this joint symposium, the information systems of all participating university hospitals are presented and systematically compared. Currently Amsterdam, Leipzig, and Heidelberg/Heilbronn are participating. In previous years faculty and students from Braunschweig, Hall in Tyrol, and Antalya also participated in the *Frank – van Swieten Lectures*. Other programs may participate in the future.

Another special course is the *research project* which is worth 12 credits. In this course, senior researchers propose research projects for one or two students, which are then reviewed by the examination board to ensure the suitability and scientific nature of the project. The objective is for the students to conduct a research project independently under the supervision of the senior researcher,

culminating in the production of a scientific paper. The research project is not assigned to a specific area of concentration. Any topic related to medical informatics may be proposed.

Survey results

The 8th version of the curriculum went live in October 2020. Since then, 99 students started in the medical informatics Master's program, ten of whom transitioned from the previous curriculum to the new version. By now, 27 of them graduated, 18 are currently writing their master's thesis and additional eight students have accumulated at least 75 credits (all dates of February 2024). Our survey targeted this specific cohort of 53 students.

Twenty-eight students or graduates responded to the survey, which corresponds to a 53% response rate. More than half of the participants received a bachelor's degree in medical informatics (n=16/28; Figure 2, left panel), six in biomedical engineering and four in computer science, and two in other academic disciplines. Twelve participants indicated an interest in pursuing a career path in industry (43%), four in academia (14%), ten are interested in both and remain undecided (36%). Two participants are interested in other areas (7%) (Q2, see translated questionnaire in Appendix 2).

Area of concentrations and catalog of electives

Before starting the program, eleven participants were fully aware of the areas of concentration and the available selection process for the areas of concentration (39%), while 17 had a general idea of the area of concentration selection options (61%) (Q3). This feature of the program influenced the decision of most participants (86%) to enroll in our medical informatics master's program (Figure 3, Q4). Nine participants were fully aware of the possibilities in the extensive catalog of electives before starting their studies (32%), 13 had a general idea (46%), and six were unaware of these possibilities (21%) (Q5). Flexibility in electives was a factor in the choice of program for 73% of the 22 participants who were aware of it (Figure 3, Q6). Of the twelve participants who did not have a

Bachelor's degree in medical informatics two were fully aware of the option to take *introductory/alignment courses* (17%), six had a general idea (50%), and four were not aware of this option (33%) (Q7). Six of the eight participants who were aware of the option responded that it influenced their decision to enroll in the program (75%) (Q8). Nine of these participants (75%) took advantage of those options and chose to take *introduction/alignment courses* (Q9). Four of them reported that the courses were to somewhat helpful for further study (44%), four reported that they were not helpful (44%), and one participant was uncertain about the courses' effectiveness (11%) (Q10).

Students perceived the wide variety of courses as positive although some limitations were identified (Q12-Q16). More than 75% of participants found the wide range of choices liberating, a pleasure, and an opportunity for personal growth (Figure 4, left panel). However, 64% of the participants also found it challenging and 39% of the participants found it confusing (Figure 4, right panel).

The areas of concentration data science, information management, and software engineering were chosen almost equally often (n=12/11/12, Figure 2, right panel, Q20). The area of concentration computer-aided diagnosis and therapy systems was chosen by six participants, and the area of concentration bioinformatics has not been chosen, yet. Thirteen participants selected courses that allowed them to complete two areas of concentration (46%). Twenty-seven out of the 28 participants (96%) had at least some notion at the beginning of their study of which areas they wanted to study and all of them pursued this notion (Q21, Q22). All participants rated the thematic bundling of the area of concentrations as just right (Q24).

Assessment of Specific Courses

Students rated gains in personal learning from the *practical training biomedical informatics* generally as high (Figure 5, left panel, Q25-Q29).

Ten of the 28 participants did a research project to earn 12 credits (36%). Seven of them utilized this experience as a foundation for pursuing a master's or doctoral thesis (70%). Three of the participants were influenced by the research project to consider a career path in research (30%). All participants enhanced their scientific expertise through the research project (Figure 5, right panel, Q31, Q32).

Overall Satisfaction

Seven of the 28 participants (25%) expressed partial satisfaction with the selection of topics offered to them during their studies. The remaining participants indicated satisfaction or high satisfaction (Figure 6, Q35).

Discussion

Just as technological advancement and knowledge in medicine are growing rapidly, medical informatics as a discipline is constantly evolving, with different topics emerging frequently. The frequent changes make it difficult to adapt a medical informatics curriculum to emerging topics[18,19]. Therefore, we developed the 8th revision of the Heidelberg/Heilbronn master's curriculum in medical informatics carefully with more flexibility to add new electives and to allow electives to be assigned to areas of concentration, in which students can qualify. The notion of areas of concentration fulfills the requirements formulated by Sapci and Sapci that health informatics programs should consider specialized tracks that include specific skills to meet the diverse needs of health care and industry[13]. However, our decision against specialized tracks with fixed courses resulted in the ability to offer a wider range of electives to students by assigning courses to one or more areas of concentration.

Our survey showed that the participants appreciated the flexibility offered by the elective courses and the opportunity to build an area of concentration. This aspect of our program influenced their

decision to enroll in our master's program in medical informatics and generated satisfaction with the program until graduation and beyond. However, we learned that the wide range of options can be confusing and challenging and may require additional counselling of students.

A curriculum with a large catalog of courses like ours requires more effort in terms of semester planning. Since several subjects may run in parallel, choices can be difficult. Over time, we developed a scheduling strategy that assures that courses belonging to the same area of concentration can be taken without conflict. Students who combine courses from different areas of concentration must make sure that the courses can be taken without conflict.

The option of *introduction/alignment courses* was not very important to students and those who chose alignment courses reported only partial benefits. In contrast to these student perceptions, some of our lecturers reported that it would have been helpful for their classes if more students had chosen *introduction/alignment courses*.

The participants were very satisfied with the selection of topics offered in the program and the thematic bundling of topics into areas of concentration. The area of concentration bioinformatics was not attractive for students. One reason may be that bioinformatics is a field for which dedicated programs with bachelor and master degrees are offered competing with our efforts. Further, significant differences in the culture of the two disciplines clinical informatics and bioinformatics[15,20,21] seem to make it difficult to integrate them in one educational solution[15,22].

We were pleased with the overall satisfaction of the participants with the design of the master's program. This is particularly noteworthy as some students started during the coronavirus pandemic, and most of the courses could only be offered virtually in the early semesters. We had anticipated that virtual courses would have caused some dissatisfaction.

Limitations

We cannot rule out the possibility that our study sample was biased and that only students and alumni in the target group who were satisfied with their studies responded. Since the response rate of 53% is high, there is however a good chance that the respondents were representative. As the survey was anonymous, participants could not expect any disadvantage from negative feedback. Despite the high response rate our survey was still limited due to the low number of graduates and advanced students for this revised curriculum. In addition, our survey did not reach students that may have rejected our program because our curricular concept seemed to flexible or confusing.

Conclusions

Medical informatics is a broad discipline. Workforce needs reflect this as demands of experts exists in a wide variety of fields[19], such as health IT units[23], in clinical research informatics, decision support, and in deep neural network training for clinical use. This diversity makes it difficult to characterize the workforce, training needs, and requirements[4,24]. The recommendations of International Medical Informatics Association (IMIA) aid considerably to systematize these needs[19]. Graduates of different programs around the world have encountered good job opportunities [7,25,26].

Offering a high flexibility to our students has motivated them to join our program and led to a high satisfaction. This was made possible by designing the curriculum in a way that 1) courses can be assigned to areas of concentration, and 2) each course has a scope of 3 credits or a multiple of this, so that courses can easily add up to 15 credit modules. The curriculum design results in a large catalog of courses from which students can choose a wide range of topics. However, this variety can also be a challenge. Therefore, we must look at how we can better support students to understand the options and to facilitate their selection process. For further development we need to consider,

whether it is necessary to offer *introduction/alignment courses* and whether the area of concentration bioinformatics makes sense in the context of a medical informatics curriculum.

Despite the inspiring results of the survey, we cannot conclude yet that our program leads to good outcomes and a solid foundation for the professional careers. This will require a more detailed survey, when more students have graduated and have had careers in their profession. When a relevant number of graduates who are further along in their professional careers exist, we can evaluate their satisfaction with the content and design of the medical informatics master's program in relation to their professional activities. We will continue to closely monitor emerging topics to adequately educate the future medical informatics workforce. Our novel concept will make it easy to adapt the course catalog to the new demands.

Clinical Relevance Statement

Digital health is increasingly finding its way into medical care. To successfully develop methods and tools that can be used in clinical routine, it is necessary to train medical informatics specialists who understand healthcare processes and the needs of clinical practitioners.

Multiple Choice Questions

When implementing master's program in medical informatics, what should be offered to students to make the program attractive?

A. high flexibility of elective course

B. the same fixed sequence of courses for each student

C. narrow program that clearly specializes in one field of medical informatics

D. high number of compulsory courses

A. is the correct answer, because our survey revealed that a lot of students chose our program because of the high flexibility offered by the catalog of elective courses.

What can be offered in a master’s program in medical informatics to students that do not have a bachelor’s degree in medical informatics, but in another field?

A. alignment courses

B. more compulsory courses

C. specialized tracks

D. practical training

A. is the correct answer because it offers courses from a bachelor's degree program that can be selected by students to build a common foundation with students who have a bachelor's degree in medical informatics.

Conflict of Interest

The authors declare that they have no conflicts of interest.

Protection of Human and Animal Subjects

The survey among students and graduates was performed in compliance with the World Medical

Association Declaration of Helsinki on Ethical Principles for Medical Research Involving Human Subjects.

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Appendices

Appendix 1:

Table 1

Appendix 2:

Abbreviations:
Q – question
SC – single choice answer options
MC – multiple choice answer options
FT – free text
Opt – Answer is optional.

Questionnaire

General information

Please note that free text fields are always optional and that you should not enter any personal data in free text fields.

Q1: In which discipline did you obtain your Bachelor's degree or comparable qualification?

SC: Medical Informatics | Informatics general or other speciality (e.g. applied informatics, technical informatics, business informatics) | Medical engineering or similar | other: (FT opt)

Q2. Are you more academia or industry focuses career-wise?

SC: academia | both | industry | other: (FT opt)

Before starting the program

Q3: Did you know about the options for choosing an area of concentration and the areas of concentration on offer before you started your studies?

SC: yes, I was fully aware of it | yes, I had a general idea | no

If answer was *yes*:

Q4: Did this influence your decision to take up the MSc program?

SC: Not at all | not really | I don't know | to some extent | strongly

Q5: Did you know about the possibilities in the extensive catalog of electives before starting your studies?

SC: yes, I was fully aware of it | yes, I had a general idea | no

If answer was *yes*:

Q6: Did this influence your decision to take up the MSc program?

SC: Not at all | not really | I don't know | to some extent | strongly

If the Bachelor's degree was not obtained in 'medical informatics' (cf. Q1):

Q7: Did you know about the possibilities of alignment courses before starting your studies?

SC: yes, I was fully aware of it | yes, I had a general idea | no

If answer was *yes*:

Q8: Did this influence your decision to take up the MSc program?

SC: Not at all | not really | I don't know | to some extent | strongly

During/after studying

If the Bachelor's degree was not obtained in 'medical informatics' (cf. Q1):

Q9: Did you choose to study alignment courses?

SC: yes | no

If answer was *yes*:

Q10: Were the alignment courses helpful for your further studies?

SC: Not at all | not really | I don't know | to some extent | strongly

Q11: Do you have any further comments on the alignment courses?

FT (opt)

Flexibility general

How did you perceive the broad choice of courses offered?

Q12: Liberating

SC: SC: not at all | not really | a bit | very

Q13: Confusing

SC: not at all | not really | a bit | very

Q14: A pleasure

SC: not at all | not really | a bit | very

Q15: Challenging

SC: not at all | not really | a bit | very

Q16: Opportunity for personal growth

SC: not at all | not really | a bit | very

Q17: Was it possible to take all the courses you wanted to take?

SC: Yes | no, due to parallel courses | no, course was not offered | no, other: (FT opt)

Q18: How would you rate the number of electives?

SC: too many | just right | too few

Q19: What other type of subject would you have liked?

FT opt

Areas of concentration

Q20: Which area(s) of concentration did you study or will you study?

MC: BI (bioinformatics) | DT (diagnosis and therapy systems) | DS (data science) | IM (information management) | SE (software engineering)

Q21: Did you already plan to study a specific area of concentration right from the beginning?

SC: No | only a tendency | yes

If area of concentration was planned before (including tendency)

Q22: Did you study the intended area of concentration?

SC: yes | no

If area of concentration was not planned before:

Q23: What made you switch areas of concentration?

FT opt

Q24: How do you rate the thematic bundling of the areas of concentration?

SC: just right | too many areas of concentration | too few areas of concentration | another bundling would be more appropriate: (FT opt)

Practicum Biomedical Informatics

How do you assess your personal learning gains due to the 'Practical Training Biomedical Informatics':

Q25: Systematic research on a specific Medical Informatics topic

SC: none | little bit | high | very high

Q26: Writing a scientific article

SC: none | little bit | high | very high

Q27: Giving peer-review

SC: none | little bit | high | very high

Q28: Receiving peer-review

SC: none | little bit | high | very high

Q29: Scientific discussions with peers and experienced researchers

SC: none | little bit | high | very high

Research project

Q30: Did you choose to do a research project?

SC: Yes | no

If *yes*:

Q31: Could you enhance your general research expertise due to the research project?

SC: not at all | little bit | much | very much

Q32: Did you gain additional specific methodological expertise?

SC: not at all| little bit | much | very much

Q33: Did you use this project as a stepping-stone for MSc thesis or doctorate?

SC: Yes | no

Q34: Did this project influence your career choice?

SC: No | yes, towards research | yes, towards industry | yes, other: (FT opt)

General closing questions

Q35: Overall, are you satisfied with the selection of topics you learned during the MSc?

SC: Not at all | not really | partly satisfied| satisfied |very satisfied

Q: Would you like to explain your answer a little? (FT opt)

Q36: Do you consider yourself a generalist in Medical Informatics or a specialist?

SC: generalist | in between | specialist

Q37: Would you decide again to study Medical Informatics at Heidelberg/Heilbronn?

SC: Yes | no

If answer was *no*:

Q38: Comment (FT opt)

Q39: What were the highlights of your Master's studies?

FT opt

Q40: What were your pain points during your Master's studies?

FT opt

Q41: Do you have any further comments for us?

FT opt

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Figure 1: Basic concept of the Medical Informatics Master Program. Numbers in brackets indicate credits. Blue: compulsory courses. Green: Mandatory area of concentration (AoC) courses. Module M3 can contain introductory/*alignment courses* from our Bachelor's program. M7 and M8 contain elective courses that can sum up to a second area of concentration.

Figure 2: Field of Bachelor's degree of survey participants (left panel, n=28) and selection of areas of concentration (right panel, n=41). Note that 41 areas of concentration were selected in total because 13 participants selected two areas. Answers from Q1 and Q20, respectively, in the translated questionnaire (Appendix 2). Abbreviations: MI: medical informatics; CSo: computer science other; MedT: medtech or similar; oth: other. DT: computer-aided diagnosis and therapy systems; DS: data science; IM: information management in medicine; SE: software engineering in medicine. Note that bioinformatics had not been selected yet.

Figure 3: Degree to which the options of choosing areas of concentration and the high number of elective courses influenced the decision to study the medical informatics Master's program (Q4 and Q6). Six of 28 participants mentioned that they were not aware of the high number of elective courses and are therefore not represented in the upper bar.

Figure 4: Participants' perceptions of the wide range of courses offered (Q16-Q20). Left panel: positive aspects, right panel: negative aspects.

Figure 5: Learning gains of participants in certain aspects due to the *practical training biomedical*

informatics (left panel) (Q25-Q29), n=28, and the *research project* (right panel) (Q31, Q32), n=10.

Figure 6: Satisfaction with the selection of topics in the program (Q35), n=28.

Table 1: Elective courses and assignment to areas of concentration (AoC).

BI = bioinformatics, DS = data science, DT = computer-aided diagnosis and therapy, IM = information management in medicine, SE = Software Engineering in medicine. An area of concentration is printed in bold if the respective course is mandatory for this area of concentration (core subjects). Core subjects are listed at the beginning of the table, the rest of the table is in alphabetical order. Core subjects can be elective courses for students that do not wish to complete the entire AoC.

AoC	Courses	Credits
Core Subjects and Applications in the Area of Concentration *Bioinformatics*		
BI	Components, Interactions, and Networks	3
BI	Introduction to Bioinformatics	3
BI DS	Statistical Genetics and Genetic Epidemiology	3
BI	Practical Training Bioinformatics	6
Core Subjects and Applications in the Area of Concentration *Data Science*		
BI **DS**	Machine Learning	3
DS IM	Medical Data Sources and their Processing	3
BI **DS** DT	Statistical Methods of Machine Learning	3
DS	Practical Training Data Science in Medicine	3
DS	Practical Training Machine Learning	3

DS	Practical Training Machine Learning	3
Core Subjects and and Applications in the Area of Concentration *Diagnosis and Therapy Systems*		
BI DS **DT**	Medical Image Processing	3
DT SE	Medical Robotics	3
DS **DT**	Medical Signal Processing	3
DT	Practical Training Diagnosis and Therapy Systems	6
Core Subjects and and Applications in the Area of Concentration *Information Management*		
BI DS **IM**	Decision Support in Medicine	3
IM	Management of Information Systems	3
IM	Medical Documentation	3
IM	Practical Training Information Management	6
Core Subjects and and Applications in the Area of Concentration *Software Engineering*		
SE	Secure Software Development in Medicine	6
DT **SE**	Software as a Medical Device	3
SE	Practical Training Software Engineering	6
Additional Elective Courses		
BI DS DT	Advance Approaches for AI-based image processing	3
SE	Advanced Software Architecture	3
BI DS	Advanced Statistics	3
DT SE	Advanced Techniques of C++	3
DS DT	Application of Deep Learning in Medical Image Analysis	3

DT IM SE	Apps, Sensoren and optimal HCI	3
DT SE	Basics of Therapy Planning	3
BI	Biological and Chemical Basics of Bioinformatics	3
DS DT	Biomarker for psychological Diseases	3
SE	Cloud Computing	3
DS SE	Current topics in cryptography	3
DS IM	Data Warehousea and Business Intelligence	3
IM	Decision Support Systems in Medicine	3
BI DS DT	Deep Learning	6
SE	DevOps and SecOps	3
DT SE	Diagnosis Systems	3
IM SE	Digital Process Management in Healthcare	6
SE	Distributed Systems	3
DS IM SE	Educational Technologies	6
IM	E-Health Application Areas	3
IM SE	E-Health Interoperability	3
BI DS DT IM SE	Ethics	3
SE	Foundations in Human-Computer Interaction	3
IM	Frank-van Swieten Lectures on Strategic Information Management in Hospitals	6
BI DS DT	GPU Programming	3

SE		
DS IM	Health Economics	6
DS DT IM SE	Health Technology Assessment	6
DS IM	Healthcare Management	6
BI DS IM SE	Information Visualisation	3
DS DT IM SE	Knowledge Management	3
DT SE	Medical Assistence Systems	3
BI DS DT	Milestones of AI-based Imaging Research	3
DT IM SE	Mobile Devices in Medicine	3
BI DS DT	Pattern Recognition	3
IM	Personal Health Informatics	3
BI DS IM	Personalized Medicine	3
BI DS DT IM SE	Personnel Law & management	3
DT	Physiological and technical Basics of medical image and signal processing	3
BI DS IM	Planning, Analysis, and Synthesis von trials in medical research	3
DS IM	Practical Knowledge Management	3
IM	Quality and Risk Management	3

	Research Project	12
BI	Systems Medicine	3
IM SE	Task Analysis & User Requirements Engineering	3
IM SE	Usability Evaluation and Testing	6
DT IM SE	Usability of Medical Devices	3
BI DS DT IM	Visual Analytics in Medicine	3