A spiral and discipline-oriented curriculum in medical imaging

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ABSTRACT

This contribution describes and evaluates an experimental combination of a spiral and discipline-oriented curriculum implemented in the bachelor's and master's program in Medicine and Technology. The implementation in the master's program is in the form of a study line in *Medical Imaging and Radiation Physics* containing three disciplines: Imaging modalities, Radiation therapy and Image processing.

The two imaging courses in the bachelor's program and the first imaging course in the master's program follow a spiral curriculum in which most disciplines are encountered in all courses, but in a gradually more advanced manner. The remaining courses in the master's program follow a discipline-oriented curriculum.

From a practical point of view, the spiral course portfolio works well in an undergraduate environment, where the courses involved are to be taken by all students and in the order planned. However, in the master's program, such a tight schedule is impractical since students are likely to seek specialization. From a pedagogical point of view, the spiral curriculum is advantageous to use in the initial semesters where the teaching can be conducted so that the students can build on their intuitive understanding of the subject.

The program was evaluated in terms of the progression in scientific demands in exam from course to course and in terms of the pattern of course selection by the students. The analysis was based on 96 students. The pattern of course selection was found to follow the intentions of the program, thus demonstrating high fulfillment of the learning outcomes.

KEYWORDS

Biomedical engineering, curriculum design, ultrasound, MRI, CT, X-ray, SPECT, PET, medical image analysis.

INTRODUCTION

Medical imaging and radiation therapy have huge impacts on modern healthcare. The broad range of established and emerging techniques relies on advanced equipment, acquisition and analysis methods with important similarities and differences between modalities. Highly skilled technical personnel are needed in hospital departments dealing with biomedical engineering, radiology and radiation therapy, in departments of research, development, service and sales in biomedical engineering companies and in university departments involved in teaching and research. This all relies on competent teaching in this and supporting areas. A successful conduct in this area is not only important for proper treatment of diseases but also for the industry employing candidates with specialization in medical imaging.

The present paper focuses on the engineering education needed to support this area now and in the future. Specifically, the paper describes and evaluates an experimental combination of a spiral and discipline-oriented curriculum implemented in the bachelor's and master's program in Medicine and Technology. It is implemented as two mandatory courses in the bachelor's program and a *study line* named *Medical Imaging and Radiation Physics* in the master's program. It is a unique approach with focus on motivation and where intuitive understanding is taught prior to mathematical rigor.

The spiral curriculum, originally proposed by Bruner in 1960[1] is based on the idea that teaching a subject can start with an intuitive account - well within the reach of a student - followed by later treatment of the subject at progressively more and more advanced levels. The spiral curriculum is reportedly used and evaluated in medical education[4], computer networks[5], engineering[2,3] and hereunder electrical and computer engineering[6] and chemical engineering[7].

Even though the spiral curriculum has some distinct advantages it is not always optimal to implement a program based on this idea only. In the present education, a combination of a spiral and a discipline oriented curriculum was found to be optimal.

DESCRIPTION OF PROGRAMS

Frame

The program in Medicine and Technology was initiated in 2003 and is offered in collaboration by the Faculty of Health Sciences, University of Copenhagen (KU) and the Technical University of Denmark (DTU) where it is anchored at the Department of Electrical Engineering. It consists of a bachelor’s and a master’s program. The undergraduate uptake is approximately 60 students per year. While approximately 85% of the courses in the bachelor’s program are common to all students, the freedom of choice of courses is much larger in the master’s program where three study lines are offered: *Signal and model based diagnostics*, *Medical imaging and radiation physics* and *Biomechanics and biomaterials.* This paper focuses specifically on the study line *Medical imaging and radiation physics*.

Course loads are between 5 and 10 ECTS. A 5 ECTS course features one four-hour module of confrontation per week in 13 weeks plus a subsequent period of exam. The total work load is approximately 140 hours for the student, all activities included.

Disciplines

The study line contains three disciplines:

1) **Imaging modalities**: ultrasound imaging (US), imaging with X-ray and computed tomography (CT), magnetic resonance imaging (MRI), Positron Emission Tomography (PET) and Single Photon Emission Tomography (SPECT)

2) **Radiation and radiation therapy:** radioactive isotopes, ionizing radiation, radiation protection, external beam radiotherapy and brachytherapy
3) **Image processing, analysis and visualization:** tomographic reconstruction and inverse problems, image registration/spatial normalization and computational atlases, image segmentation, and deformable models

Learning objectives

The candidate that successfully completes the study line in *Medical imaging and radiation physics* will be able to:[13]

- demonstrate a comprehensive understanding of diagnostic imaging from physical principles to diagnostic information for modalities such as ultrasound, magnetic resonance imaging, computed tomography, X-ray, positron emission tomography and nuclear medicine
- design and evaluate data acquisition and processing systems, image analysis and computer graphics in medical imaging systems as well as being able to modify existing systems
- develop and evaluate new diagnostic methods and make new applications of existing techniques
- contribute in the set-up, simulation and evaluation of new physiological models with emphasis on diagnostic imaging and radiation physics
- demonstrate comprehensive knowledge of isotopes applied in the major specialties of diagnostic medicine

Course portfolio

The imaging courses are distributed over the bachelor's and master's programs as illustrated in Figure 1. Two of the courses in the bachelor's program are mandatory and one is optional. The courses in the master's program[13] are so-called *technological specialization* courses among which the students must have at least 30 ECTS to fulfill the requirements of the study line. Courses with two course numbers are given in collaboration by the two institutions behind the program (KU and DTU).

The two imaging courses in the bachelor's program as well as the first imaging course in the master's program follow the format of a spiral curriculum in which the disciplines (or most of them) are encountered in all courses, but in a gradually more advanced and sophisticated manner as the students go from course to course. The remaining courses in the master's program follow a discipline-oriented curriculum concentrating on one or a few disciplines per course.

An implemented curriculum is subject to a number of important constraints. Some of the most important are:

- Pedagogical considerations other than those inferred from the spiral/discipline approach
- Availability of qualified teachers as well as their interests and abilities
- Existence of relevant courses at the time of curriculum design
- Use of existing and new courses in other educational programs
- Desired number of students for a given discipline
- Practical considerations (*e.g.,* experimental facilities, teacher availability)

Due to this, not all disciplines are taught in all spiral courses and not all discipline oriented courses contain a single topic. An overview of topics can be found in Table 1. As seen in this table, even at very advanced levels, some degree of the spiral approach is used (KU181 and KU180).

THE CHALLENGE OF MRI

As an example, consider MRI which is taught in four courses. It is a flexible and demanding method that is now widely used clinically and in research. MRI is a high-profile technique due to the use of exceptional hardware providing extreme magnetic fields. Furthermore, it's highly publicized role in neuroscience makes it a good candidate for motivating students while pushing the limits of their mathematical abilities. Nevertheless, teaching of the subject is often postponed to late stages of educational programs, since advanced mathematics and high levels of abstraction are required for traditional teaching, which often involves elements of quantum mechanics and vector dynamics. The fact that data are collected in reciprocal space adds to the difficulties.

However, the understanding of the basic resonance phenomenon only requires familiarity with magnetism and compasses. This is exploited[9] in the described study program. Applications of MRI are introduced and a "dry lab" exercise targeting the basic MR phenomenon is conducted already after a few weeks of study in the course 31500&KU008 (shown in Figure 1) introducing several imaging modalities at a basic level[8]. The students subsequently prepare and present posters on different imaging modalities including MRI.

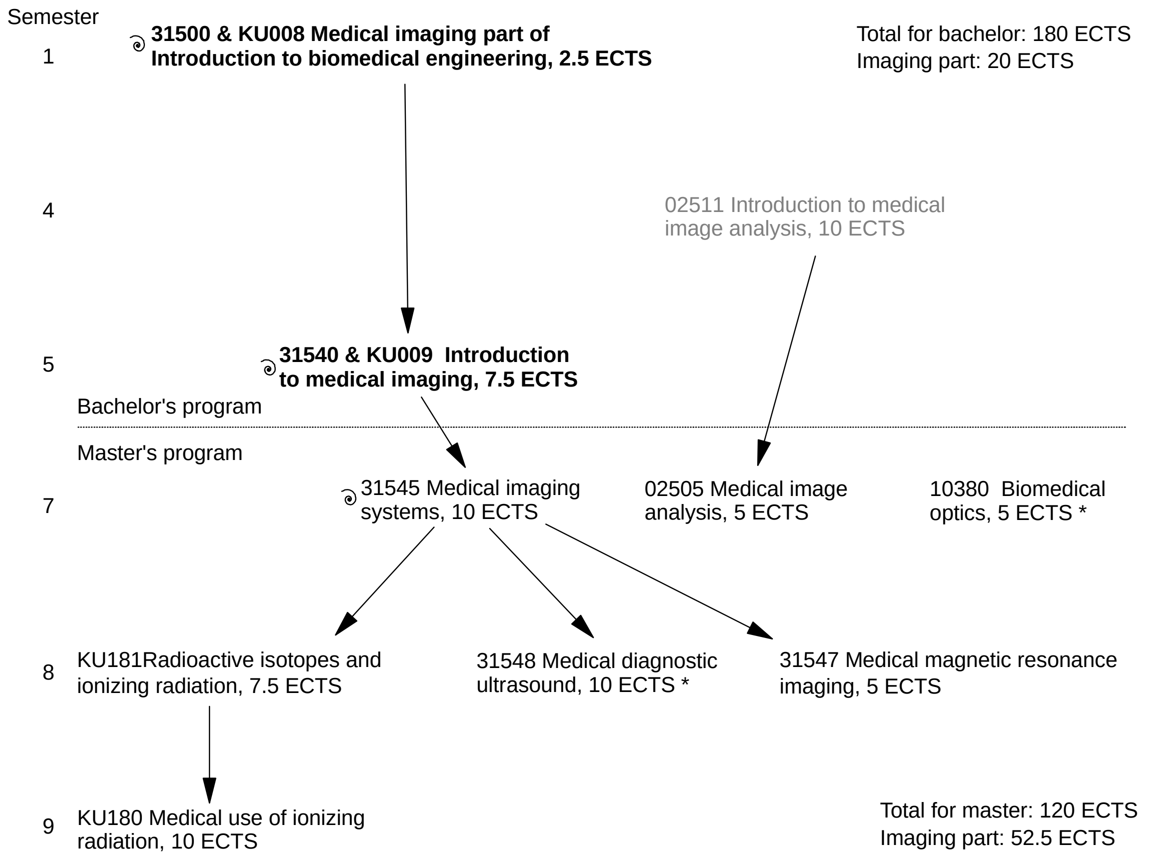

Figure 1. The entire course portfolio in the imaging part of the education in Medicine and Technology. A graphic spiral marks the three courses constituting a spiral course portfolio (remaining courses are discipline oriented). Bold font indicates mandatory courses in the bachelor's program while gray font signifies elective courses. Normal font is used for technological specialization courses in the master's program. Arrows indicate preferred or needed prerequisites. "*" indicates planned courses.

At the 5th semester, in course 31540&KU009, the students again encounter MRI and other imaging modalities. Building upon the compass needle analogy, the students are now introduced to nuclear dynamics, MRI hardware, collective nuclear phenomena, relaxation and contrast manipulation. They write a report following an exercise where an unknown object is scanned using several modalities[10]. The interactions between MRI hardware and nuclear samples are explored in an MRI simulator[12] allowing for dry lab experimentation with MRI hardware that is not otherwise possible at this level due to safety and resource constraints.

In the first semester of the master's program (7th semester in Figure 1), the course 31545 increases the mathematical emphasis. MR imaging methodology and reconstruction techniques are introduced and techniques are demonstrated in vivo during a site visit. Spin dynamics, contrast manipulation and imaging concepts are explored using simulation software developed for the purpose[11]. External lecturers present clinical and research applications and reconstruction of MRI images is done in a lab exercise. This course is the final one in the spiral curriculum and is followed by a specialized MRI course, 31547, focusing on advanced concepts and applications (quantitative imaging, spectroscopy and functional MRI) for students who wish to specialize in the subject. The students contribute to the lectures and conduct measurements in small groups at collaborating hospitals.

Table 1 Approximate content in percent of the different courses. Course sizes and location in the program can be seen in Figure 1. The course Radioactive isotopes and ionizing radiation is not tabulated as the content falls outside this table. "*" indicates planned courses.

Course	X-ray CT	SPECT/PET	MRI	US	Optics	Therapy	Analysis
Intro. BME (imaging)	15	15	30	30		10	
Introduction to med. imaging	23	23	23	23			8
Intro. to med. image analysis	5	5			5		85
Medical imaging systems	29	13	25	33			
Medical use of ion. radiation	30	30				30	10
Medical diagnostic ultrasound*				100			
Medical image analysis	5		5		5		85
Med. magnetic res. imaging			100				
Biomedical optics*					100		

EVALUATION

The previously mentioned learning objectives are normally obtained by passing the exam of 30 ECTS of imaging courses in the master's program in Figure 1. If the prerequisites are adhered to, the present degree of implementation allows for a number of combinations considered below. Thus, in the evaluation of the program it is relevant to consider the progression in the level of difficulty in the exam and which pattern of courses that the students select.

Progression in scientific demands in exam

In order to illustrate the progression in exam requirements, examples of the exam in three courses are given below.

The exam in course 31540 Introduction to medical imaging is based on one report and one multiple-choice exam. A typical question regarding MR is:

Which of the following combinations of static and RF magnetic fields is used for MRI?

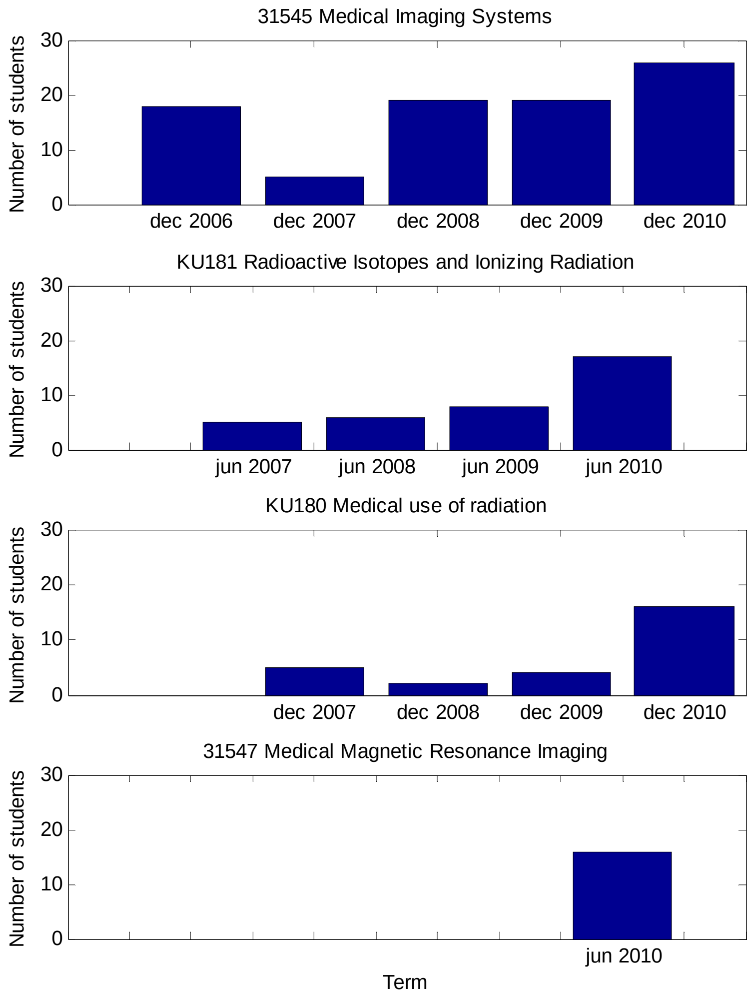

Figure 2. Number of students passing the exam to and including 2010.

A) A static field and a weaker radio-frequency field oriented perpendicular to the static field

B) A static field and a weaker radio-frequency field oriented parallel to the static field

C) A static field and a stronger radio-frequency field oriented parallel to the static field

D) A static field and a stronger radio-frequency field oriented perpendicular to the static field

E) Do not know

The exam in course 31545 Medical imaging systems is based on three reports and an oral exam. The central question in the oral exam regarding MR in this course is:

- Explain the physical interaction mechanisms for MR scanning

The exam in course 31547 Medical magnetic resonance imaging is based on three reports and an oral exam. One of the ten topics for the oral exam that best matches the above is:

- Explain inhomogeneity and artifacts

Pattern of course selection

The evaluation presented here is limited to students passing the exam in at least one of the imaging modality courses 31545, KU181, KU180 and 31547. This criterion yielded a total of 96 students. Figure 2 shows the number of students passing the exam up to and including 2010. In order to study how well the learning objectives were met by the students, Table 2 shows how many students took the course chains of Figure 1. The numbers in the table are based on the same data as in Figure 2.

Table 2 Number of students passing the exam in different combinations of courses and their pre-requisites (as shown in Figure 1). "-" indicates not counted or not applicable.

Course	31545	KU181	31545 and KU181
KU181	31	-	-
KU180	0	0	24
31547	15	-	12
KU180 and 31547	-	-	11

The first row in Table 2 concerns course KU181. Thirty one students have taken this together with the prerequisite course 31545. The second row concerns course KU180. None of the students have taken this without the prerequisites. Specifically, 24 students have taken the complete chain of “ionizing” courses: KU180-KU181-31545. Eleven out of these 24 students have taken all four courses as seen in the fourth row.

Going back to the third row, 15 students have taken course 31547 with the required prerequisite course 31545. Of these, 12 have also taken course KU181. And as stated above, the vast majority - 11 students - have also taken course KU180.

Only students from the education Medicine and Technology are included here, so the actual number of students on the courses are typically higher.

DISCUSSION

From a practical point of view, the spiral course portfolio works well in an undergraduate environment, where the courses involved are to be taken by all students and in the order planned. However, in the master’s program with a large degree of freedom of choice, a schedule as tight as that is often unpopular and impractical, since students are likely to seek specialization in just one or a few areas. With respect to resources, in a spiral course, more teachers have to agree and coordinate their schedule than in a discipline oriented approach. Thus, the more expensive spiral curriculum should be used only when the pedagogical advantages at least outbalances the extra costs. With respect to teachers in the program, some are staff members while others are affiliated with hospitals or other research institutions. However, only faculty staff are affiliated to such a degree, that they are able to participate in several courses (within MRI, the same person is responsible for all MRI education).

From a pedagogical point of view, the spiral curriculum is advantageous to use in the initial semesters: The earlier a discipline is introduced, the higher a level can be reached in the most advanced course, everything else being equal. Starting a discipline in a course at the first semester requires that the teaching builds on the student’s intuitive understanding. This is only possible for maybe just a few weeks. After this, the learning objectives in reach with just intuitive understanding are exhausted and further progress need skills (*e.g.,* mathematical) from courses that the student will not meet until later. It will therefore be optimal to continue with a new discipline, thus initiating the idea of a spiral approach. Doing this yields some other advantages:

- It encourages student involvement and learning, which is particularly important at the entrance of the program
- When teaching several disciplines in the same course, analogies between them are easily drawn, broadening the horizon of the students
- The students are taught about all modalities, which is deemed important since students with no knowledge about other disciplines than their own easily become narrow minded

This intuitive understanding of the students can be exploited in all disciplines, except those requiring extensive knowledge from the very beginning. This paper has exemplified how even MRI can be taught in the first semester, as long as only the most basic aspects are considered and analogies to aspects of every-day-life are used (*e.g.,* compass needles).

The pedagogical advantages of shifting into a discipline-oriented approach during the master's program are partly that students at that stage will most likely want to concentrate on one or a few topics and being able to do that will be more motivating. Also, the simple fact that a new format provides a "change of air", also increases motivation. From a teacher point of view, it is easier to make changes to content in discipline oriented courses.

Nevertheless, to some degree, the spiral curriculum is exploited all the way through the chain ending with KU180, where all ionizing disciplines are included. Coherent tuition coordinated with all teachers and with mutual knowledge of their respective fields is essential for the success of this course model.

A central part of success in a curriculum like this is the availability of knowledgeable and pedagogically experienced teachers that can participate in all - or most - of the courses. It is important that the teachers manage to dispense the material to the different courses in a balanced way and that he/she is capable of teaching the subjects at a beginner's level as well as at an advanced level.

A quantitative evaluation is presented in Figure 2 and Table 2. The results are given in actual number of students, not as relative numbers for two reasons: a) These data do not reflect a "steady-state" condition since the education is quite young (the master's program had its first uptake in the fall of 2006). b) It is very difficult to establish a robust reference. One possibility would be to use the number of students that have taken the first course in the master's program, 31545, but the time period in which this number should be counted is difficult to establish, since student progression speed is heterogeneous and students does not necessarily take courses in the same order (*e.g.,* due to periods of studying abroad, projects of directed research, conflicts between course schedules, personal matters).

Based on the data in the last two rows of Table 2, it is shown that the students follow the suggested chain of courses. Apparently, this seems to have been successfully communicated to the students via information meetings, the homepage[13] of the programs and the fields of "Qualified Prerequisites" in the course catalogue[14]. The data also shows, that the longer the chain of courses, the fewer the number of students. Apart from the data being non-steady-state, this is also due to the way the requirement of the master's program is set up: the students must select 30 ECTS (as a minimum) of the entire pool of Technological specialization courses, which also covers the courses in the remaining two study lines, not considered here. Also notice how the yearly number of students completing KU181 from the beginning until present increases nearly exponential (second panel of Figure 2), made possible by the increasing number of students that have passed the exam of 31545 (first panel of Figure 2). This pattern is somewhat repeated for course KU180 with a natural time lag of one semester.

CONCLUSIONS

This paper has described a spiral and discipline-oriented curriculum in medical imaging implemented in the educational program Medicine and Technology, offered in collaboration by the Faculty of Health Sciences, University of Copenhagen and the Technical University of Denmark. The program was evaluated in terms of the progression in scientific demands in exam from course to course and in terms of the pattern of course selection by the students. The analysis was based on 96 students. The pattern of course selection was found to follow the intentions of the program, thus demonstrating high fulfillment of the learning outcomes

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Biographical Information

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