White Paper: Radiology Curriculum for Undergraduate Medical Education in Germany and Integration into the NKLM 2.0

White Paper: Curriculum Radiologie für das Studium der Humanmedizin und Implementierung in den NKLM 2.0

Autoren

Sabine Dettmer[1], Jörg Barkhausen[2], Erik Volmer[3], Hans-Joachim Mentzel[4], Sebastian Reinartz[5], Florian Voigt[6], Frank K. Wacker[1], Bettina Baeßler[7]

Konferenz der Lehrstuhlinhaber für Radiologie (KLR):

G. Adam, G. Antoch, U. Attenberger, F. Bamberg, J. Barkhausen, M. Beer, T. Bley, A. Bücker, T. Denecke, C. Düber, M. Forsting, B. Hamm, W. Heindel, R.-T. Hoffmann, N. Hosten, O. Jansen, H. U. Kauczor, G. Krombach, T. J. Kröncke, C. Kuhl, J. Lotz, A. Mahnken, D. Maintz, M. Makowski, K. Nikolaou, M. Pech, J. Ricke, E. Rummeny, S. Schönberg, A. Schreyer, C. Stroszczynski, U. Teichgräber, M. Uder, T. Vogl, F. Wacker, M.-A. Weber, W. Wohlgemuth

Vorstand der Deutschen Röntgengesellschaft (DRG):

G. Antoch, F. Anton, J. Barkhausen, A. Dörfler, F. Körber, G. Layer, S. Neumann, S. Schönberg, T. Vogl, J. Wessling, M. Wucherer

Vorstandskommission der AG Lehre der DRG:

J. Barkhausen, S. Afat, B. Baeßler, F. Bamberg, S. Dettmer, A. Frisch, O. Goldschmidt, N. L. Hansen, E. Hattingen, D. Maintz, H. J. Mentzel, I. Molwitz, K. Müller-Peltzer, D. Pinto dos Santos, S. Reinartz, F. Rengier, U. Teichgräber, T. J. Vogl, M. Völker, M. Weis

Affiliations

1 Department of Diagnostic and Interventional Radiology, Hannover Medical School, Hannover, Germany
2 Department of Radiology and Nuclear Medicine, University Hospital of Schleswig-Holstein, Lübeck, Germany
3 Institute for Diagnostic and Interventional Radiology, Pediatric and Neuroradiology, Rostock University Medical Center, Rostock, Germany
4 Section of Pediatric Radiology, Institute of Diagnostic and Interventional Radiology, University Hospital Jena, Germany
5 Department for Diagnostic and Interventional Radiology, University Hospital Aachen, Germany
6 Medical Faculty, University of Leipzig, Germany
7 Institute of Diagnostic and Interventional Radiology, University Hospital Zürich, Switzerland

Key words

undergraduate medical education, curriculum radiology, National Competency-based Learning Objectives Catalogue in Medicine, competency-based teaching, innovative teaching concepts, E-learning

received 20.05.2021
accepted 20.07.2021
published online 22.09.2021

Bibliography

Fortschr Röntgenstr 2021; 193: 1294–1302
DOI 10.1055/a-1586-3372
ISSN 1438-9029

Georg Thieme Verlag KG, Rüdigerstraße 14, 70469 Stuttgart, Germany

Correspondence

PD Dr. Sabine Dettmer
Department of Diagnostic and Interventional Radiology, Hannover Medical School, Carl-Neuberg-Str. 1, 30625 Hannover, Germany
Tel.: +49/5 11/5 32 34 21
dettmer.sabine@mh-hannover.de

Supplementary material is available under https://doi.org/10.1055/a-1586-3372

ABSTRACT

Objective The aim was to develop a new curriculum for radiology in medical studies, to reach a national consensus and to integrate it into the new national competence-based learning objectives catalog (NKLM 2.0). In this statement of the German Radiological Society (DRG), the process of curriculum development is described and the new curriculum is presented together with suggestions for practical implementation.

Materials and Methods The DRG has developed a new curriculum for radiology. This was coordinated nationally among faculty via an online survey and the result was incorporated into the NKLM 2.0. Furthermore, possibilities for the practical implementation of the competency-based content are shown and different teaching concepts are presented.

Results The developed curriculum is competency-based and aims to provide students with important skills and abilities for their future medical practice. The general part of the curriculum is divided into the topics "Radiation Protection", "Radiological Methods" and radiologically-relevant "Digital Skills". Furthermore, there is a special part on the individual organ systems and the specific diseases. In order to implement this in a resource-saving way, new innovative teaching concepts are needed that combine the advantages of face-to-face teaching in small groups for practical and case-based learning with digital teaching offers for resource-saving teaching of theoretical content.

Conclusion We have created a uniform radiology curriculum for medical studies in Germany, coordinated it nationally and integrated it into the NKLM 2.0. The curriculum forms the basis of a uniform mandatory radiology teaching and should be the basis for the individual curriculum development of each faculty and strengthen the position of radiology in the interdisciplinary context.

Key Points:

- A radiology curriculum for undergraduate medical education was developed.
- The curriculum was brought into agreement among the faculties in Germany and integrated into the NKLM 2.0.
- This curriculum is intended to be the basis for curriculum development and to strengthen the position of radiology.
- In order to implement the competence-based teaching, new innovative teaching concepts are necessary.

Citation Format

- Dettmer S, Barkhausen J, Volmer E et al. White Paper: Radiology Curriculum for Undergraduate Medical Education in Germany and Integration into the NKLM 2.0. Fortschr Röntgenstr 2021; 193: 1294–1302

ZUSAMMENFASSUNG

Ziel Ziel war es, ein neues Curriculum für die Radiologie im Medizinstudium zu entwickeln, national zu konsentieren und in den neuen nationalen kompetenzbasierten Lernzielkatalog (NKLM 2.0) zu integrieren. In diesem Artikel soll als ein Statement der Deutschen Röntgengesellschaft (DRG) der Prozess der Curriculumentwicklung beschrieben und das neue Curriculum zusammen mit Vorschlägen zur praktischen Umsetzung vorgestellt werden.

Material und Methoden Die DRG hat ein neues Curriculum für die Radiologie erarbeitet. Dieses wurde mittels einer Online-Umfrage national unter den Lehrverantwortlichen abgestimmt und das Ergebnis in den NKLM 2.0 eingebracht. Des Weiteren werden Möglichkeiten der praktischen Umsetzung der kompetenzbasierten Inhalte aufgezeigt und verschiedene Lehrkonzepte vorgestellt.

Ergebnisse Das erarbeitete Curriculum ist kompetenzbasiert und soll den Studierenden wichtige Fähigkeiten und Fertigkeiten für ihre spätere ärztliche Tätigkeit vermitteln. Der allgemeine Teil des Curriculums gliedert sich in die Themen „Strahlenschutz", „Radiologische Methoden" und radiologisch relevante „Digitale Kompetenzen". Des Weiteren gibt es einen speziellen Teil zu den einzelnen Organsystemen und den spezifischen Krankheitsbildern. Um dies ressourcensparend umzusetzen, sind neue innovative Lehrkonzepte nötig, die die Vorteile des Präsenzunterrichts in kleinen Gruppen zum praktischen und fallbasierten Lernen mit digitalen Lehrangeboten zur ressourcensparenden Vermittlung theoretischer Inhalte kombinieren.

Schlussfolgerung Wir haben ein einheitliches radiologisches Curriculum für das Medizinstudium in Deutschland erstellt, national abgestimmt und in den NKLM 2.0 integriert. Das Curriculum bildet die Grundlage einer einheitlichen verpflichtenden radiologischen Lehre und soll Grundlage für die individuelle Lehrplanentwicklung der einzelnen Fakultäten sein sowie die Position der Radiologie im interdisziplinären Kontext stärken.

Introduction

Radiology is an important interdisciplinary subject within the study of human medicine. Radiological content is taught in preclinical subjects, such as anatomy (cross-sectional anatomy) and physics (radiation physics and equipment technology), and is essential in almost all clinical subjects for both diagnostics and radiological interventional therapy of specific pathologies. On the one hand, as a subject that is so widely represented, it is a challenge to convey the radiological course content coherently while remaining visible as an independent subject in conjunction with other individual disciplines. On the other hand, this also offers the opportunity to use synergies together with other disciplines in integrative teaching, to accompany students throughout their studies and continuously inspire them for the subject with new aspects.

The study of medicine has undergone constant change during the past decades and which continues through the present. Whereas basic science subjects used to be integrated into medical curricula, this has changed in recent decades to problem-oriented and integrative teaching, in which the separation between preclinical and clinical subjects has been largely eliminated, especially in the reform and model degree programs [1]. Currently, the focus is increasingly on competency-based and digital teaching, in which instead of theoretical content, skills and competencies are increasingly taught. This reform process was initiated by recommendations for the further development of medical studies in Germany, which were published in 2014 by the Science Council of the Federal Republic of Germany [2]. Based on this, the Medical Faculty Association (MFT), together with the Society for Medical Education (GMA), developed the National Competence-Based Learning Objectives Catalog for Medicine (NKLM), published for the first time in 2015 [3]. In 2017, the Federal Ministry of Education and Research decided on extensive changes to medical studies in the “Master Plan for Medical Studies 2020”, which include, in particular, practical relevance, a stronger focus on competencies, a strengthening of general medicine, and a reorganization of examinations, and which are to be anchored in a new licensing regulation for physicians [4]. The new licensing regulations are due to come into force in 2025; the first draft was published at the beginning of this year [5]. In the course of the revision of medical education by the Master Plan for Medical Studies 2020, the NKLM as well as the Catalog of Medical Subjects (GK) were also fundamentally revised. The NKLM 2.0, in which representatives of the individual scientific professional societies were represented in its creation, as well as the MFT and the Institute for Medical and Pharmaceutical Examination Questions (IMPP), was published in the spring of 2021 [6]. In addition to the learning objectives contained in the mandatory core curriculum, individual medical school departments can also set their own priorities, which are defined in the form of an optional curriculum in the NKLM. The curriculum developed on the basis of the NKLM 2.0 is to be further elaborated by 2025 and will then no longer merely have the character of a recommendation, but will be an integral part of the new licensing regulations for physicians and relevant examination content of the IMPP.

The NKLM is intended to reduce theoretical factual learning in favor of teaching skills and competencies in the medical profession. In particular, this involves competencies that represent behaviors and so-called soft skills as overarching learning objectives, such as medical communication skills as well as respect and empathy in dealing with patients, their relatives and colleagues from medical and non-physician professional groups [7]. For radiology, this no longer means just imparting knowledge, but also teaching basic practical skills such as independent image and report description of X-ray images as well as practical performance of orienting ultrasound examinations of the neck, abdomen and blood vessels. This also includes the acquisition of competencies for the assessment of diagnostic value, i. e. which method is suitable for which issue, the indications and contraindications of the various radiological modalities as well as the classification of diagnostic and therapeutic methods in an interdisciplinary context, including adequate communication with the referring physician and the patient. Finally, increased digitalization is a significant innovation. This concerns both teaching content per se, but also digital competencies to be learned for medical studies and the practice of medicine.

The NKLM differentiates the depth of learning into three different levels of competence which build on each other. In this context, factual knowledge (competence level 1) and practical and theoretical knowledge (competence level 2) are prerequisites for achieving practical competence (competence level 3, a: under guidance and b: independently) [3]. During medical school, various teaching contents recur in a learning spiral, each with an ascending level of competency. The aim of our committee work was to develop a new curriculum for radiology in medical studies, to reach a consensus with the department chairs and those responsible for teaching at the individual faculties, and ultimately to integrate it into the NKLM 2.0. The curriculum is intended to be a guideline for practical implementation and at the same time serve as an official statement of the German Radiological Society (DRG) when coordinating the teaching content with the deans of studies at the individual universities. In this paper we would like to introduce the process of curriculum development and national coordination and present the result. Furthermore, we shall present different teaching concepts and consequently provide suggestions for an effective and resource-saving implementation of these innovations.

Materials and Methods

Mapping

Curriculum development involved mapping of the entire NKLM in its 2015 version [3] including the radiology teaching content at three medical departments (Hannover, Cologne, and Mannheim); this was performed by the respective teaching staff. For this purpose, for each learning objective specified in the NKLM, it was documented whether it was taught or not. A model radiology curriculum was designed based on this mapping as well as publications on teaching content by the *European Society of Radiology* (ESR) [8], the DRG [9] the *Joint Commission of the Swiss Medical Schools* [10].

Coordination with Radiology Department Chairs and Faculty

The developed model curriculum was sent to the chairs of radiology and – as far as differentiated and known – to the teaching staff of all 36 medical faculties in Germany with the request for additions, comments and approval. The invitation was sent via DRG as an online-based survey using EvaSys 7.0 (Electric Paper Evaluationssysteme GmbH, Lüneburg, Germany). In principle, the questionnaire was designed as an anonymous survey. However, since correlation with the individual departments can sometimes be helpful and enable queries, there was also the option of providing one's name and location.

The questionnaire was divided into three parts: “Radiation Protection”, “Methods” and “Organ Systems”. In the sections “Radiation Protection” and “Methods”, comments with changes or additions to the proposed teaching content could be made in free text fields. In the “Organ Systems” section, the radiologically-relevant pathologies were listed according to organ systems after evaluation of the mapping. The assessment regarding their relevance in radiology teaching was made using an ordinal scale (0 = not relevant in radiology, 1 = may be relevant in radiology and should be taught optionally depending on the focus of the department, 2 = very relevant in radiology and should be taught compulsorily in the core curriculum). In addition, free text fields were used to record further comments.

Results

Survey

Twenty-four respondents participated in the radiology department chair and faculty survey, in addition, the three departments at Hannover, Cologne and Mannheim where the mapping was performed were included. Due to the fact that the survey was anonymous and sent to both department chairs and faculty members, it is unclear how many departments actually participated. Nevertheless, representatives of all faculties had the opportunity to give feedback, and together with the rather high number of participants of 24 + 3 persons, considering that there are 36 medical schools in Germany, the response can be considered as sufficiently representative.

Overall, consensus on the already developed curriculum was high. Due to the survey results the curriculum was revised and expanded. Free text comments from the “Radiation Protection” and “Methods” were integrated. Based on the weightings of the relevance of the different pathologies in the “Organ Systems” section, the median was calculated and differentiated accordingly into “radiologically very relevant and should be taught compulsorily in the core curriculum” and “radiologically possibly relevant and should be taught optionally depending on the focus of the department”. Pathologies that were deemed “radiologically irrelevant” by the vast majority of respondents were removed from the curriculum. Based on suggestions by survey respondents, some new pathologies were added. Digital competencies and the field of interventional radiology appeared underrepresented in the 2015 NKLM, so that in conjunction with the project group “Digital Competencies” and the working group “Therapeutic Measures” of the NKLM/GK Development, there was a corresponding expansion of the curriculum.

Curriculum

▶ **Table 1** shows the general part of the developed and nationally-coordinated curriculum with the topics “Radiation Protection”, “Radiological Methods” and radiologically-relevant “Digital Competencies”. In addition to the pure listing of learning objectives, the depth of competencies to be achieved as of the various dates of the state examinations are also indicated. Furthermore, there is a special section on the individual organ systems and the specific clinical pathologies with reference to the various chapters of the NKLM. The list of pathologies of particular relevance to radiology, compiled with the help of the survey, is presented with reference to the respective chapters of the NKLM in ▶ **Table S1–S8** in the Online Supplement. Depending on relevance, a distinction is made here between “core curriculum” for mandatory teaching content and “departmental curriculum” for optional instructional content depending on the focus of the department.

Discussion

Based on our work, we were able to create a new curriculum for medical studies, obtain approval from department chairs and relatedfaculty, and ultimately integrate it into the new national competency-based learning objectives catalog (NKLM 2.0). The curriculum is intended to be a guideline for practical implementation while serving as an official statement of the German Radiological Society (DRG) when coordinating teaching content with the deans of studies at the individual universities.

The essential innovation of this curriculum is competency-based learning. In particular, this involves competencies that represent activities and practical skills as overarching learning objectives. In radiology, these include the independent description of images and findings on X-rays, practical performance of orienting ultrasound examinations, selection of the correct examination modality depending on the issue and the patient, as well as the classification of diagnostic and therapeutic methods in an interdisciplinary context, including adequate communication with the referring physician and the patient. In addition, there is increasing digitalization, affecting both the teaching content and digital skills to be learned during training and medical practice and which should ultimately be reflected in our teaching activities.

In order to implement this new curriculum, extensive changes in teaching will be required at the vast majority of departments. This concerns both the structure and teaching concept in the overall context of the respective university as well as the teaching approaches within radiology, including increasing digitalization. The following will present various options as well as a discussion of related advantages and disadvantages.

Instructional Concepts in Radiology

The overall approach to teaching this content will vary from department to department. Depending on whether the program is a regular, model, or reform program and the organization at each site, radiology may be taught separately as a single subject or integratively in conjunction with other clinical and preclinical subjects. From our point of view, a combination of both is desirable: a modality-oriented part (corresponding to Parts 1–3 of the curriculum), which is mainly taught subject-specifically or integrated in a methodological course, and an organ system-oriented part (Part 4 and sections of radiological image analysis in Part 2), for which integrative teaching is appropriate. If teaching is exclusively integrative, there is a risk that students will not get a sufficient overview of the basics of radiation protection and radiological methods, and the focus on radiology as a subject in its own right can be lost. Purely subject-specific teaching can neglect the interdisciplinary context of radiological diagnostic and therapeutic procedures, and the clinical relevance of radiological content recedes into the background.

The timing of radiological teaching during medical studies also differs greatly from department to department. In standard curricula, radiology usually appears relatively late as an independent course. In model and reform programs, radiology is often taught integratively with other subjects throughout the course of study, although here, too, the focus on radiology is usually in the higher semesters. On the other hand, surveys as well as our internal evaluations show that students would like to see radiology implemented earlier in their studies, especially to learn skills such as chest X-ray diagnosis and reporting [11, 12].

▶ **Table 1** Radiological methods and radiation protection: chapter, learning objectives and competency levels in NKLM.

chapter	competency/Learning objective	GL M1 s	BK M1 m	PY M2	WK M3
VII.2–03	Graduates select imaging procedures without ionizing radiation with or without contrast agents according to indication, patient, gender, age and situation and use the results for further diagnostic and therapeutic decisions.				
VII.2–03.1	They are familiar with sonography including color duplex, Doppler, B-scan sonography, Doppler occlusion pressure, endosonography, echocardiography (TTE+TEE) with or without echo-enhancing contrast. They can …				
VII.2–03.1.1	… explain and provide the indications and contraindications of the various sonography procedures with and without contrast and request the examination (e. g. electronically).	1	2	2	3a
VII.2–03.1.2	… understand and explain the basic principles of image formation and underlying tissue properties in sonography.	2			
VII.2–03.1.3	… explain the significance of sonographic findings in the clinical context, use sonographic findings for further diagnostic and therapeutic decisions, and take appropriate action.		2	2	3a
VII.2–03.1.4	… explain the basic procedure of abdominal and cervical sonography and perform B-scan sonography.		2	3a	3a
VII.2–03.2	They are familiar with diagnostic radiology with or without contrast. They can …				
VII.2–03.2.1	… understand and explain the physical principles of image formation and tissue properties in X-ray and CT.	2			
VII.2–03.2.2	… explain and apply the legal requirements and guidelines of radiation protection for the use of ionizing radiation and the handling of open radionuclides and use biological-physical principles to protect patients, the environment and themselves from the consequences of ionizing radiation.		2	3a	
VII.2–03.2.3	… explain indications and contraindications for X-rays and fluoroscopy including angiographic diagnostics with and without contrast, provide relevant information, document this and request the examination (e. g. electronically). They know the risks and side effects of X-ray contrast agents and have mastered the basics of contrast-associated complication management.	1		2	3a
VII.2–03.2.4	… name and differentiate relevant anatomical structures in radiographs.	1		2	
VII.2–03.2.5	… recognize and describe relevant pathological changes and structures extraneous to the body in radiographs.		1	2	2
VII.2–03.2.6	… name and explain the most important pharmacological and physical properties of contrast agents and other diagnostically-used drugs.				
VII.2–03.3	They are familiar computed tomography (CT) with or without contrast. They can …				
VII.2–03.3.1	… recognize relevant anatomical structures in cross-sectional imaging (sonography, MRI, CT) and apply this knowledge when locating the structures independently.	1		2	
VII.2–03.3.2	Explain indications and contraindications for computed tomography with and without contrast, provide relevant information and document this. They know the risks and side effects of iodine-based contrast agents and can explain the basics of contrast-associated complication management.	1	2	2	3a
VII.2–03.3.3	… recognize and describe relevant pathological changes in cross-sectional imaging (sonography, MRI, CT) and classify them in the context of applicable guidelines.	1		2	2
VII.2–03.4	They are familiar with magnetic resonance imaging (MRI) with or without contrast. They can …				
VII.2–03.4.1	… explain the indications and contraindications of an MRI with or without contrast agents and request the examination (e. g. electronically). They know the risks and side effects of MRI contrast agents and can explain the basics of contrast-associated complication management.	1	2	2	3a
VII.2–03.4.2	… understand and explain the basic principles of image formation and tissue properties in MRI, including the most important sequences and special safety aspects.		2		
VII.2–03.4.3	… Educate and prepare patients for an MRI scan.		2	3a	3b
VII.2–13	The participants know the significant of digitalization in medicine and diagnostics.				

▸ **Table 1** (Continuation)

chapter	competency/Learning objective	GL M1 s	BK M1 m	PY M2	WK M3
VII.2–13.1	They are familiar with digitalization in medicine, current developments in the field of artificial intelligence, personalized medicine and digital imaging. They can …				
VII.2–13.1.1	… name important standards in medical information technology. They know the term interoperability and its necessity, levels and requirements and can explain them with a clinical example.			2	
VII.2–13.1.2	… apply and evaluate the recent techniques of virtual reality (VR), augmented reality (AR), and computer-assisted medicine in a reflective manner.	1		2	
VII.2–13.1.3	… explain the concept personalized medicine and know the basics as well as medical applications of machine learning and AI systems also in the context of the Medical Devices Act.	1	2		
VII.2–13.1.4	… explain different types of knowledge-based systems and medical applications of clinical decision support systems (CDSS) to optimize patient care and know their advantages and limitations.		2		
VII.2–13.1.5	… explain deployment scenarios for telemedicine applications and their framework conditions.		2		
VII.2–13.1.6	… explain and apply procedures for image enhancement as well as visualization, registration and segmentation of medical images.		2	3a	
VIII.2–06.3	… recognize and reflect on the impact of digital applications with regard to the doctor-patient conversation and the doctor-patient relationship.	1	2		3a
VIII.6–04.3	… explain specific requirements, challenges, opportunities and limitations of the doctor-patient relationship due to new technological procedures and take them into account in their activities.		2	3a	

1 = Specialized knowledge: identify and explain descriptive knowledge (facts). 2 = Skill and reasoning knowledge: explain facts and relationships, classify them in the clinical-scientific context and evaluate them based on data. 3a = Competency: perform and demonstrate under supervision. 3b: Competency: perform independently and in a manner appropriate to the situation, knowing the consequences. GL = Basic skill; BK = Basic medical skill for training that is directly related to the patient; P = Practical Year skill; WK = Medical license and advanced training skills; M1 s = 1st state examination (written); M1 m = 1st state examination (oral); M2 = 2nd state examination; M3 = 3rd state examination.

Different Teaching Formats and Digitalization in Radiology

Evaluation and adaptation of teaching methods is necessary in addition to the basic structure and timing of teaching radiology in the overall concept of the respective university. A change in didactics is essential if skills and competencies are increasingly taught instead of theoretical content. Although theoretical principles can generally be presented in the traditional lecture format, practical implementation of these changes will no longer be possible in a lecture hall with several hundred students, rather in smaller groups and competency-based instruction. In addition to new teaching content and improved didactics, however, resources and the considerably increased personnel requirements must also be addressed. Even in the case of lecture-based teaching, it is sometimes a time challenge to be sufficiently engaged in student teaching in addition to patient care and scholarly activities. The problem will increase many times over with competency-based instruction in smaller groups if innovative teaching concepts that conserve personnel and resources are not developed. In order to develop such concepts and utilize them synergistically, the working group "Implementation of the NKLM" was established and located at the MFT as part of the working group "Teaching" and will – with radiological participation – accompany and support the introduction and implementation of the NKLM at the medical faculties in Germany.

Digitalization in medicine has given us opportunities to implement the revised NKLM and has called for new concepts for practical implementation [13–15]. One widespread format is e-learning, in which purely computer-based content is presented. Once the content is created, this form of teaching is very resource-efficient and is also popular with students as a supplement to traditional teaching because it is independent of time and place and allows students to learn at their own pace. Disadvantages include a lack of interpersonal interaction and sharing as well as an absence of opportunity to impart practical skills [16]. Furthermore, the initial additional effort involved in creating digital teaching content, acquiring the necessary media skills and creating a functioning IT infrastructure should not be underestimated, which, in contrast to conventional teaching, cannot be done by lecturers alone. Another rather organizational disadvantage of e-learning is that it is not taken into account in many departments both in the allocation of performance-based funds and in the recognition of personal teaching performance, e. g. for an intended qualification to teach at a university. There is a lot of catching up to do here, which has certainly been accelerated in many places with the change in teaching concepts as a result of the COVID-19 pandemic.

As a result of the pandemic-related contact ban, digital forms of communication such as videoconferencing systems in particular have come into focus in addition to e-learning. Video conferences can be seamlessly and advantageously integrated into teaching to allow individual interaction between instructors and students. For example, as in a lecture or seminar, questions can be asked or opinion polls can be conducted. Screen sharing allows the teacher to convey knowledge in the form of a presentation or a whiteboard in real time, while students can make entries interactively and point out certain image content – this particularly applies to seminars. Likewise, small-group work dividing the video conference participants into further subgroups is also possible.

Interactive case collections, e. g. on DRG's "conrad" learning platform (UniRad, CoRad-19), significantly support digital teaching concepts. Students are able to deal with real radiological problems individually and interactively. The combination with video conferencing offers the possibility to work on cases with the support of a teacher and clarify open questions or problems. In the case of classroom activities such as block internships, clinical traineeships or during the practical year, the combination of case-based learning using routine cases or specially preselected teaching cases with video-based discussions offers the possibility of teaching close to reality, comparable to the workplace.

In the field of examinations, this implementation is more difficult, especially for legal reasons, since attempts to cheat can only be countered by taking considerable technical precautions. On the other hand, computer-based testing of higher skill levels is easier than using multiple-choice questions.

The advantages and disadvantages of classic teaching methods in the form of classroom events and e-learning are obvious. In order to effectively utilize the respective advantages and minimize the disadvantages, teaching concepts have been developed in which both forms of teaching are combined [17], including blended learning and the "flipped classroom", concepts which have already been tested in radiology. They have a high level of acceptance among students and also offer the potential to improve the visibility and attractiveness of the discipline [11, 18, 19]. In the following, different teaching formats are briefly presented and possible applications in radiology are explained.

The **lecture** is the classic teaching method in which the instructor imparts knowledge in an auditorium in the form of an oral presentation, usually with the help of slides, and the students take a mostly passive role. This form of teaching is very common because it saves resources, especially with larger groups of students, even though it is now considered outdated from a didactic point of view [1, 20]. Some teaching can certainly still take place as lectures, but the majority of courses should not be taught using this format, and a combination should be sought with teaching in small groups as well as innovative teaching methods to impart competencies. In the case of lectures, engaging the students can contribute significantly to improvement. Numerous well-tested and scientifically evaluated methods for the use of digital media (e. g. quiz tools) are available for this purpose, leading to improved knowledge acquisition and a more sustainable learning effect.

In radiology, **small-group teaching** is particularly suitable for problem-based learning with independent viewing and diagnosis of X-rays and cross-sectional images [19, 21] as well as learning the basics of sonography and interventional radiology [22, 23]. For example, the focus may be on anatomical orientation, recognizing and describing pathology, or acquiring skills. This type of instruction can be devoted solely to radiology or integrated with other subjects; it allows for a high level of interaction and sharing of experiences and is very popular with students. Disadvantages include high personnel demands and the provision of sufficient facilities with appropriate technical equipment, such as computers with image viewing software or ultrasound units. Therefore, with the given resources at many departments, it will only be possible to design some of instructional activities in this format. Furthermore, small-group instruction is particularly appropriate for select groups of students, e. g., as part of an elective or compulsory elective subject course. In addition to resources, it should also be considered here that students who are very interested in radiology in particular can sign up for such courses and be motivated to specialize.

When local conditions permit, hands-on radiology instruction is also available in larger student groups. This requires appropriate equipment, such as a multimedia room. At Hannover Medical School (MHH), **radiological reporting training** [19] with special reporting software (Visage Imaging, Pro Medicus Limited, Richmond, Australia) has already been in place since 2015; this software provides all the functions required for clinical routine, such as multiplanar reformation and volume rendering. Here, 4th and 5th year students work on radiology cases independently and then present them as a group; the instructor assists and provides background information. Similar formats already exist at other universities [24, 25]. This form of teaching supports instruction of larger groups of up to approximately 30 students. The format is thus somewhat more resource-efficient than small-group instruction and can be used for at least some of the compulsory instruction.

E-learning provides computer-based instruction. Some universities have special web-based programs for this purpose, such as "Ilias" at the Hannover Medical School, OLAT at the University of Zürich, or Moodle. Following preliminary work by the University of Tübingen (TUERAD), the DRG, in cooperation with MeVis, has created the digital teaching platform "conrad", on which, in addition to certified online courses and practical case collections for physicians and lecture recordings from congresses, several courses for students are also available (UniRad, CoRad-19) [26]. Depending on the software used, interaction in the form of cases and questions is possible in addition to pure knowledge transfer. For radiology, special attention should be paid to the possibility of image viewing. In addition to single images, it should also be possible to view CT data sets in DICOM viewers. Likewise, integration of videos is also helpful [26–28]. Unlike instructor-based instruction, this digital teaching format supports learning at one's own pace, detached from time and place. Once the content is created, the method is time and resource efficient, especially when content is shared across departments through collaboration. Disadvantages include the lack of interaction and limited personal attention from the instructors, which can lead, among other things, to a reduction of attention among the audience.

Unlike e-teaching, **instructional films** do not support student interaction, much like a lecture or presentation. In addition to slides with audio, recorded lectures can also be counted as part of this. Nevertheless, students are independent of time and place and can choose their own learning pace by interrupting the video or repeating certain sequences. Educational videos are already widely available [29], and there are radiology educational videos on YouTube [30] and "conrad", for example, that explain the basics of the various radiological modalities or provide an introduction to chest X-ray reporting. Instructional films can be used independently or embedded in e-learning modules.

Blended learning (integrated learning) combines traditional in-person formats with e-learning. An example of practical application is an e-learning module on the topic of FAST sonography with a subsequent classroom event in small groups, in which the theoretically learned content can be practically demonstrated [22]. There are also reports regarding instruction in radiological anatomy [31] as well as mammography [32]. The approach supports effective and flexible forms of teaching combined didactically with practical instruction during in-person events. The disadvantage of the lack of competence transfer in the context of e-learning is mitigated by the subsequent practical live event, and at the same time instruction remains resource-efficient due to the preceding independent digital learning component. Blended learning thus provides a suitable combination of different media and methods to enhance their advantages and minimize their disadvantages. To achieve this, the phases of classroom teaching and online teaching must be closely coordinated. By using the optimal medium in each step of the learning process, blended learning represents an almost universally applicable form of instructional organization [33, 34].

The concept of the "**flipped classroom**" was introduced in 2012 [35]. Here, the usual sequence of first conducting lessons and then doing homework is reversed. Students prepare independently and in subsequent classes apply their newly-acquired knowledge directly. In addition to independent preparation using a textbook, an e-learning module or an educational film can also be used as homework [36]. Subsequent classroom activities can be used to apply the knowledge already gained and to discuss it in the group. The instructor is not the focus of the action here, but merely assists the students with advice and action and can flexibly respond to gaps in knowledge and correct misunderstanding. Thus, there is a change from instructor-centered to student-centered teaching [37, 38]. Time used for interaction between student and instructor can be used more effectively through prior self-study, since acquiring basic knowledge has already taken place [39, 40]. The practical skills acquired can then be further consolidated in the follow-up using digital case collections in self-study. The flipped classroom demonstrably increases the satisfaction and personal involvement of students, active participation allows them to manage their learning success themselves. The high practical relevance and the direct applicability of what has been learned increase their motivation and interest in the subject matter, consequently providing the learning content with greater emotional significance while enabling more substantial learning [38]. Increased interaction in the classroom also increases the learning effect for the students [14, 40]. This instructional format has been used successfully for years, especially in the Anglo-American region, in a wide variety of disciplines, and initial reports for use in radiological teaching have now been published [41–44].

Summary

The new radiological curriculum for medical studies was drawn up in collaboration with the department heads of radiology in Germany and their instructional staff and integrated into the NKLM 2.0. The competency-based instruction described here is reflected in radiology primarily in the independent diagnosis of X-ray images, performance of orienting ultrasound examinations, assessment of the diagnostic value and indications of the various radiological modalities, the classification of diagnostic and therapeutic methods in an interdisciplinary context and communication with the referring physician and the patient and/or caregiver. In order to implement these skills in a resource-saving manner, new, innovative teaching concepts are necessary which combine the advantages of classroom teaching in small groups for practical and case-based learning with digital courses in the form of e-learning and educational films for resource-saving instruction of theoretical content. With respect to digital content in particular, there is a national level of cooperation that has already begun with UniRad and which opens up new opportunities with the implementation of NKLM 2.0.

Conflict of Interest

The authors declare that they have no conflict of interest.

Acknowledgements

We would like to thank all of you who participated in the survey and thus contributed to the development of the curriculum and all members of the project group "Digital Competencies" and the working group "Therapeutic measures" of the NKLM/GK for the professional exchange and collaboration. Furthermore we thank Dr. Volkhard Fischer from the Hannover Medical School for his support in carrying out the online survey with EvaSys and Mrs. Sandra Ermisch from the DRG for the support in the communication with the members of KLR and the board of the DRG.

References

[1] Frenk J, Chen L, Bhutta ZA et al. Health professionals for a new century: transforming education to strengthen health systems in an interdependent world. Lancet Lond Engl 2010; 376: 1923–1958

[2] Wissenschaftsrat. Neustrukturierung des Medizinstudiums und Änderung der Approbationsordnung für Ärzte. Empfehlungen der Expertenkommission zum Masterplan Medizinstudium 2020. https://www.wissenschaftsrat.de/download/archiv/7271-18.pdf. abgerufen am 11.02.2020. 2018

[3] Medizinischer Fakultätentag 2015. Nationaler Kompetenzbasierter Lernzielkatalog Medizin (NKLM). http://www.nklm.de/files/nklm_final_2015-07-03.pdf; abgerufen am 11.02.2020. 2015

[4] Bundesministerium für Bildung und Forschung. Masterplan Medizinstudium 2020. https://www.bmbf.de/files/2017-03-31_Masterplan%20Beschlusstext.pdf; abgerufen am 08.07.2021. 2017

[5] Bundesministerium für Gesundheit. Verordnung zur Neuregelung der ärztlichen Ausbildung. Referentenentwurf des Bundesministeriums für Gesundheit. https://www.bundesgesundheitsministerium.de/fileadmin/Dateien/3_Downloads/Gesetze_und_Verordnungen/GuV/A/Referentenentwurf_AEApprO.pdf; abgerufen am 08.07.2021. 2021

[6] Medizinischer Fakultätentag. Nationaler Kompetenzbasierter Lernzielkatalog Medizin – Version 2.0. https://nklm.de/zend/menu/index; abgerufen am 16.05.2021. 2021

[7] Richter-Kuhlmann E. Lernzielkatalog Medizin: Mehr als Faktenwissen. Dtsch Arztebl International 2015; 112: 1366–1367

[8] European Society of Radiology. Curriculum for Undergraduate Radiological Education U-Level Curriculum Edition March 2019.

[9] Ertl-Wagner B, Barkhausen J, Mahnken A et al. White Paper: Radiological Curriculum for Undergraduate Medical Education in Germany. ROFO Fortschr Geb Rontgenstr Nuklearmed 2016; 188: 1017–1023

[10] Bloch R, Bürgi H. The Swiss catalogue of learning objectives. Med Teach 2002; 24: 144–150

[11] Nyhsen CM, Steinberg LJ, O'Connell JE. Undergraduate radiology teaching from the student's perspective. Insights Imaging 2013; 4: 103–109

[12] Kraft M, Sayfie A, Klein K et al. Introducing First-Year Medical Students to Radiology: Implementation and Impact. Acad Radiol 2018; 25: 780–788

[13] Qureshi Z. Technology and medical education: change for the better? Clin Teach 2016; 13: 461

[14] Sivarajah RT, Curci NE, Johnson EM et al. A Review of Innovative Teaching Methods. Acad Radiol 2019; 26: 101–113

[15] European Society of Radiology (ESR). ESR statement on new approaches to undergraduate teaching in Radiology. Insights Imaging 2019; 10: 109

[16] Ruiz JG, Mintzer MJ, Leipzig RM. The impact of E-learning in medical education. Acad Med J Assoc Am Med Coll 2006; 81: 207–212

[17] Salajegheh A, Jahangiri A, Dolan-Evans E et al. A combination of traditional learning and e-learning can be more effective on radiological interpretation skills in medical students: a pre- and post-intervention study. BMC Med Educ 2016; 16: 46

[18] Dettmer S, Weidemann J, Fischer V et al. Integrative teaching in radiology – a survey. ROFO Fortschr Geb Rontgenstr Nuklearmed 2015; 187: 260–268

[19] Koestner W, Otten W, Kaireit T et al. Competency-Based Teaching in Radiology – Implementation and Evaluation of Interactive Workstation-Based Learning to Apply NKLM-Based Content. ROFO Fortschr Geb Rontgenstr Nuklearmed 2017; 189: 1076–1085

[20] Mehta NB, Hull AL, Young JB et al. Just imagine: new paradigms for medical education. Acad Med J Assoc Am Med Coll 2013; 88: 1418–1423

[21] Schober A, Pieper CC, Schmidt R et al. "Anatomy and imaging": 10 years of experience with an interdisciplinary teaching project in preclinical medical education – from an elective to a curricular course. ROFO Fortschr Geb Rontgenstr Nuklearmed 2014; 186: 458–465

[22] Bintaro P, Schneidewind S, Beck C et al. Erfahrungen mit der Implementierung eines interdisziplinären eFAST-Sonografie-Seminars für Studierende der Humanmedizin [Bericht über Entwicklungsprozess] 2018.

[23] Stoehr F, Schotten S, Pitton MB et al. Endovascular simulation training: a tool to increase enthusiasm for interventional radiology among medical students. Eur Radiol 2020; 30: 4656–4663

[24] Chen Y, Zheng K, Ye S et al. Constructing an experiential education model in undergraduate radiology education by the utilization of the picture archiving and communication system (PACS). BMC Med Educ 2019; 19: 383

[25] Petsch I. Austausch zum Thema Befundtraining in der Radiologie, Erfahrungsbericht aus dem Uniklinikum Münster 2020.

[26] MeVis Medical Solutions AG. UNIRAD. https://academy.mevis.de/drg/.o.J

[27] Pinto A, Brunese L, Pinto F et al. E-learning and education in radiology. Eur J Radiol 2011; 78: 368–371

[28] Wentzell S, Moran L, Dobranowski J et al. E-learning for chest x-ray interpretation improves medical student skills and confidence levels. BMC Med Educ 2018; 18: 256

[29] Kahn S. Salman Khan TED Talk 2011. https://www.youtube.com/watch?v=gM95HHI4gLk, abgerufen am 11.02.2020, 2011

[30] Baeßler B. Radio-RESET. https://www.youtube.com/channel/UCRwDz9QUWf2LcWiUbynsdmA, abgerufen am 11.02.2020, o. J.

[31] Shaffer K, Small JE. Blended learning in medical education: use of an integrated approach with web-based small group modules and didactic instruction for teaching radiologic anatomy. Acad Radiol 2004; 11: 1059–1070

[32] Vásquez A, Palazuelos G, Pinzon BA et al. Blended Learning in Radiology: Evaluation of a Nationwide Training Program on Breast Imaging. J Am Coll Radiol JACR 2018; 15: 458–462

[33] Liu Q, Peng W, Zhang F et al. The Effectiveness of Blended Learning in Health Professions: Systematic Review and Meta-Analysis. J Med Internet Res 2016; 18: e2

[34] Mahnken AH, Baumann M, Meister M et al. Blended learning in radiology: is self-determined learning really more effective? Eur J Radiol 2011; 78: 384–387

[35] Young TP, Bailey CJ, Guptill M et al. The flipped classroom: a modality for mixed asynchronous and synchronous learning in a residency program. West J Emerg Med 2014; 15: 938–944

[36] Green DE, McNeeley MF. Practice corner: is radiology education ready for a flipped classroom? Radiogr Rev Publ Radiol Soc N Am Inc 2013; 33: 533–534

[37] Sharma N, Lau CS, Doherty I et al. How we flipped the medical classroom. Med Teach 2015; 37: 327–330

[38] Ramnanan CJ, Pound LD. Advances in medical education and practice: student perceptions of the flipped classroom. Adv Med Educ Pract 2017; 8: 63–73

[39] Chen F, Lui AM, Martinelli SM. A systematic review of the effectiveness of flipped classrooms in medical education. Med Educ 2017; 51: 585–597

[40] Hew KF, Lo CK. Flipped classroom improves student learning in health professions education: a meta-analysis. BMC Med Educ 2018; 18: 38

[41] Afzal S, Masroor I. Flipped Classroom Model for Teaching Undergraduate Students in Radiology. J Coll Physicians Surg-Pak JCPSP 2019; 29: 1083–1086

[42] Tan N, Bavadian N, Lyons P et al. Flipped Classroom Approach to Teaching a Radiology Medical Student Clerkship. J Am Coll Radiol JACR 2018; 15: 1768–1770

[43] Belfi LM, Bartolotta RJ, Giambrone AE et al. "Flipping" the introductory clerkship in radiology: impact on medical student performance and perceptions. Acad Radiol 2015; 22: 794–801

[44] O'Connor EE, Fried J, McNulty N et al. Flipping Radiology Education Right Side Up. Acad Radiol 2016; 23: 810–822