Review

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Technical infrastructure for curriculum mapping in medical education: a narrative review

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Abstract: Curriculum mapping is the process of designing a multidimensional model of an educational programme for a complete, more transparent and better-integrated learning experience. Many universities worldwide are building or expanding their technical infrastructure to manage their curricula. Our aim was to deliver a synopsis of current practices and describe the focus of research interest in implementing curriculum mapping tools for medical education. As part of the Building Curriculum Infrastructure in Medical Education (BCIME) project, we conducted a state-of-the-art narrative review of the literature. A systematised search of the PubMed/MEDLINE database for the years 2013–2019 resulted in 352 abstracts, from which 23 full-text papers were included in the final review. From these, we extracted guidance on 12 key characteristics of curriculum mapping tools. The collected experiences formed four thematic categories: visualisations, text descriptions and analysis, the outcome-based approach and adaptability in curriculum mapping. As result of the review, we summarised topics regarding ways of: implementating new competency-based catalogues (like NKLM) in curriculum mapping software (e. g., using dynamic checklists), methods of streamlining the authoring process (e. g., by automatic detection and alignment of action verbs in learning objectives descriptions) and graphical forms of presenting curriculum data (e. g., network visualisations using automatic clustering of related parts of a curriculum based on similarities between textual descriptions). We expect further developments in text-mining methods and visual/learning analytics in curriculum mapping. The collected data informed the design of a new curriculum management system called EduPortfolio, which is currently being implemented by the BCIME project.

Keywords: curriculum management; curriculum mapping; outcome-based education; state-of-the-art review.

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Introduction

Curriculum management is a complex process consisting of tasks related to designing, implementing, monitoring, evaluating and optimising study programmes. Part of this process is curriculum mapping, which focuses on building a formal model of a curriculum (a 'curriculum map') [1] and aligning it with educational standards or other curricula in order to identify gaps or redundancies in the curriculum [2, 3].

A curriculum map is a multifaceted model of an educational programme that provides answers to a wide range of questions that derive from a fundamental one which asks 'where do we teach what?' [4]. Typically, a curriculum map comprises descriptions of the learning objectives/outcomes, learning units (e. g., individual lectures, seminars, simulation sessions), educational content and assessments that form a given curriculum [1]. However, what is probably most important about a curriculum map is the relations between its elements [5]. The great number of curricular building blocks and the complexity of connections between them make it practically impossible to present such a complex structure on paper printouts in a legible and efficient way. Thanks to the versatility of computers, stakeholders at medical schools (students, the faculty, accreditation bodies) may explore a curriculum conveniently from several angles (in Harden's parlance, these are called 'windows' [1]), thus gaining different views into its limitations and the opportunities it presents.

Curriculum mapping is not just about sophisticated views of syllabuses: beneath the surface of the various visualisations there is an outcome-based education approach [6] that focuses on achieving a pre-defined catalogue of educational objectives rather than targeting the time-dependent educational process itself. This aims to make students feel more responsible for reaching their educational goals; it also encourages teachers to be more transparent about their expectations and cognisant of what is being taught in other parts of the curriculum. In recent years, the outcome-based approach has been expanded into a competency-based one that highlights students' achievement of successive levels (milestones) of measurable abilities that are crucial for medical practice [7]. Curriculum mapping is also a convenient tool in quality control as it can be used to verify that a curriculum complies with the required accreditation standards, local and global competency catalogues, and the internal expected characteristics of university graduates [8]. Finally, a computer-based representation of a curriculum makes it possible to compare different educational programmes across medical schools and gives opportunities for more advanced medical education research [5, 9].

The Building Curriculum Infrastructure in Medical Education (BCIME) project aims to capitalise on the strengths of curriculum mapping and develop a software platform to describe, optimise and compare curricula across medical schools from five European countries: Czechia, Germany, Poland, Romania and Slovakia [10]. Co-funded by the European Union as a 3-year endeavour (2018–2021), the project follows a multi-step pathway that includes needs analysis, development and evaluation at different levels to arrive at a complex technical infrastructure that aims to help curriculum designers, faculties and students get an overview of their programme of study. While doing so, the project strives to apply state-of-the-art curriculum mapping concepts and technologies and to inform the community about the established best practices and the lessons learnt.

The goals of this study were to perform a state-of-the-art review of the most recent technical developments around curriculum mapping and on this basis describe current best practice and research interest in implementing curriculum mapping software for medical education.

Methods

In order to answer the posed question, we considered a range of different methods of conducting literature reviews [11, 12]. As our aim had a broad scope but also required qualitative data analysis and dealt with rapidly changing technology, we decided to implement it as a state-of-the-art narrative review [12].

We systematically searched the PubMed/MEDLINE database in the 5 years prior to the start of the project and during the project lifetime (from January 1st, 2013 until December 31st, 2019). The implemented PubMed/MEDLINE search strategy is presented in the Appendix. We included full-text articles describing the curriculum mapping software tools in use in medical education. We excluded curriculum development and comparison initiatives in which the details of the software in use were not discussed. In addition, a manual search of the references of the included studies was performed.

The located papers were shared in a web folder and analysed by the authors from the perspective of the needs analysis outcome that was obtained prior to the study by the BCIME project partners at their institutions [13]. The outcome of the needs analysis was a list of 12 key characteristics that were expected to be implemented in the planned technical curriculum mapping infrastructure. We treated these characteristics as a deductive coding frame in the qualitative analysis of the identified literature, and we used these codes to mark the relevant sections in the reviewed publications. The themes were: (1) available online; (2) visual overview of curriculum; (3) integration of different user roles; (4) export of curricula by course, study field, department, faculty; (5) visual relations between various components of a curriculum; (6) keyword search functionality; (7) integration of international recommendations; (8) possibility to modify reports and outputs according to institutional requirements; (9) evaluation of learning objectives; (10) identification of redundancies in learning objectives; (11) outcome-based education compatibility; (12) complex reporting based on available curriculum building blocks. For the purposes of concise presentation and to reflect better the data that were actually in the studies, in the second round of analysis, we inductively grouped these themes into four categories (Figure 1): (1) visualisations (themes 2, 5 and 10); (2) text-based descriptions and analytic functions (themes: 6 and 12); (3) the outcome-based approach (themes: 4, 9 and 11) and (4) adaptability (themes: 1, 3, 7 and 8).

Results

Included studies

Our search strategy identified 352 abstracts. We downloaded 21 studies for detailed inspection and excluded four

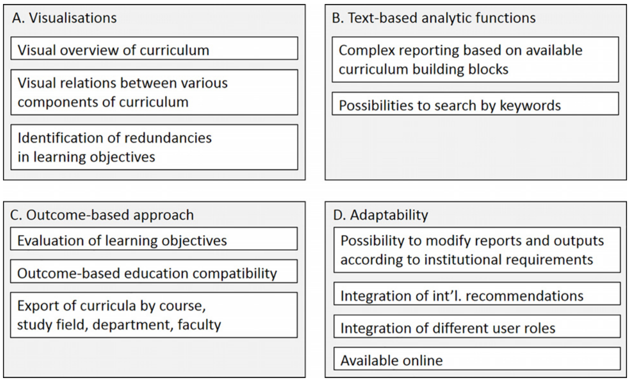

Figure 1: Four main thematic categories in descriptions of technical infrastructure for curriculum mapping.

of them due to their focus on repositories of reusable learning objects instead of curriculum mapping or description of a curriculum without specifying the technical details of the software. The manual search of references yielded six additional articles that were included in the final set of 23 studies. A tabular summary of the included studies is available in the Appendix. The studies contained descriptions of the use of 11 systems in curriculum mapping: ACLO-Web [14], CLUE [15], Electronic Thematic Map [8], Excel/Entrada [16], LOOOP [17], Medtrics [18], MERLIN [19–21], One45 [22], OPTIMED [23–27], Prudentia [28] and SOLE [22]. In four cases, the name of the system was not given [29–32]. One study described a technological data exchange standard in curriculum management [5]. Two of the studies were reviews [33, 34].

Visualisations

In the first thematic category, we included scientific contributions that described experiences with visual data presentation in curriculum mapping. Topics from this category were frequently mentioned in the reviewed papers. The three common recommendations were to visualise curriculum maps as [1] graphs or networks, [2] business diagrams such as bar or pie charts or [3] as coloured tables or panels.

The application of graphs was explicitly discussed in two papers [24, 29], whereas several other studies used graph-based visualisations [23, 27, 30]. The nodes in the graphs represented learning units [29], medical disciplines [24], content descriptors from medical terminologies [23] or learning objectives [30]. The relations displayed as links between the nodes in the graphs visualised prerequisite subjects [29], similarities of textual descriptions of learning units in medical disciplines [24] and associations between keywords in learning unit metadata [23]. The weight of the edges connecting the nodes depicted the degree of similarity [24] or the attained learning objective success rate [30]. In the latter example, by graphically showing the presence or lack of educational success, the authors discussed reaching a constructive alignment of learning and assessment methods [30]. The topology of nodes in the curriculum maps was reported in one study to have been calculated using the Kamada–Kawai force-directed method [29]. By analysing the length and quality of the pathways of prerequisite relations, the authors attempted to discuss the coherence of the curriculum [29]. Subgraphs in the maps were detected using methods known from Social Network Analysis (e. g., the WalkTrap algorithm, the Louvain method) [24, 29]. The results were utilised to highlight areas of isolated knowledge communities in the maps that required better integration in the curriculum [23, 24, 29]. Visualisations of graphs were implemented using programming APIs such as Cytoscape, D3.js, iGraph (R), NetworkX (Python), NVD3 and yEd Graph Editor [23, 24, 27–30].

Further types of visualisation included diagrams known from common business applications, such as bar, balloon, pie and doughnut charts. Fritze et al. provided a summary of 10 exploratory question types addressed by the MERlin web-application, which delivered insights into various aspects of curriculum maps such as presenting a longitudinal competency development profile or applied assessment methods [20]. The questions were answered by diagrams visualising a lot of information in one view by using several presentation dimensions as an arrangement of elements in the x-/y-axes, and varied size and colour of the shapes in the diagram. For a given sub-competency from the German NKLM learning objectives catalogue [35], the graphics showed a temporal breakdown of the covered learning objectives across semesters or departments, additionally indicating the covered level of competency (e. g. basic knowledge, applied knowledge, competence in practice) and frequency of occurrence in the curriculum [20]. Komenda et al. described the implementation of 25 analytical reports, including a visualisation of the use of Bloom's taxonomy action verbs in learning objective descriptions across curricula [26].

Finally, several studies presented curriculum maps in tabular views and panels [8, 14, 16, 18, 31]. In two aligned columns of panels, Al-Eyd et al. [18] showed the learning objectives at the programme and course level. Jarvis-Selinger & Hubinette presented a medical undergraduate programme curriculum as a large spreadsheet table (called the Matrix) [16]: the columns represented individual medical systems, themes and clinical experiences; the rows represented courses, weeks and week topics; the cells indicated the focus of a specific week. Thanks to its chronological, vertically ordered rows and thematically diverse columns, the Matrix made it possible to verify whether the new curriculum had a developmental (increasingly complex), spiral (regularly revisited), integrated and competency-based style [16]. Presenting the Matrix as an Excel spreadsheet imposed a technical limitation as only a small amount of information could be presented at cell level. This issue was temporally solved by introducing Word documents called Virtual Course Books with itemised schedules for each week or session-level learning objective that were linked from the cells of the Matrix. However, the long-term plan was to introduce a more sophisticated software tool (Entrada). This and other similar experiences (e. g. [21, 31]) clearly show the limitations of using generic office software for curriculum mapping tasks.

Text-based descriptions and analytic functions

In this category, we covered methods of description, analysis and reporting of text-based curriculum data which encompass themes such as selection of the right description categories, terminologies and measures of similarity.

One of the biggest challenges that has to be faced in curriculum mapping is the laborious and tedious process of entering descriptions of curriculum elements [4]. This can be remediated in various ways that are described in the reviewed literature. One of them is to reduce the number of curricular aspects documented in the first instance. Although it might be tempting to describe all categories from the curriculum mapping framework proposed by Harden [1], some authors have recommended deliberately limiting the number of characterised aspects to make the data entry process manageable in a short time frame [20]. Fritze et al. reported that thanks to the reduction of the described curricular windows to four crucial ones (i. e., competency level, transparency, percentage of learning objectives covered and assessment format), it was possible to reduce the time needed for description of the whole medical curriculum to six months [20]. Likewise, the curriculum mapping initiative described by Al-Eyd et al. limited the number of 'curriculum windows' to four (i. e., learning expectations, learning event information, pedagogy and assessment) [18].

To enable flexible search functionality in curriculum maps, it was recommended to index descriptions with terms and concepts from medical thesauri and ontologies [14, 23]. This helped in handling the diversity of natural human language with its many synonyms, near synonyms, hypernyms and hyponyms. It was also advised to use standardised terminologies and coding systems to help achieve automated integration of curriculum mapping tools with the remaining IT components of universities' technical infrastructure [23]. The added value was more precise and sensitive searches of curriculum descriptions, which contributed to more adaptive learning facilities and higher user satisfaction. The medical terminologies integrated in the described studies included MeSH [14, 17, 23], UMLS [28] and ICD10 [14, 17]. Balzer et al. [17] and Komenda et al. [26] incorporated in their systems a dictionary of action verbs from Bloom's taxonomy [36]. Cottrell et al. reported using MedBiquitous controlled vocabulary to standardise instructional and assessment methods and types of learning resources; they also used USMLE Step 1 & 2 year-end profile reports to populate catalogues of tags to annotate curriculum descriptions [22]. Finally, Spreckelsen et al. implemented their software tool using the Semantic Media Wiki technology, which enabled distributed curriculum description, querying, and consistency validation using Semantic Web technologies (RDF/OWL/SPARQL) [14].

The last theme in this category related to numerical values which helped to summarise properties of curricula. Similarities between text descriptions of learning units in curricula were calculated using data- and text-mining techniques, including metrics such as cosine distance [24], normalised Pearson correlation coefficient [27] and Jaccard similarity coefficient [23]. The importance of nodes (learning units, medical disciplines) in curricula was expressed by centrality measures (closeness, betweenness, or eigenvector centrality) [24, 29]. Detection of similarities enabled automatic clustering of related parts of a given curriculum. For instance, Komenda et al. applied this to the automatic matching of virtual patients with relevant sections in the curriculum [27].

Outcome-based approach

This category is made up of functions that facilitate the outcome-based approach in curriculum mapping, e. g., outcome- and competency-based frameworks, hierarchies of curriculum building blocks, and technical standards for exchange and comparison of learning objectives and other elements of curricula descriptions.

Several competency-based frameworks and learning outcome catalogues were implemented in the reviewed software tools. The CLUE system was built around the competency frameworks of the General Medical Council, the Singapore Medical Council and the Accreditation Council for Graduate Medical Education [15]. Sharma et al. determined the alignment of a local curriculum with the British Association of Dermatologists undergraduate medical curriculum and the already mentioned General Medical Council standard [32]. Schneider et al. mapped the learning objectives in their curriculum against the Commission on Dental Accreditation (CODA) standard [8]. In the Prudentia system, cross-references were made to the Australian Medical Council Student Outcomes [28]. The LOOOP system visualised learning objectives according to the respective category of Anderson's 24-square-table [36] and Reporter-Interpreter-Manager-Educator (RIME) roles [37]. In their visualisations, Vaitsis et al. used learning outcomes of the Swedish Higher Education Authority for undergraduate medical education [30]. The introduction of a national competency-based catalogue of learning objectives for undergraduate medical (NKLM) and dental education (NKLZ) in Germany in June 2015 [35] had a considerable impact that was visible in several reviewed papers. Systems such as MERlin or LOOOP were promoted as tools that help in achieving and maintaining the alignment of local curricula with the NKLM framework [19–21]. The NKLM list of competencies/sub-competencies and associated learning objectives is incorporated in these software tools and enabled rapid selection of the covered learning objectives (e. g., by ticking off checkboxes) in the described learning units [20, 21]. Filtering learning units by standardised learning objectives and competencies enabled rapid searches for gaps and redundancies in the curriculum. Using MERlin software, Behrends et al. searched the curriculum at Hannover Medical School for 52 medical informatics-related learning objectives from the NKLM catalogue to locate learning units in the curriculum which shared the same leaning objectives [19]. This was done to enable a more collaborative and integrated approach to teaching these competencies across different stages of the medical study programme.

However, not all countries had adopted national-wide learning objectives and competency catalogues. Additionally, some institutions from countries with formalised national competency frameworks were keen to maintain their internal competency rubrics. These users needed functionality to design spacious customary learning objective collections. For instance, teachers at Masaryk University used the OPTIMED system to write 7,000 local learning objectives [23]. The German ACLO-Web system encompassed 5,350 learning objectives in the Aachen Medical Model Curriculum [14], which illustrates how comprehensive a curriculum description might become. The built-in functionality to support authoring of learning objectives included the automatic detection and alignment of verbs in the new entries with lists of standardised action verbs from Bloom's taxonomy (as available, e. g., in the LOOOP system [17]).

Standardisation of learning objectives in competency frameworks enabled wide-scale comparison and auditing of curricula. As the goal to promote the use of one single curriculum management system that covers the needs of all stakeholders turned out to be futile [5], the alternative idea was to equip the plethora of available software with standardised interfaces for data exchange. This was implemented by the MedBiquitous Curriculum Inventory standard [5]. This technical specification is based on an object-oriented model that consists of two classes of elements: base components (including learning events and expectations) and aggregating elements for curriculum organisation and structuring (academic levels, sequence blocks, integration blocks). The goal was to develop a technical infrastructure including curriculum inventory aggregators and analytic tools and reports around this standard to enable wide-scale auditing, quality improvement, and research in the area of medical curricula [5]. Other solutions for curriculum data interoperability included the use of Semantic Web technologies [14], a connection to electronic scheduling systems using the iCal format [17], PDF printouts and data collection forms [20, 22], and Microsoft Excel imports/exports [14].

Adaptability

In the last category we included themes which dealt with methods that enabled smooth access to curriculum data that was adjusted to the needs of a particular group of users.

It may be concluded from the reviewed literature that even though there are advantages to a common core database structure and shared development efforts, higher education institutions also require individual site-specific features [31]. One-fit-all solutions are likely to meet with resistance from prospective users, as has been demonstrated on the example of the CurrMIT system in North America [5, 18]. This observation was confirmed in Europe, as was reported in Fritze et al.'s study regarding four German medical schools' shared effort to implement a software tool called MERlin [20]. The participating institutions wanted to add their own site-specific features, including local terminology, folksonomies, protected data-sets and free-text fields, which could be used to enter descriptions of characteristic elements of their curriculum (e. g., special teaching methods) [20]. An interesting feature for dynamic adjustment of the curriculum was implemented in the LOOOP system. This software tool analysed the demand to cover particular clinical learning objectives and estimated current ward teaching capacities. When an insufficient number or type of patients or teachers was available, the system dynamically suggested alternative wards where patients presenting the needed diagnoses were available [17].

As the perspectives of students, teachers and external accreditation auditors differ substantially, personalisation of functions based on the user's role in the curriculum management process is highly recommendable. Balzer et al. developed a hierarchical system of online users' roles with different rights to read or write in the designated sections in the LOOOP system [17]. In the MERlin curriculum mapping tool, management of differences in deployments was enabled by a three-tier hierarchy of users with one global administrator, several local administrators (responsible for on-site management of organisational structures), and local users (as mappers and curriculum developers) who authored and maintained the actual curriculum [20]. In the paper by Cottrell et al. [22], two user role models were presented. The first model was decentralised and involved course and clerkship directors who individually annotated their courses with tags from a controlled vocabulary (West Virginia University). The second tested model was centralised with 1–2 staff members working as points of contact to collect session plan templates and then enter them into the software system (Texas A&M). There was no clear preference as to which of these two models was better.

The described tools were implemented using web technologies. This enabled the use of systems from different client platforms and freed the user of the need to install any additional software. To further streamline the user experience, some of the developed tools underwent intensive usability testing [14] and were equipped with drop-down lists, check boxes and auto-completion fields to speed up curriculum mapping [14, 21]. The users could select flexible, exploratory views and an individual navigational path through the curriculum with personalised queries [14, 20, 27]. The writing process of descriptions was accelerated by the availability of prefilled session mapping templates [18, 22]. Finally, curriculum mapping skills were honed by organising dedicated courses and setting up telephone hotlines, frequently asked question sections on websites, and e-mail ticket systems for instant, tracked user support [17, 31].

Discussion

In this narrative review, we have delivered a summary of the current practices and research in implementing software tools that support curriculum mapping in medical education. Directed by the outcome of the BCIME project needs analysis, we searched the literature for recommendations on how to implement our 12 characteristics of a modern curriculum mapping infrastructure. We presented the results in four thematic categories that gathered the focal points of interest of the community that works on the technical aspects of curriculum mapping.

The result of this work is a structured set of guidelines which summarises technical curriculum mapping developments. A BCIME project report related to this review is available as an open access document on the project's website [38]. To increase its accessibility, the original English version of the report was translated into five project partner languages (Czech, German, Polish, Romanian and Slovak). The review influences the project consortium by informing technical developments aimed at building a new curriculum management platform called EduPortfolio, which is being coordinated by Masaryk University [39]. Furthermore, the collected knowledge base helps in structuring dissemination activities at workshops organised by the BCIME project.

When comparing the outcomes of this review with the results of a study on curriculum mapping that was published by Willett a decade ago [4], it became clear that the extensive workload related to curriculum mapping still remains an issue, but some new methods had been proposed to remedy the situation. The new methods included mechanisms for completing parts of the curriculum description based on data already present in curricula databases and formalised knowledge available in controlled vocabularies and ontologies (e. g., [14]). It was also advised to optimise the number and semantics of the data entry fields required in curriculum descriptions (e. g., [20]). In order to motivate the faculty to persist in the description of curricula, the authors of the reviewed papers proposed presenting use case demonstrations, progress displays, and technical support (e. g., [17]).

In a previous review, Willett [4] noticed the lack of a standard for the exchange of curricular data. This changed with the introduction of the MedBiquitous Curriculum Inventory standard and related specifications [5]. Recent analysis of the usage of standards in medical education has shown that this formal specification is increasingly being used in curriculum management systems [40, 41]. However, what was surprising in our analysis is that not many recent studies have reported on the actual integration of curriculum mapping software with other elements of the technical infrastructure of universities, such as e-portfolios, learning management systems, or electronic assessment systems. This was reported differently in previous studies [42, 43], and it might be just a sign of a more precise focus on mapping functionality in the reviewed papers and not necessarily a lack or disregard for such functionality.

A major driving force in the development of curriculum mapping tools was the release of national competency frameworks for medical education. This is visible in Germany, where publication of the NKLM catalogue [35] correlated with rapid advances in the implementation of two complex tools for curriculum mapping: LOOOP [17] and MERLin [20]. Similar trends are apparent in other countries of Central and Eastern Europe. For instance, in Poland a national outcome-based standard for undergraduate medical education was released a few years ago [44] and was recently updated. This fuels the discussion around implemented learning objectives and increases interest in using technical curriculum management infrastructure to cope with changing legal requirements.

However, the role of curriculum mapping is not only limited to satisfying administrative accreditation needs. In their paper, Watson et al. distinguished two generations of tools in curriculum mapping [42]. Whilst the first generation was designed primarily for academic administrators and curriculum designers, the second wave of tools was designed as knowledge management tools for students and teachers with the goal of helping in the navigation of outcome-based educational programmes. This prediction was confirmed by the results of our review, in which many of the tools are designed with consideration of students as an important user group in mind. This resulted in positive feedback from students that was manifested in high satisfaction and usage rate (up to 95% of students) and even some early evidence of improved learning outcomes [17].

This review is limited by the relatively narrow timespan of the covered literature, which embraced the 5 years prior to the commencing of the project and was extended to cover the most recent studies published in the project lifetime; however, this was deliberately defined as the typical review period for state-of-the-art reviews is 5 years [12]. Including older studies could paint an inadequate picture of the current technical capabilities. Furthermore, we selected the PubMed/MEDLINE research database only to identify the studies in the review that had the greatest impact and were therefore likely to be indexed by MEDLINE. Considering the qualitative character of the synthesis, we do not feel that adding more research databases would substantially change the general picture presented in the review.

When trying to interpolate the next steps in the development of curriculum mapping from the collected data, we predict the further development of text mining methods in the automatic alignment of curriculum elements and improved free text search functionality [27]. The resurgence of interest in artificial intelligence and progress in learning analytics is likely to result in the implementation of student-centric decision aids to help in selecting personalised educational pathways in curricula for more adaptive learning [45]. We may also expect further sophistication in graphical displays in terms of the use of visual analytics methods and adjustment of curriculum maps for display on mobile devices (e. g., smartphones) or maybe directly in the learning environment of students (e. g., using augmented reality) [46].

Conclusions

In this state-of-the-art narrative review, we have summarised the recent technical developments around the curriculum mapping process. The four emerging thematic categories cover aspects of visualisation, text descriptions and analysis, the outcome-based approach, and adaptability in curriculum mapping software. We hope that the collected literature references and summarised technologies and techniques will inform future infrastructure developments for more integrated, comprehensive and accessible curricula in medical education.

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