ZDM – Mathematics Education
https://doi.org/10.1007/s11858-024-01559-x

ORIGINAL PAPER

Research on curriculum resources in mathematics education: a survey of the field

Sebastian Rezat[1]

Accepted: 16 February 2024

Abstract

This survey describes the structure of the field of research on curriculum resources in mathematics education in the period from 2018 till 2023. Based on the procedures of a systematic review relevant literature was identified using Web of Science as a database. The included literature was analyzed and categorized according to the type of curriculum resource and the area of study. Seven areas of studies were identified: studies on the role of curriculum resources, content analysis, user studies, studies on the effects of curriculum resources, studies on curriculum resource design, curriculum resources as data, and reviews. The areas were further subdivided into different subcategories based on the research questions of the included papers. The findings show that research on mathematics textbooks is still predominant in the field. The most popular areas of research are content analysis, user studies, studies on design, and studies on effects. Emerging areas are research on students' use of curriculum resources and the employment of user data from digital curriculum resources as data basis in mathematics education research.

Keywords Mathematics · Curriculum resources · Curriculum materials · Textbooks · Learning trajectories · Learning environments · Systematic review

1 Introduction

Ten years ago, Fan (2013) and Fan et al. (2013) provided two comprehensive overviews of the status and future directions of textbook research as a field in mathematics education research. At that time, textbooks were still the generic and dominant curriculum resource. In the past ten years, this status of textbooks has been challenged. Due to digitalization, many new resources have been developed that can be regarded as curriculum resources: for example, paper textbooks have been transformed into e-textbooks. This has not only changed the modality but also yielded new features and design modes (Pepin et al., 2016). Platforms are providing opportunities to learn mathematics on a curricular basis and are becoming more and more influential. The growing variety of curriculum resources is evident in comprehensive volumes such as the one edited by Fan et al. (2018) and in special issues of ZDM – Mathematics Education (53(5), Rezat et al., 2021; 50(6), Schubring & Fan, 2018), which comprise an increasing number of papers related to digital curriculum resources. This development is also apparent in volumes and special issues not specifically dedicated to textbooks, but to a wider range of resources (Clark-Wilson et al., 2020; Engelbrecht et al., 2020; Pepin et al., 2013, 2017; Trouche et al., 2018). The *Handbook of Digital Resources in Mathematics Education* (Pepin et al., 2024) provides an up-to-date and comprehensive overview of the recent developments. The COVID-19 pandemic with its requirements for distance learning due to school closures in many countries has even accelerated this development. However, a systematic overview of the field of research on CR is still missing.

In 2013, Fan characterized the field of textbook research in comparison to other fields of research in mathematics education as "still at an early stage of development" (Fan, 2013, p. 766). Ten years have passed since then, and therefore, it is appropriate to survey the status of the field again. However, due to the above-mentioned developments, it is necessary to broaden the perspective and include a wide array of curriculum resources and not only textbooks. Accordingly, this paper aims to give an account of how the field of research on CRs has evolved in the past five years. This time covers

✉ Sebastian Rezat
srezat@math.upb.de

1 Paderborn University, Paderborn, Germany

Published online: 15 March 2024

the period since two important overviews of the field of curriculum resources were published: The ZDM – Mathematics Education special issue "Recent advances in mathematics textbook research and development" (Schubring & Fan, 2018) and the ICME-13 Monograph "Research on mathematics textbooks and teachers' resources: Advances and issues" (Fan et al., 2018).

2 Curriculum resources (CRs): terms and definitions

The field under study is characterized by a diverse and ambiguous terminology. Therefore, it is sometimes difficult to identify the actual objects of study that lie behind the used terminology. Consequently, it is important to clarify the terminology used in this article.

In its broad meaning, the notion of *resources for school mathematics* "extends beyond basic material and human resources to include a range of other human and material resources, as well as mathematical, cultural, and social resources." (Adler, 2000, p. 210). Ruthven (2019) refers to a narrower meaning of the notion of resources that developed in the 1960s to denote "curriculum-related materials intended to support learning or teaching activity" (p. 44). In this paper, I refer to the latter meaning. Nevertheless, this set of resources comprises "a wide array of programs and tools, print and digital" (Remillard et al., 2020, p. 3). Curriculum-relatedness is a defining characteristic though.

The term curriculum has different meanings. It is widely associated with the ideas of structure and sequencing of opportunities to learn (OTL). According to Remillard and Kim (2020, p. 3) the adjunct 'curriculum' in 'curriculum material' expresses that the materials contain an "intended learning progression for particular mathematical domains" and thus refers to "a course or pathway for learning." This definition shares commonalities with the notion of Learning Trajectory (LT). While some authors define LTs as "research-based frameworks developed to document in detail the likely progressions, over long periods of time, of students' reasoning about big ideas in mathematics" (Confrey et al., 2014, p. 720) and thus do not connect them closely to OTL that engender the relevant mental processes, others regard OTL as a constituent part of LTs (e.g., Clements & Sarama, 2004; Simon & Tzur, 2004). Advocates of the latter understanding underline that the difference between LTs and learning progressions or developmental sequences is that they are "inextricable interconnected with instruction" in the form of "instructional tasks and pedagogical strategies" (Clements et al., 2019, pp. 2512–2514). Thus, LTs in the latter understanding also provide sequences of OTL designed to reach an instructional goal. The distinguishing feature is the structure of these OTL as they are organized based on a hypothesis of learners' cognitive development in the content area.

Focusing on digital curriculum resources, Pepin et al., (2017, p. 647) emphasize that "it is the attention to sequencing—of grade-, or age-level learning topics, or of content associated with a particular course of study (e.g., algebra)—so as to cover (all or part of) a curriculum specification" that distinguish digital curriculum resources form other digital resources. This definition comprises a third idea besides the ideas of structure and sequencing. By mentioning the requirement of covering a "curriculum specification" Pepin et al. (2017) relate the idea of sequencing and structure to aims and intentions provided by an external specification. This is also apparent in the definition of curriculum provided by Schmidt et al. (1997) who attribute this specification of aims and goals to an educational authority: "curriculum provides a basic outline of planned and sequenced educational opportunities that express the "aims and intentions of educational authorities" (p. 4). Thus, it is the "idea of structure imposed by authority for the purpose of bringing order to the conduct of schooling" (p. 4).

Curriculum in this understanding can be mediated by different means. Traditionally, these were official curriculum documents, textbooks, and teacher guides. However, CR can be also included in digital technologies, learning environments, or platforms. This review refers to research related to all kinds of resources mediating curriculum.

Thus, in this paper, the term CRs is used to denote all kinds of analogous or digital materials mediating curriculum understood as structured and sequenced progressions of OTL over time, i.e. for a particular mathematical domain, age, or grade level related to the aims and intentions of educational authorities.

3 Analytical framework

As there is no prior synthesis that provides an overview of the broad field of CRs, this review cannot build on existing systematizations of the field. However, Fan et al. (2013) provided a synthesis of the field of textbook research that can be used as a starting point. This synthesis identifies four categories of research on mathematics textbooks:

1. Studies focusing on the *role of textbooks*; This category relates to studies that focus on the relationship between textbooks and the official curriculum, as well as on textbooks as a means to guide or govern classroom instruction.
2. Studies analyzing the *content of textbooks*; This category comprises studies that analyze the content of a single book, a book series, or different books or book series from either one country or several countries. This

category also includes comparative studies comparing similarities and differences between the analyzed books or book series. Fan et al. (2013) distinguish three further subareas of content that are analyzed: "mathematics content and topics", "cognition and pedagogy", and "gender, ethnicity, equity, culture and value".
3. Studies on *how textbooks are used by teachers and/or students* and how this use influences mathematics teaching and learning.
4. *Other areas*, comprising the effects of textbooks on students' achievement and other student variables, such as identity in mathematics learning as well as studies on e-textbooks.

The scheme by Fan et al. (2013) was developed to systematize research on mathematics textbooks. As textbooks are a particular kind of curriculum resource, there is supposedly a considerable overlap between the two fields. However, the scheme likely needs to be amended to achieve a better fit for the broader field.

4 Aims and scope

The main aim of this review paper is to survey the field of research on CRs and to develop a differentiated framework for systematizing the research in this field. This step is necessary before providing a research synthesis of the results of research on CRs. The latter can be done subsequently by building on this survey and focusing on specific subthemes.

The framework provided by Fan et al. (2013) is used as an initial access to the field of research on CRs and will be extended in the course of the analysis—if necessary—to apply to the broader field. On the one hand, the amendments will show in what way research on curriculum resources differs from research on mathematics textbooks, and on the other hand, it will help to identify new trends in research on mathematics textbooks and other curriculum resources that were not apparent ten years earlier.

Furthermore, the intention is to characterize each area of research in more detail and develop subcategories for each area. Accordingly, the literature from 2018–2023 is analyzed according to three questions:

1. What types of CRs can be identified in the literature since 2018 and how is research on CRs distributed over different types?
2. What different research areas in the field of CRs can be identified and how is research on CRs since 2018 distributed over these areas?
3. Which subcategories of the major areas of research on CRs can be identified?

5 Methodology

A literature search was carried out using *Web of Science* as a database. Based on the theoretical considerations about the terminology, the following search term was used:

> mathematics (Topic) and resource* OR textbook* OR curriculum OR "curriculum material*" OR "curriculum program*" OR "learning material*" OR "learning trajector*" OR platform* OR "learning environment*" (Title)

As pointed out in the section on terms and definitions, resources referred to as "platform", "learning trajectory", or "learning environment" may also mediate curriculum specifications by providing sequenced sets of OTL for a particular mathematical topic. Therefore, these terms were included in the search term to achieve a broad overview of contexts in which CRs are studied.

Before the results were screened, the results were restricted to publications from 2018 or later, covering the range of the past five years. This yielded n = 481 results. The number of results was further reduced by only including publications in English published in the 20 most important journals in mathematics education[1] and relevant conference proceedings. Furthermore, all chapters from books and from other journals with a *Journal Citation Indicator* (*Web of Science*) equal to or more than 1.0[2] in either 2020 or 2021 were included.

The obtained results were screened by titles and abstracts. Exclusion criteria were (a) not being a study related to mathematics or (b) curriculum resources were not the major object of study. Two examples are provided to illustrate this procedure:

- Example 1: The paper by Wan and Lee (2022) refers to science as the major content area in the title: "Coherence of Topics from Middle-School Integrated Science Textbooks from Taiwan and Korea". Therefore, it was excluded due to criterion 1.
- Example 2: The paper by Fonger et al. (2020) is an example of a study related to the ambiguous case of LTs that was included because it relates to CRs. The title of the paper generally refers to the notion of 'learning trajectory' which was part of the search term: "A quadratic growth learning trajectory". From this title, it is not clear

[1] These were identified based on a review by Williams & Leatham (2017).

[2] A value of 1.0 represents world average, with values higher than 1.0 denoting higher-than-average citation impact (2.0 being twice the average) and lower than 1.0 indicating less than average. (https://clarivate.com/blog/introducing-the-journal-citation-indicator-a-new-field-normalized-measurement-of-journal-citation-impact/).

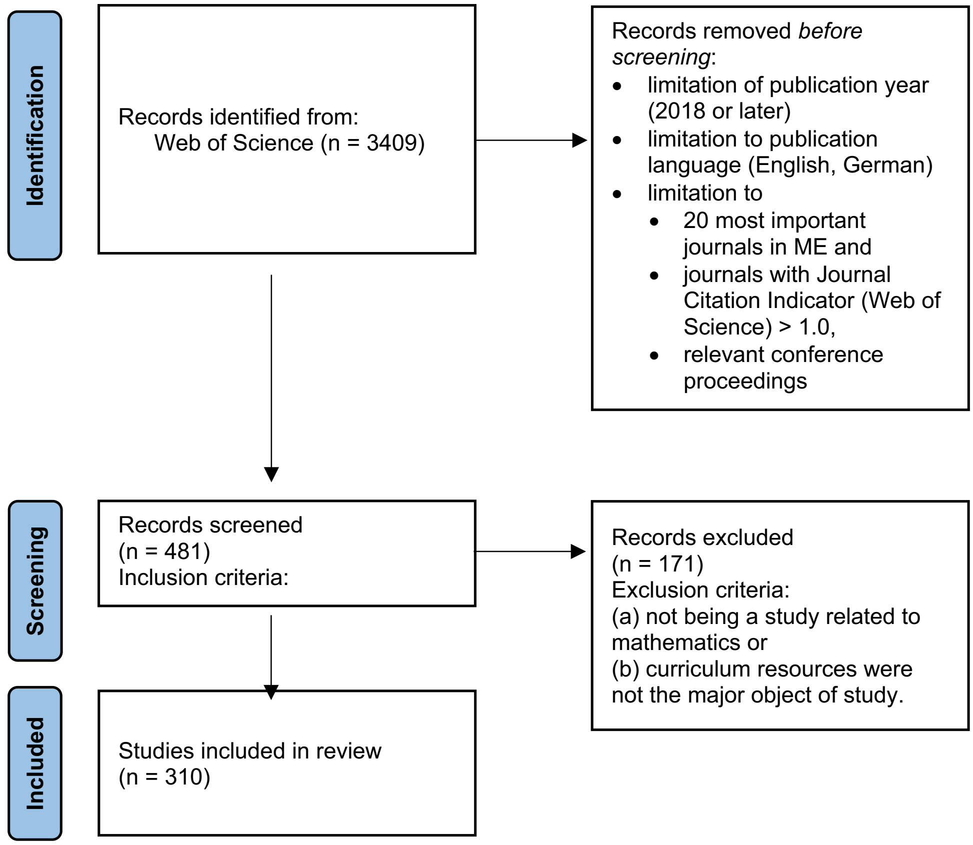

Fig. 1 Flow diagram summarizing the flow of information through the different phases of the systematic review

if this study relates to an understanding of LTs which can be regarded as CR. Therefore, the abstract was checked. There, the authors specify that they define a LT as "a series of transitions in students' ways of thinking (WoT) and ways of understanding (WoU) quadratic growth in response to instructional supports emphasizing change in linked quantities". In the paper, it is further specified that the authors "define a learning trajectory to be an empirically based model of students' understandings, along with an account of changes in understanding in relation to students' interaction with instructional supports including mathematical tasks, tools and representations, and teacher moves" (Fonger et al., 2020, p. 3). As this definition considers OTL to be part of the LT, the paper was included.

Applying the exclusion criteria reduced the number of relevant papers to n = 310. An overview of the whole procedure is provided in Fig. 1. The remaining papers were tagged based on screening titles and abstracts applying the four categories provided by Fan et al. (2013): *Role of CRs, Content of CRs, use of CRs,* and *Other*. To develop subcategories that enable a more differentiated characterization of studies in each of the four main categories, open coding procedures from Grounded Theory (Corbin & Strauss, 2015) were applied. Based on the constant comparison method, studies were grouped according to the similarities of their objects of study and their research questions. This was done until saturation of the categories was achieved, i.e., until all studies in one area could be attributed to one or more of the developed subcategories.

As the main aim of this survey is to give an overview of research on CRs over different types of CRs and areas of research, rigor and quality of the included studies were not evaluated. It is argued that this was part of the review process that these studies had to undergo to be published in the included high-ranked journals, proceedings, or books.

6 Types of CRs

Table 1 and Fig. 2 show the distribution of studies according to the type of CR. About 48 percent of the studies in the literature sample investigate issues related to mathematics textbooks. This is followed by studies investigating issues related to curriculum (19%), curriculum resources (9.7%), and resources (8.1%).

A brief description of the different types of CRs is provided. This overview is restricted to types comprising more than ten studies.

Table 1 Distribution of types of resources over the sample of studies and intersections

Type	n	%	resources	curriculum	textbook	teacher guide	learning trajectory	learning environment	technology	OER	platform	CR	Σ
resources	25	8.1%		2									2
curriculum	59	19.0%			8		1	1	1		1	1	13
textbook	150	48.4%				1	1	1	2	2		3	10
teacher guide	2	0.6%											0
learning trajectory	17	5.5%											0
learning environment	13	4.2%							2		1		3
technology	11	3.5%											0
OER	4	1.3%											0
platform	5	1.6%											0
CR	30	9.7%											0
Σ	355	101.9%	0	2	8	1	2	2	5	2	2	4	28

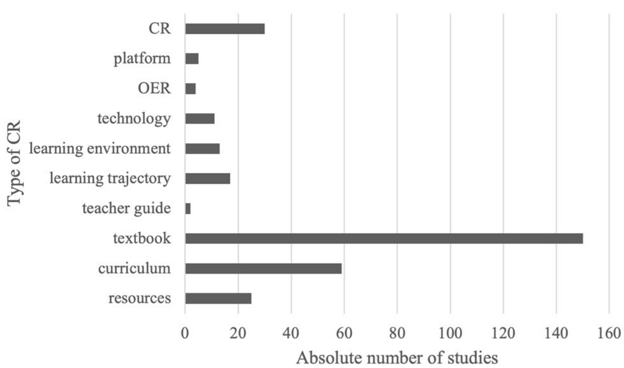

Fig. 2 Distribution of types of resources over the sample of studies

6.1 Textbooks

The largest number of studies in the sample is devoted to textbooks as the generic type of CR. Altogether 150 papers (48.4%) were categorized as textbook studies; However, only 24 (16%) of these focus on digital textbooks. More than half of the studies in this category (57%) analyze the content of mathematical textbooks. Almost a quarter of them (23%) investigate the use of textbooks by teachers or students, and 14% analyze the effects of textbooks on teacher or student variables. Seventeen (11%) investigate issues related to the design of textbooks. The remainder comprises studies related to governance issues and reviews.

6.2 Curriculum

The 59 studies (19%) in this category investigate issues related to official curriculum documents as prescribed by educational authorities. Depending on the organization of the school system, these may be national, district-, or school-level curricula. 42% of these studies analyze the content of official curriculum documents. For example, Ow-Yeong et al. (2023) analyze how and to what extent data knowledge and skills are learned and assessed within the existing mathematics curriculum in Singapore in comparison to other mathematics content domains. Seventeen studies (29%) make suggestions for improving the design of curricula including design principles (e.g., Dreyfus et al., 2021). Issues of implementation are also investigated by nineteen of the studies (32%). These may be the design of OTL based on curriculum prescriptions or factors that might affect the implementation of curriculum reforms such as teachers' perceptions of curriculum reform (e.g., Byrne & Prendergast, 2020). Understanding the mechanisms of curriculum reform in educational systems is also an issue in several studies (e.g., Yoon et al., 2021). Besides the official curriculum documents, these studies may also include other CRs, e.g., textbooks.

6.3 Curriculum resources (CRs)

This category comprises all studies that investigate issues related to a wider range of CRs that are not specified as textbooks or curricula. Studies may also focus on more than one CR, e.g., the set of CRs provided by curriculum programs such as textbooks, teacher guides, and further supplementary materials for teachers. As opposed to the category *resources* the focus of these studies is explicitly and solely on curriculum resources. This category also includes studies related to CRs that are not specified in the paper. Almost 10% of the studies relate to CRs.

6.4 Resources

The 25 studies (8.1%) in this category mostly investigate CRs as part of a wider set of resources, such as video-recorded lectures (e.g., Kempen & Liebendorfer, 2021; Maclaren, 2018), materials provided in professional development programs (e.g., Ntow & Adler, 2019), manipulatives, and even social and cognitive resources (Pepin & Kock, 2021). Major issues are the selection of resources from an array of available resources and their interplay building on notions such as *resource system* (e.g., Trouche et al., 2018).

6.5 Learning trajectories (LTs)

17 studies in the sample (5.5%) focus on LTs. 41 percent of these studies are concerned with the design or validation of LTs or related assessments. As these studies explicitly or implicitly follow a design research methodology they usually include data related to the use or effectiveness of a LT. The same proportion of studies (41%) is concerned with the effectiveness of LTs. Five studies on LTs have an explicit focus on use and implementation including adaptions of LTs.

6.6 Learning environments (LEs)

The 13 studies on LEs (4.2%) usually take a broader perspective. To be included in this review, the LEs comprise a sequenced set of OTLs to achieve a learning goal as prescribed in a curriculum specification. These are usually either supplemented by technology or integrated into online environments. Further features that distinguish them from other CRs are adaptiveness and immediate feedback, a focus on collaboration, or the implementation of particular pedagogical approaches such as gamification or game-based-learning (e.g., de Mooij et al., 2022), embodied learning (e.g., Duijzer et al., 2019), or problem-solving with realistic problems combined with simulation or Virtual Reality (e.g., Zwart et al., 2022). Some studies take instruction based on a specific CR as a starting point and analyze characteristics of the broader LE (e.g., Berlin & Cohen, 2020). Other studies in this category use instruction relying on a classical CR such as the textbook as a control condition compared to instruction implementing a particular learning environment (e.g., Birgin & Topuz, 2021).

6.7 Technology

Altogether 11 studies (3.5%) belong to the category “technology”. These studies either use technology that comprises sequenced OTL and thus match the definition of CRs used in this paper, or they investigate issues related to the integration of technology into a curriculum or matters of coordination of different resources including technology and CRs (e.g., Clark-Wilson & Hoyles, 2019; Fonger, 2018). In the latter case, the technology itself is not a CR but an amendment to CRs. This category also comprises studies that use a CR—mostly textbooks—as a control condition to be compared with a technology-rich intervention (e.g., Birgin & Topuz, 2021).

7 Areas of research on CRs

All studies in the sample were coded according to the categories by Fan et al. (2013): *Role, Content Analysis, User Studies,* and *Other*. During the coding process, subcategories that further differentiate the studies in the category *Other* emerged. These were *Design*, *Effects*, *CRs as Data*, and *Reviews*.

The coding procedure yielded the distribution of studies over the categories as depicted in Table 2 and Fig. 3. Most studies are assigned to the category *Content Analysis*, followed by *User Studies*, studies related to the *Design* of CRs, and studies on the *Effects* of CRs. Only very few studies focus on the *Role* of CRs.

7.1 Role

Studies in the category *Role* analyze how CRs are embedded in broader activities such as reform or the governance of the education system. For example, Polikoff et al. (2020) ask, how California school districts make decisions about which textbooks to adopt in the core subjects, and the factors that influence these decisions; de Carvalho (2018) describes the governmental textbook assessment system in Brazil. In these

Table 2 Distribution of studies on CRs over the different areas and intersections

area	n	%	role	content analysis	user study	effects	design	CRs as data	reviews	Σ
role	6	1.9%				1			1	2
content analysis	113	36.5%			3	3	4			10
user study	91	29.4%				5	6	1	2	14
effects	58	18.7%					6	2		8
design	65	21.0%							3	3
CRs as data	7	2.3%								0
reviews	11	3.5%								0
Σ	351	113.2%	0	0	3	9	16	3	6	37

studies, the focus is not on the CR itself but on the policy surrounding societal decisions about CRs.

7.2 Content analysis

Studies in the category *Content Analysis* apply methods of content or document analysis to make assertions about the content of CRs. The studies in this category can be systematized based on their research questions into the three subcategories presented in Table 3.

Most studies belong to subcategory 1 and thus aim to answer variations of the question *How is (the content related to topic/competence X in) CR A characterized (compared to CR B) in terms of feature α?* Studies in this subcategory differ in that they either analyze the content related to a particular topic or competence of CRs or aim to characterize the content of CRs as a whole. The characterization of the content may be either quantitative analyzing the distribution of a particular feature within a CR or across several CRs or qualitative.

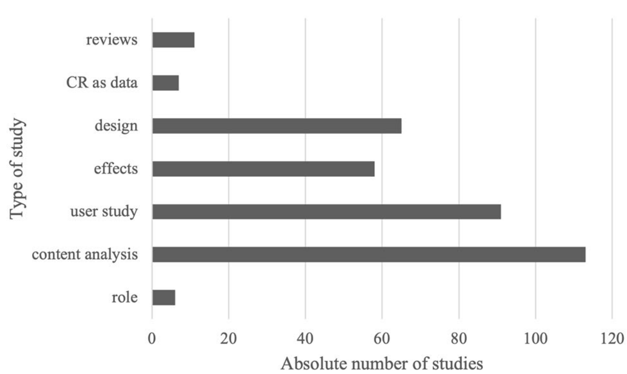

Fig. 3 Distribution of studies on CRs over the different areas

Comparative studies are a subset of this category. As apparent in the generalized research questions in Table 3, the direction of the questions in comparative studies is the same as in studies only focusing on one CR. However, comparative studies ask and answer these questions in relation to other CRs. CRs in comparative studies might be of the same kind, e.g., two textbooks, or of a different kind, e.g., comparing textbooks and the official curriculum. Studies investigating the alignment of textbooks to the official curriculum are an example of the latter type (e.g., Polikoff et al., 2021). Comparison between CRs of the same kind may be either between CRs co-existing at the same moment in time, e.g. comparing two textbooks from different textbook series, or between CRs that are from different periods taking a historical perspective (e.g., Jia & Yao, 2021).

A second subset of studies in the category *Content Analysis* uses CR as data to infer information about the educational system. For example, Karp (2021) investigates "how close contemporary Russian education is once again to American education" based on the analyses of textbooks and other CRs.

A third subset of studies in the category *Content Analysis* aims to make methodological contributions to content analysis. For example, Zhang et al. (2020) ask "what is a sufficiently effective sampling design to obtain an accurate representation of the OTL data and/or a simple measure of alignment covered/not-covered with the intended curriculum?" to suggest a method for textbook analysis that is less time consuming than coding the whole book.

Table 3 Subcategories of studies in the category *Content Analysis*

Subcategory	Synthesis of research questions
Characteristics of the content of CRs	How is (the content related to topic/competence X in) CR A characterized (compared to CR B) in terms of feature α? ▻ Quantitative: distribution ▻ Qualitative: characterization
Content of CRs as a source of information about the educational system	What information about characteristics of the educational system can be retrieved from the content of CRs?
Methodological contributions for content analysis	What method is suitable for the analysis/comparison of CRs?

Extended versions of this and the following tables which also include references to exemplary studies are provided in a digital supplement to be downloaded at the journals' website

Table 4 Subcategories of user studies with teachers as users of CR

Subcategory	Synthesis of research questions
1. *Teachers' selection of CRs*	▻ What CRs do teachers choose to support their planning/instruction? ▻ What are the reasons/criteria/influences for/on teachers' choices of CRs? ▻ What are the patterns of teachers' selection of resources?
2. *Teachers' attending and noticing when using curriculum resources*	▻ What do teachers attend to or notice in CRs? ▻ How do teachers' noticing practices interact with CRs when planning and enacting instruction?
3. *Teachers' adaptions and modifications of CRs and how it is influenced*	▻ What do teachers adapt in CRs and how do they adapt it? ▻ What influences teachers' adaptions?
4. *Issues of implementation and alignment*	▻ How are the intentions of CRs implemented? / To what degree is classroom practice aligned with the intentions of CRs? ▻ Which factors are associated with the implementation of CRs (e.g., teachers' views about reform curricula; design of CRs)?
5. *Teachers' interaction with CRs*	▻ How do teachers use CRs? ▻ What factors influence teachers' use of CRs?
6. *The role and influence of collectives on teachers' use of CRs*	▻ What is the role of CRs in teachers' collective work? ▻ How does collective work influence teachers' use of CRs?
7. *Theoretical and methodological contributions*	▻ How can teachers' use of/interaction with CRs be conceptualized? ▻ What is the contribution of framework X to understanding teachers' use of/interaction with CRs? ▻ How is alignment to be measured?

Some studies focusing on the use, design, or effects of CRs build their argument or investigation on a content analysis of the involved CRs to make assertions about the relationship between specific characteristics of the content and the other areas. Thus, there is an intersection between studies in this category and studies in other categories.

7.3 User studies

Studies categorized as *User Studies* focus on the interaction between a user or a group of users and CRs. Based on the analysis of the interaction, the characteristics of this interaction are specified. User studies are mainly differentiated by the groups of users that are investigated.

7.3.1 Research on teachers' interactions with CRs

Altogether 69 studies (75%) in the sample were classified as *User Studies* with *teachers* as users. These studies were subdivided into six sub-categories based on their research questions. The different subcategories obtained are shown in Table 4.

As studies often have more than one research question, one study may belong to more than one of the subcategories in Table 4. For example, attending and noticing are often coupled with the aim of understanding teachers' adaptions of CRs when planning and enacting mathematics instruction. Therefore, some of these studies belong to categories 2 and 3.

The largest number of studies classified as *User Studies* investigate teachers' use of or interaction with CRs to develop a better understanding of this interaction. Several

Table 5 Subcategories of studies on students' use of CR

Subcategory	Synthesis of research questions
1. *Students' selection of CRs*	▻ What CRs do students select (from a wider set of resources usually not limited to CRs) for their learning of mathematics? ▻ What factors influence students' selection of CRs?
2. *Students' interaction with CRs*	▻ How can students' interaction with CRs be characterized? ▻ What factors influence students' interaction with CRs?
3. *Students' evaluation of CRs*	▻ What are students' perceptions, views, and evaluations of CRs or of a particular aspect of them regarding a specific goal?

studies in this subcategory build on the notions of "instrumentalization" and "instrumentation" from the instrumental or documentation approach (Gueudet & Trouche, 2009; Rabardel, 2002) to conceptualize this interaction (e.g., Mesa et al., 2021; Misfeldt et al., 2019).

As user studies need to build on an understanding of the used CRs, there is an intersection between the categories *User Study* and *Content Analysis* (3 studies, e.g., Pansell & Boistrup, 2018; Remillard et al., 2019). There is also an intersection with the category *Design* (4 studies).

7.3.2 Research on students' use of CRs

Investigating students' selection of and interaction with CRs is a theme of growing prominence. Based on their research questions, studies can be further differentiated in the subcategories presented in Table 5. Several studies on students' use of CRs belong to two of these sub-categories.

Especially at tertiary level, a growing number of studies investigate students' preferences for specific resources (including CRs) and the reasons explaining the findings. In the sample, four studies investigate students' selection and use of resources at the tertiary level. While the focus of all studies included in this review is mathematics, the studies in the tertiary context vary in the major study subjects of the participants (business, computer science, engineering, mathematics, physics). Also, the types of resources included and the conditions under which the courses were taught vary. For example, Kempen and Liebendorfer (2021) investigate German students' use of resources in a fully digital learning environment during the COVID-19 pandemic; Howard et al. (2018) study Irish students' preferences in a context where students have the choice between attending live lectures or watching lecturer-prepared videos; Pepin and Kock (2021) investigate Dutch students' use of resources in courses based on a particular pedagogical approach, namely challenge-based education.

At secondary level, the use of CRs by students gets increasing attention in particular related to self-regulated learning (e.g., Otieno & Povey, 2022; Wang & Fan, 2021). Students' use of CRs is also studied at primary level. There, the focus is not on self-regulated learning, but more on students' meaning-making of information from CRs (e.g., Norberg, 2022).

There is an intersection with studies on the *effects* of CRs (2 studies). These studies mainly aim to identify influential factors that could explain the observed effects (e.g., Shechtman et al., 2019).

7.4 Design

Studies in this category focus on issues related to the design of CRs. They can be subdivided according to the different aims of the research. Subcategories are provided in Table 6.

Some studies in this category merely describe the design of a particular CR or the related design process (subcategories 1 and 4). Several studies elaborate on design principles (subcategory 2). Among these, some argue for new design principles that gain importance due to changes in societies and the learning culture. For example, Barlovits et al. (2022) analyze the challenges encountered during distance learning in five European countries. Based on the identified challenges, they build a framework with design requirements for online learning environments in mathematics education. O'Halloran et al. (2018) investigate how the possibilities of digital artifacts afford particular design features such as new ways of representing and connecting knowledge. Gueudet et al. (2018) even go a step further and argue for "connectivity" as an important design principle for digital textbooks based on established conceptualizations of learning mathematics and "connectivism" as an epistemological position and theory of learning based on societal developments. However, only a few studies investigate the effect of particular design principles on teachers' or learners' behavior in intervention studies. For example, Clinton and Walkington (2019) investigate how different types of illustrations influence students' immediate problem-solving accuracy and their learning. Some of the studies are also more exploratory investigating which design principles have a positive effect on specific student or teacher variables. For example,

Table 6 Subcategories of studies on the design of CR

Subcategory	Synthesis of research questions
1. *Descriptions of the design of CR*	Studies in this category typically do not formulate research questions, but the description of the design as the main aim
2. *Design principles and their evaluation*	▻ What are the characteristics of design principle Y? ▻ How is student/teacher variable X influenced by a CR designed based on design principle Y? ▻ Which design principles have a positive effect on student/teacher variable X?
3. *Recommendations for the design of CRs*	▻ What suggestions do teachers/students make for the design of CRs? ▻ What design principles can be derived from student/teacher behavior in area X?
4. *Descriptions of design processes*	Studies in this category typically do not formulate research questions but describe design processes
5. *Influences on design*	▻ What factors influence the design of CRs? ▻ How does factor X influence the design of CR Y?
6. *Theoretical or methodological contributions related to the design of CRs (including meta-reviews related to particular design features)*	▻ What does the research literature report on design principle X to support student/teacher variable Y? ▻ How can the design of CR X be conceptualized? ▻ How can a CR be designed to foster/implement goal X? ▻ What methodology/theory is required to design CR X?

Edson and Phillips (2021) investigate which teacher dashboard features support teacher enactment of a problem-based mathematics curriculum embedded in a digital collaborative platform. As apparent from the two previous examples, design features may be intended to influence student or teacher variables. While these studies specifically start from a particular design principle or aim to identify related design features, studies in subcategory 3 start with analyzing learning behavior in general or interactions with CRs in particular to derive recommendations for the design of CRs from the findings. For example, Olsher and Even (2019) ask what changes teachers would make in the mathematics textbook they use in class if they were allowed to do so. Identifying influences on the design or the design process is the focus of the studies in subcategory 5. This category also comprises research on collaboration among teachers or in multi-professional teams (including teachers from other subjects, researchers, or students) as one influential factor. Finally, some studies make methodological or theoretical contributions related to the design of CRs. Literature reviews aiming to provide a synthesis of a particular aspect of learning mathematics to derive design principles from this are also included in this category.

7.5 Effects

Studies in this category are characterized by making assertions about the relationship between using or interacting with a CR and some other user variable. The research questions address this relationship either directly:

How is student/teacher variable X related to (a particular feature of) CR A? Or studies analyze the effect by relating variation in variables to different conditions that differ in terms of CRs: How is variation in student/teacher variables related to/explained by different conditions in terms of CRs? The effect of CRs may also be investigated as a moderator between two other variables: How does CR A moderate the relationship between student/teacher variables X and Y? These studies differ in how the analyzed variables and the relationship to CRs are measured.

Some studies are more explorative, investigating which features of CRs yield variation in student/teacher variable X. Most studies in this category are based on quantitative methods relating the used CRs to measures of user variables. Most typically, studies in this category are carried out in an intervention study design. Few studies aim at understanding the effect in a qualitative way characterizing how interaction with CRs influences students' learning of mathematics (e.g., Moyer et al., 2018; Rezat, 2021).

Student variables taken into account are:

- *Mathematical achievement*: The predominant number of studies in this category investigates the effects of CRs on students' mathematical achievement in general (e.g., Shechtman et al., 2019) or related to a particular content area or competency (e.g., mathematical thinking: Drijvers et al., 2019a, 2019b; adaptive expertise: Sievert et al., 2019). Some studies have a longitudinal perspective, covering a whole school year or even longer periods (e.g., van den Ham & Heinze, 2018), others are carried out as intervention studies over shorter periods.

- *Affective variables*: A second set of student variables that is investigated by several studies are affective variables, especially attitude (towards mathematics) (e.g., Lindorff et al., 2019), motivation, or self-efficacy (e.g., Tarnanen et al., 2023). Affective variables are mostly investigated in combination with achievement.

Some studies investigate the effects of CRs on teacher variables. Predominantly, the *effect of CRs on teaching practices* is considered. Effects of CRs on teacher variables are mostly investigated in connection with effects on student variables. Few studies include data on teacher variables to determine if these moderate differences between the measures of student variables (e.g., Sievert et al., 2021). To develop a better understanding of the effects, a few studies (3) also analyze the content of the used CR and thus intersect with the category *Content Analysis*.

7.6 CRs as data

An emerging area particularly related to dCRs is the employment of user data from digital systems to make inferences about some other aspects of user behavior. The sample of literature comprised eight papers that use different types of user data to derive information about students' interaction with dCRs and their learning behavior or achievement. Due to the small number of studies, no subcategories were identified.

Data used from dCRs may comprise the used tasks or sections of a textbook and related used materials, the received feedback (type and timing), students' solutions (e.g., Castro-Rodriguez et al., 2022; Zhang et al., 2019) or the accuracy of the solutions (Spitzer & Moeller, 2022), measures such as time on task (Castro-Rodriguez et al., 2022; Hoch et al., 2018), or post-error slowing (de Mooij et al., 2022).

The studies in this area are mostly double-edged: On the one hand, they have a methodological aim in that they contribute to the operationalization of an aspect of students' behavior based on user data provided by dCRs. On the other hand, they contribute to a better understanding of the interaction with dCRs and related learning of mathematics.

From the studies in this category, it becomes clear that dCRs provide rich sources of data. Most of these studies do not gather the data in experimental settings but in real learning scenarios, which ensures the ecological validity of the data. However, it also becomes clear that the enormous amounts of data from dCRs require methods that stem from big data analysis. At the same time, dCRs and big data analysis provide new possibilities to describe and understand students' learning of mathematics.

7.7 Reviews

This category contains review papers presenting an overview, summary, or reanalysis of other studies related to some aspect of research on CRs. This category also comprises introductory chapters to edited books or commentary papers/chapters.

8 Discussion and conclusion

The main aim of this review was to characterize and structure the field of research on curriculum resources (CRs). Therefore, a systematic review using *Web of Science* as a database was conducted. The papers included in this review were classified according to.

- the type of CR studied, and
- the area of research using the categories provided by Fan et al. (2013) as a starting point.
- Subareas of interest based on a synthesis of research questions addressed by the studies in each area

The distribution of studies over the types of CRs showed that research on mathematics textbooks is still predominant in the field followed by research on curriculum, curriculum resources, and resources. This shows that research still predominantly focuses on the generic CR—the mathematics textbook—and only slowly takes into account that teaching and learning comprise the interaction with a broader range of different resources.

The distribution over the areas of research on CRs showed a more balanced picture than ten years ago. However, content analysis is still the predominant area followed by user studies, studies on design, and studies of effects. Nevertheless, the field has moved in directions identified as important for future research by Fan et al. (2013). The only area that is still not sufficiently developed is research on the role of CRs. Consequently, the call by Fan et al. to establish.

> a more solid fundamental conceptualization and theoretical underpinning of the role of textbooks and the relationship between textbooks and other variables not only in curriculum, teaching and learning but also in a wider educational and social context (Fan et al., 2013, p. 643)

can be repeated and extended to the broader field of research on CRs.The application of the categories by Fan et al. (2013) proved to be useful as a first approach to the broader field of CRs. Based on a qualitative analysis of the research questions, it was possible to differentiate these categories further, adapt them to this broader field, and provide an overview of the different areas of research on CRs and related research questions. Seven main categories of studies evolved: studies on the *Role of CRs*, *Content Analysis* of CRs, *User Studies*, studies on the *Effects* of CRs, studies on the *Design* of CRs, studies using *CRs as Data*, and *Reviews*. Sub-categories were developed that further differentiate these overarching areas of research related to CRs.

The categories show that the field has changed with the further development of CRs. With the introduction of other CRs besides mathematics textbooks issues of coordination, orchestration (Drijvers, Gitirana, et al., 2019), and connectivity (Gueudet et al., 2018; Pepin, 2021) in resource systems (Wang, 2018) became increasingly relevant. The diversification of different types of CRs can be mainly attributed to the fast-evolving development of dCRs. Nevertheless, only 15 percent of studies in this review focus on dCRs. This ratio is mirrored in the subcategory textbook, where almost the same proportion of studies (16%) focus on digital mathematics textbooks.

From the small number of studies that belong to the intersections of two areas, it becomes apparent that many issues related to CRs are addressed in isolation. For example, most studies in the category *content analysis* solely focus on a particular aspect of the content rarely taking into account the effect of the presentation of the content on teachers or students; studies in the category *user study* either address the use by teachers or by students. Rarely is the interrelations between the two user groups investigated. From the perspective of research methodology, this is only natural. However, as CRs are but one important agent in the didactical situation (Rezat & Sträßer, 2012), a more systemic view considering the interrelations between the mathematics, the CRs, the teachers, and the students is needed. Only a few examples were identified in this review that already take this route. This also becomes apparent in the integration of CRs in the wider context of teaching and learning (e.g., in learning environments or platforms) and how they connect more closely to students' thinking (e.g., LTs). These efforts could be identified due to the wide perspective taken in this review, including LEs, platforms, and LTs in the search term. However, investigating the complex interrelations of CRs, the mathematics and the other agents in the didactical situation remains a methodological challenge in the field, especially in terms of feasibility. The close interrelationship of CRs with aspects of their users and mathematics shows that research on CRs can almost be considered a micro-cosmos of research in mathematics education. This is reinforced by the detailed account of research questions in the different areas of research on CRs provided in this survey as they cover a wide range of relevant research questions in mathematics education.

Especially related to dCRs, there is a trend that the demarcations between different kinds of resources vanish. Technology-rich learning environments increasingly comprise curricular OTL and thus become inseparately linked with CRs. Similarly, tools such as Dynamic Geometry or Computer Algebra Systems that were not considered curriculum resources also seem to develop in this direction. This is achieved by either combining them with other CRs in more complex learning environments or by enhancing the technologies through sequences of OTL adherent to a curriculum.

Furthermore, the introduction of dCRs has not only led to new issues relating to the design of CRs, but also to new research methodologies as subsumed in the category *CR as data*. While CRs have been already used as data to make inferences about the educational system (category *Content Analysis*, subcategory 2), the data that is collected by dCRs allows for making inferences about user variables. This emerging field will even attract more attention in combination with resources comprising artificial intelligence (AI). AI will likely become relevant in all other areas of research on CRs as well.

Due to the wide scope of this survey and the differentiated structure of the field, the findings related to each of the research questions in the different areas could not be synthesized within this article. It will possibly require several subsequent reviews to provide a differentiated synthesis of findings related to each of the sub-areas. In summary, the findings present a broad, rich, and very multifaceted knowledge base with many important contributions to a better understanding of issues related to the role, design, use, and effects of CRs. However, these findings are mostly singular and closely tied to their particular research design as well as their specific socio-cultural contexts. Within the field of research on CRs, it is not clear if and how these findings can be transferred to other socio-cultural contexts. In other words, due to their socio-cultural situatedness, the generalization of the findings is questionable. Consequently, there is a strong need for a more systematic cumulative development of scientific knowledge in the field of research on CRs. Replication studies could be one way to respond to this need. However, none were found in this survey. Additionally, a more solid and more widely shared theoretical foundation of important concepts is equally important to ensure that the findings of different studies are comparable.

This survey has taken a very general perspective. It provides an overview of issues investigated in the field of research on CRs and structures the field into different sub-areas with their related research questions. Thus, it is a good starting point for subsequent research syntheses within each of the fields.

9 Limitations

This study has some limitations that are important to consider when interpreting the results:

1. Only *Web of Science* was used as a database. Including other databases may provide a different picture.
2. As a consequence of using *Web of Science* as a database, most conference proceedings that are relevant to research in mathematics education were not included in this survey. The time that it takes to publish a paper in a peer-reviewed journal is usually much longer than publishing research in conference proceedings. Especially, since the field of dCRs is evolving very fast this might result in an overview that has not included the most recent developments in the field.
3. The results are further biased by the search term that was used to identify relevant literature in the database. The decision on the final search term was made after several rounds of exploratory searches and related analyses of the results. The final search term yielded the most relevant selection of literature according to the judgment of the author. However, other search terms may yield a different picture.

Funding Open Access funding enabled and organized by Projekt DEAL.

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