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REVIEW ARTICLE

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"GIS works!"—But why, how, and for whom? Findings from a systematic review

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Abstract

This article presents the findings from systematically reviewing 26 empirical research studies published from 2005 to 2014 on the use of GIS for learning and teaching. By employing methods of narrative synthesis and qualitative content analysis, the study gives evidence about the state of knowledge of competence-based GIS education. The results explain what factors and variables effect GIS learning in terms of technology use, major subject contents, learning contexts, and didactic and pedagogical aspects. They also show what facets of knowledge, process skills, and affect the research literature has investigated. The analysis of the type and quality of the methods used indicates that current GIS education research is a heterogeneous field that needs a systematic research framework for future efforts, according to empirical education research.

1 | INTRODUCTION

Systematic literature reviews have been a part of evidence-based practices for meta-analytical research in many disciplines, such as medicine, health science, psychology, and empirical social sciences, for decades. More recently, this approach has also gained interest in the field of education research (Zawacki-Richter, Kerres, Bedenlier, Bond, & Buntins, 2020). Review articles in geography and geoscience connected to educational inquiry are sparse. For example, Zadrozny, McClure, Lee, and Jo (2016) use a non-systematic systematic review approach for an explorative summary of methods' design, techniques, and reporting strategies in geography education research. Lane and Bourke (2019) use a systematic research approach for a descriptive summary of the types and formats of assessment in geography education. However, in the field of GIS education research, the systematic literature review as a tool of structured and reliable data reanalysis has not yet been applied; though we already learned much about the opportunities, potentials, and obstacles of applying geospatial technology (GST) in geography teaching and learning in higher education and schooling over the last two decades (Baker, Kerski, Huynh, Viehrig, & Bednarz, 2012; Demirci, 2015; Milson, Demirci, & Kerski, 2012; Tan & Chen, 2015). However, no empirically synthesized conclusions demonstrating the actual effectiveness as well as the shaping factors for the successful implementation of GIS in teaching and learning processes were available until now. In short: the state of knowledge in the field of empirical GIS education research is still fuzzy.

One of the main reasons for this situation is the insufficient quantity and transferability of the existing research findings in the area of GIS education research on a large scale (Baker & Bednarz, 2003; Baker et al., 2012; Demirci, 2015). Therefore, it should not come as a surprise that Baker et al. (2015) observed for the emerging field of learning with GST: “Existing research in this area has been sparse and fragmented, with no clear plan to provide guidance to aspiring investigators” (p. 118). They continue: “Unless a significant paradigm shift takes place in the field of GST education research, we will continue to plod along with incomplete, fragmented, and inconclusive findings” (p. 126). This points out the apparent current research-method deficits and, at the same time, refers to a future broader technological orientation of the present GIS education research. Before we speak about the new and broad vast field of “GST and learning,” we should first ask what we actually know about “GIS and learning” as a presumable central component of the GST core components of remote sensing, GPS, and digital globes (Baker et al., 2015).

Against this background, this article provides a comprehensive systematic summary of the state of knowledge in the area of empirical GIS education research. In the form of an integrative research review (Cooper, 2010), 26 studies of quantitative and qualitative research from the period 2005–2014 were systematically synthesized to summarize and evaluate the empirical knowledge of teaching and learning with GIS. The selection of publications from this period covers the decade of GIS education research that lies between the first critical review remark on GIS education research by Baker and Bednarz (2003) and the call for a new research paradigm towards GST in education by Baker et al. (2015). According to Schulze (2017), this period of GIS in education can be denoted as the consolidation phase of research on Geographic Information Science and Technology (GIS&T) in education. The guiding research question of this study is: “What empirical results on GIS-based learning are available, and to what extent can these be summarized as valid statements regarding competence-oriented learning with GIS? This research question is further operationalized by means of three aspects:

- **Q1:** What study designs and methods for the investigation of GIS-based learning have been used?
- **Q2:** What factors or variables effect GIS learning in terms of technology use, major subject contents, learning contexts, and didactic and pedagogical aspects?
- **Q3:** What facets of knowledge, process skills, and affect in terms of competence-based GIS learning have been investigated?

In the following, the article first explains the value of systematic literature as a yet unutilized tool in the field of GIS education research. Subsequently, the methodological approach, which is based on a narrative synthesis and the qualitative aggregative method procedure of thematic and content analysis, is described. Thereafter, the results of the synthesis of the individual study results are presented. The discussion section deals with subject-related, as well as methodological, implications for the future field of empirical GIS education research.

2 | SYSTEMATIC REVIEWS: AN UNUTILIZED INSTRUMENT IN GIS EDUCATION RESEARCH

2.1 | Qualities of systematic reviews for evidence-based research

Generally, the goal of a meta-analysis of published literature is synthesizing evidence from empirical research to "see the similarities and differences among the methodologies and the results of many studies" (Rosenthal & DiMatteo, 2001, p. 63). Accordingly, systematic reviews identify, summarize, and assess all the available literature on a particular topic using *a priori* planned consistent procedures to minimize bias (De Vet, Verhagen, Logghe, & Ostelo, 2005; Roberts, Stewart, & Pullin, 2006). It is a research approach for the retrospective systematic aggregation, reanalysis, and synthesis of the empirical findings published in primary studies within a specific area of knowledge and intervention (Cooper, 2010). As Popay et al. (2006, p. 10) point out: "the key element of a systematic review is the synthesis." According to Newman and Gough (2020), review synthesis:

> Is more than a list of findings from the included studies… All types of synthesis involve some kind of data transformation that is achieved through common analytic steps: searching for patterns in data; checking the quality of the synthesis; integrating data to answer the review question… (p. 14)

Therefore, to encourage the quality of reviews, there must be a clear definition of the used criteria for the inclusion or exclusion of studies during the review process. This includes, for example, documentation about the used method to search the literature, the way primary data have been extracted from published studies for question-based synthesis (descriptive, interpretative, aggregative), and how the quality of the studies is assessed (De Vet et al., 2005).

In addition to the quantitative synthesis of empirical results via effect size statistics (Rosenthal & DiMatteo, 2001; Rustenbach, 2003; Schulze, 2004; Waddington et al., 2012), for qualitative (text-based) research synthesis, interpretative and narrative methods have become established (Pope, Mays, & Popay, 2007; Sandelowski & Barroso, 2006; Snilstveit, Oliver, & Vojtkova, 2012). This also applies to mixed-method research synthesis, which aims at purposefully mixing qualitative and quantitative primary-level findings with qualitative and quantitative synthesis techniques for integrated or segregated/separated data analysis (Heyvaert, Maes, & Onghena, 2013). Both areas of qualitative and mixed approaches share a common spectrum from aggregative to configurative methods for generating, exploring, or testing hypotheses or theory such as case surveys, meta-summaries, thematic analysis, content analysis, grounded theory, or critical interpretative synthesis (Snilstveit et al., 2012).

This brief overview of the qualities of systematic reviews as part of the "evidence-based practice movement" (Hammersley, 2020) suggests that this approach of structured summary and reliable data reanalysis is currently missing in the field of GIS education research. More specifically, at the beginning of the present study, an initial non-systematic search in Google Scholar for the period until 2015 was carried out for the search terms "systematic literature review + GIS education."[1] Additionally, international key journals in the field of geography education and geoinformation science were hand-searched. These include the *Journal of Geography in Higher Education*, *Journal of Geography*, *Review of International Geographical Education Online*, and *Transactions in GIS*. However, no narrow systematic reviews were found. Steiger, de Albuquerque, and Zipf (2015) reported a comparable result when searching for systematic literature reviews in the field of GIScience.

Publications reporting a literature review approach to summarize some state of knowledge in GIS in education appeared later. Bakri, Sugiarti, and Wahyudin (2019) published a conference paper summarizing the best practices in teaching with GIS in science vocational high schools as a basis for a regional study in Indonesia. The same applies to a short literature study on GIS in vocational education for the period 2014–2019 by Dewa, Mulyanti, and Widiaty (2020). Although both contributions are comprehensive, given that the literature includes 59 publications for the former and 30 for the latter, together they provide just findings from *narratively* reviewing a broadly selected body of literature for a thematic overview of the field of GIS in secondary-school vocational education.

That is, both contributions generally lack the rigor and validity of systematic article selection procedure and final study inclusion. The same applies to the methods used for the synthesis of concrete empirical findings for additional knowledge generation in their field.

2.2 | State of knowledge in GIS education research

The systematic literature review presented in this study deals with primary research in the field of empirical GIS education research. According to Baker et al. (2012, p. 258), this field of action can be defined as "research [that] focuses on how and what educators and students learn with spatial data, spatial analysis methods, and GIS tools." The research agenda in this domain-specific field of action has evolved throughout the last two decades, being largely influenced by the efforts of colleagues in the Anglo-American discourse on GIS and GST in education. As shown in Table 1, research in GST and learning (Baker et al., 2015) is currently characterized by four thematic categories. The first, "connections between GST and geospatial thinking," focuses on the multiple relationships of learning and working with GST and the development of geospatial thinking skills among learners and users. The research interest in this field evolves from the discourse on GIS as a support system for spatial thinking (National Research Council, 2006) and the later, more focused, concept of geospatial thinking and reasoning as a higher-order cognitive process (Bodzin, Fu, Kulo, & Pfeffer, 2014). The categories of "learning about GST" and "curriculum and student learning through GST" derive from the classical opposition of teaching and learning *about* and learning *with* GIS (Kerski, 2008; Sui, 1995). While the former concept relates to teaching, learning, and training the technical and professional skills of GST, the latter focuses on the application of GST in different disciplines for subject-specific inquiry and problem-based learning (Baker et al., 2015). Also, research interest in the "educators' professional development with GST" can already be traced back to discourse on the challenges and strategies of teacher education and training in dealing with GIS, since it has always been of major importance for the effective design of GIS-based teaching and learning in different educational levels.

Publications that offer dedicated overviews on the state of knowledge in GIS education research are sparse. Within their interrelated work on developing a research agenda for learning with GIS and GST, Baker et al. (2012, 2015) made great efforts in identifying and summarizing an extensive body of research articles, case studies, dissertations, and book chapters on teaching and learning with GIS, since the mid-1990s. For example, Baker et al. (2012) use a matrix to structure the identified literature along the emerging themes of GIS education research (Table 1). The authors came to a classification of the literature in terms of the pedagogical model of teaching and learning, curriculum/subject matter, cognitive facets such as process skills (e.g., spatial thinking and geographic inquiry) and affect (e.g., attitude, motivation, and self-efficacy), and technology use/skills. Beginning in the early 1990s, Demirci (2015) summarized multiple empirical research studies as well as theoretical and conceptual papers to discuss the potential and effectiveness of learning through GST. Furthermore, as part of the European Project *GI Learner*, Zwartjes et al. (2017) published a review of the most important literature on learning lines and spatial thinking. This includes a comprehensive section on GIS as a tool for geospatial critical thinking in education. Finally, Çepni (2013) published a small summary on the use of GIS in geography teaching, summarizing international and Turkish literature in the categories of "GIS and education" and "geography teaching and GIS." Although the cited authors made a great effort at summarizing and structuring the research and knowledge in GIS education, their work is mostly synoptic, rather than synthesizing empirical findings for added empirical evidence. As with the literature studies by Bakri et al. (2019) and Dewa et al. (2020), *why* and *how* the considered research literature and studies were selected and to *what* extent and with *which* methods different findings from qualitative, quantitative, or mixed-method study designs on investigating GIS teaching and learning have been compared, categorized, or merged remain unclear. The same is true for describing and clustering the characteristics of the involved study populations (e.g., sample size, age, gender, and level of education), the type and duration of GIS intervention and instruction (e.g., lectures and hands-on labs), and the used GIS application and geospatial data.

TABLE 1 Categories of research in GST and education

Research in GIS education (Baker & Bednarz, 2003, p. 232)	GIS education research (Baker et al., 2012, p. 261)	Research in GST and learning (Baker et al., 2015) listed keywords are not exhaustive
• **Student learning and outcomes.** "(…) how to identify and measure student learning in the GIS context." • **In-service teacher training.** "(…) how to prepare the next generation of educators to infuse GIS in their teaching repertoire." • **Technical development.** "(…) are there strategies to use Internet-based mapping as a surrogate for traditional desktop-based computing technologies?"	• **Student learning and outcomes.** "(…) identifying changes in student achievement, cognitive skills, or other affective indicators." • **Teacher training.** "(…) documenting training methodologies and teacher implementation." • **Technical development.** "(…) studying the value and effectiveness of various software functionalities and interface elements."	• **Connections between GST and geospatial thinking.** Reciprocal relationship of the factors and impacts of GST use/learning and geospatial thinking/reasoning. • **Learning about GST.** Sequence, contents, skills, technology tools, variables affecting learning of GST. • **Curriculum and student learning with GST.** Development of learner's geospatial knowledge, skills, and practices; learning contexts; GST display design; curriculum design practices; instructional strategies. • **Educators' professional development with GST.** Teachers' technological, pedagogical, and content knowledge development (TPACK); best practices of professional development for teacher education.

Finally, there is no reported quality assessment of the considered studies to evaluate the validity of included research results. Thus, these narrative reviews do not answer the vital question of why, how, and for whom GIS works on a large scale—in contrast to a single instance of intervention.

2.3 | Preliminary theory of "GIS learning"

Addressing the above described in the present study, the previously cited overview publications provide robust assumptions for the formulation of a basic theory of GIS learning, following a constructivist approach (Brown, Collins, & Duguid, 1989; Gerstenmeier & Mandl, 1995). That is, they allow for an active, social, self-directed, context-based, and situated development of the learners' knowledge and skills based on real-world inquiry and problem-based GIS learning environments (cf. Bryant & Favier, 2015; Foote, 2012; Kanwischer, Reudenbach, & Schulze, 2009; Schultz, 2012). In this context, collaborative small-group and project-based learning environments have a positive impact on student-centered GIS learning in geography. The driving factors for knowledge gain due to GIS learning include active cognitive reasoning on geographical phenomena, patterns, and processes with multiple spatial representations (like map layers and images) and data representations (such as tables and graphs); individual hypotheses testing (visually and analytically) and drawing individual conclusions on geographical questions; and the active processing of geospatial data in terms of exploring, querying, managing, manipulating, analyzing, and visualizing. Additionally, students' deeper insights into content knowledge are assumed to be built upon in sequenced lessons (cf. Bednarz, Heffron, & Huynh, 2013). Enhancements in learning in geography, in connection with the use of GIS, are related to the positive development of knowledge and understanding, skills, and facets of motivation for learning, attitude towards technology, and self-efficacy while working with scientific tools and techniques. This is assumed for the increased development of geographic knowledge (i.e., student achievement), both topographical and factual, as well as the promotion of understanding and synthesizing everyday life-related geographic problems and questions at different scales (i.e., geographical thinking and geographical literacy). Another focus is on the potentially positive development of cognitive skills and abilities of (geo)spatial thinking (i.e., spatial habits of mind, critical spatial thinking, spatial skills) and problem-solving. The same is true for the discussion on whether learning with GIS results in high-order-thinking skills such as analytical and critical thinking, as well as in systemic thinking competence going beyond just memorizing geographical factual knowledge.

2.4 | Competence-based GIS education

From the perspective of the GIS&T domain (DiBiase, Foote, Tate, & Unwin, 2012), GIS education at both levels of schooling and higher education is related to fostering a wide range of subject-related and generic competences. However, besides the technical and methodological knowledge and skills of geoinformation processing, it is especially cognitive aspects—like spatial thinking, problem-solving abilities, and critical thinking—that are in the foreground (Bednarz & Van der Schee, 2006; National Research Council, 2006; Schulze, Kanwischer, & Reudenbach, 2013; Sinton, 2012). As Tate and Jarvis (2017) conclude, contemporary GIS education is progressively influenced by the capabilities of Web 2.0 technologies for open and participatory learning in the formal and informal learning situations of collaborative knowledge construction.

For the operationalization of the abstract construct of "GIS learning," this study applies the competence-based approach of formal education. Referring to pedagogical psychology, "competence" is understood as the individual's learnable capacity to cope appropriately and successfully within unfamiliar, context-specific situations to solve problems (Klieme et al., 2004; Koeppen, Klieme, & Leutner, 2008). Facets of competence comprise domain-specific knowledge and skills as well as generic competences, cognitive abilities, metacognition, experiences, and motivational and volitional aspects as prerequisites for performing actions. For describing the visible outcomes of learning (Hattie, 2009) through GIS in terms of learning outcomes description (Kennedy, Hyland, & Norma, 2006), this study integrates the *Revision of Bloom's Taxonomy of Educational Objectives* by Anderson & Krathwohl (2001). This framework provides an approved, two-dimensional construct of different knowledge dimensions (i.e., factual, conceptual, procedural, and metacognitive knowledge) as well as ranked cognitive processes (like remembering, understanding, applying, analyzing, evaluating, and creating).

3 | METHODS, STUDIES' CHARACTERISTICS, SYNTHESIS PROCESS

The overall conceptual framework of the present study has been developed based on *Guidance for Undertaking Systematic Reviews in Health Care*, published by the Centre for Reviews and Dissemination (2009). Although this guideline belongs to the area of health interventions, it provides an internationally recognized, well-structured reference of the core principles and methods for rigorously conducting systematic reviews. The adaption of this source to a different discipline is justifiable (Roberts et al., 2006). The present study utilizes this guidance for developing a sound *a priori* research protocol that includes the major criteria for identifying, summarizing, and assessing the relevant publication and research results from GIS education research.

3.1 | Definition of inclusion criteria

To be included in this review, relevant studies need to fulfill the following criteria:

1. *Documentation of the use of GIS applications such as DesktopGIS, WebGIS, and MobileGIS*. Since WebGIS generally means a provision of GIS functionality and applications based on a web–client–server communication, this study also includes digital globes. Although digital globes and geobrowsers (like Google Earth© and NASA WorldWind) have limited spatial analysis functions (Abend, 2013; Bailey, Whitmeyer, & De Paor, 2012), their consideration here is due to the further integration of GIS-specific functionality in terms of the evolution of GIS in "digital worlds" (Butler, 2006; Tate, 2012).
2. *Description of the distinct use of geospatial data*. The actual connection to geospatial data within the learning process, that is, working with different types and formats of georeferenced data and information describing objects, structures, events, and phenomena on the Earth's surface, is important because it is from this that the relevance of the GIS implementation in the learning process exists at all. There is no application of GIS without a connection to geospatial data processing.
3. *Demonstration of a competence-centered user–GIS interaction*. This refers to the learner's actual GIS application, that is, showing the performance of action in dealing with GIS, as described by facets of competence such as domain-specific knowledge and skills, cognitive abilities (e.g., spatial thinking and reasoning), and metacognition. Due to this, pure conceptual or theoretical approaches without any connection to applying GIS during the intervention are not included.

In addition, only those articles that transparently document the study design to perceive the robustness of the reported research in terms of the studies' reliability and validity are included. Therefore, this work includes only studies that:

4. were peer-reviewed;
5. refer to at least one concrete research question or hypothesis;
6. describe the methods and tools or techniques used for data sampling and analysis;
7. describe the study group by age and educational level, gender, and sample size; and
8. discuss the research results and findings.

3.2 | Selection of research studies and descriptive data extraction

The identification of relevant studies began with a keyword search in *WoS—Web of Science*, *Core Collection*, *LISTA—Library, Information Science & Technology Abstracts*, and *ERIC—Education Research and Information Center*. This database selection was expected to cover the relevant subjects' fields of study, including major citation index publication bodies for science, social science, and humanities (WoS) as well as specialized bibliographic databases for information science (LISTA) and education (ERIC).

The search terms were derived from a previous pilot study and weighted frequency analysis of relevant key terms used within the titles and keywords of empirical-focused articles on GIS education research. The analyzed body of literature (n = 889) includes hand-searching the contributions to journals with a focus on geography teaching and learning in conjunction with GIS. It started with the verification of all conference proceedings of the *GI_Forum* for the period 2006–2011. The sample also contains verification of all articles from the *Journal of Geography in Higher Education* and the *Journal of Geography* for the same period. Furthermore, the analysis includes two key German-speaking journals of geography education with English abstracting: the *Journal of Geography Education* (2006–2011) and *GW-Unterricht* (2009–2011). Based on the main categories of inclusion criteria, the search terms were structured in four search categories (see Table 2).

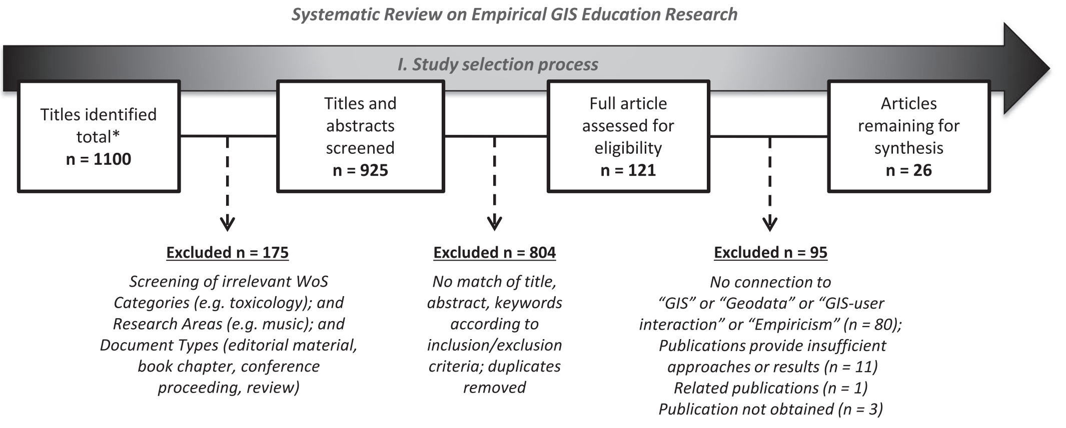
The database query was conducted within all titles, keywords, and abstracts for the period 2005–2014. The single search terms were combined with “OR” operations, and the four categorical groups among themselves with “AND” operations. A truncation of search terms was used where possible. Of the n = 1,100 publications initially identified, n = 121 articles remained for full-text examination after the screening of titles and abstracts and the removal of duplicates. The publications were pooled, saved, and coded for further examination in *Citavi* (Swiss Academic Software). Two encoders using a tabulated review sheet according to the described inclusion criteria carried out the full-text assessment with the items designated as “relevant study,” “not relevant study,” and “unclear relevance.” After the deduction of n = 24 articles for coder training, for the full-text assessment of the remaining articles, an inter-rater reliability coefficient (Cohen's kappa) of κ = 0.641 was achieved, which can be interpreted as a good agreement between the two coding judgments. Finally, n = 26 publications remained for further analysis and data aggregation. Figure 1 summarizes the selection process of relevant articles.

All the identified publications, except for one peer-review anthology article, were published in international journals (Table 3). With eight publications each in the *Journal of Geography* and the *Journal of Geography in Higher Education*, most of the studies were published in geographical journals. According to the count of the corresponding authors or the named first authors, the majority of the individual studies originate from the USA (n = 12), followed by publications from South Korea, Taiwan, and Turkey, with n = 3 studies each, and Australia and Denmark, with n = 2 studies each. One publication is from the Netherlands. Only 31% of the articles were published in the period 2006–2009, with the majority of the publications (69%) from the period 2010–2014.

For the interpretation of the gradual GIS learning aspect, the distribution of the study participants with reference to their level of education was extracted from the studies (Table 4). It turns out that most studies were carried out on the level of secondary education or middle school, encompassing 64% of all pooled study participants. Only

TABLE 2 Categorization of keywords and search terms

Categorical grouping	Search terms
Subject area	GIS, Geographic Information System, Geographic Information Technology, Google Earth, Virtual Globe, Digital Globe
Learning reference	learning, teaching, education, thinking, student, curriculum, pedagogy, inquiry
Competence reference	skills, knowledge, competence, understanding, ability, experience
Research reference	investigation, research, method, empirical study, validation, effect, assessing, analyzing, testing, achievement



*Titles identified per database: *WoS* n = 729, *ERIC* n = 251, *LISTA* n = 120

FIGURE 1 Selection process of relevant studies

TABLE 3 Identified articles and corresponding publications

Journal/anthology*	Articles identified
CBE—Life Sciences Education	1
Computers in Human Behavior	1
Computers & Education	1
Educational Technology & Society	1
International Journal of Science Education	1
International Research in Geographical and Environmental Education	2
Journal of Geography	8
Journal of Geography in Higher Education	8
Journal of Science Education Technology	1
Theory and Research in Social Education	1
**The Geological Society of America Special Paper 492*	1
Total	**26**

two studies were carried out in primary education. The high number of participants at the middle-school level results from two comprehensive studies on the effects of a geospatial curriculum on promoting energy literacy, with more than 1,000 participants each (see Studies Bodzin, Fu, Peffer, & Kulo, 2013; Bodzin, Fu, Kulo, & Pfeffer, 2014). In contrast, 10 studies are related to higher education levels, accounting for 34% of all study participants.

The reviewed studies' designs (Table 5) were analyzed based on the given self-descriptions throughout the articles. Each documented study design or method procedure was checked to determine the extent to which the study could be classified in terms of experimental study, quasi-experimental study, or non-experimental study, as well as by approaching qualitative, quantitative, or mixed-method procedures for data collection and analysis. Experimental study designs are defined by criteria such as testing the causal influence of one or more independent variables on the characteristics of one or more dependent variables with pre- and post-tests, the active alteration of variables of intervention, and the randomized allocation of participants to either an experimental or a control group. Non-experimental study designs are characterized by no experimental manipulation of variables and no

TABLE 4 Aggregated number of total study population referring to levels of education

Educational level	Absolute number of studies' populations	Relative number of studies' populations (%)	Number of studies
Elementary school	58	1.2	2
Middle school	2,424	50.1	5
Secondary school	704	14.5	7
University or college	1,653	34.2	10
Total	**4,839**	**100**	**24***

Note: The affiliation of the educational institution is based on the reported age or educational grading of participants. *Four individual articles are treated as one instance each due to the reported identical group of participants. This includes two articles on GIS learning and its effects on the components of spatial literacy thinking (Kim & Bednarz, 2013a, 2013b). Furthermore, this belongs to studies on the effectiveness of using GIS in an elementary classroom (Shin, 2006, 2007).

TABLE 5 Summary of research designs of the reviewed studies

	Methodological approach			
Study design	Quantitative	Qualitative	Mixed method	Number of studies
Experimental	Edsall and Wentz (2007)	–	Huang (2011)	**2**
Quasi-experimental	Aladag (2010), Bodzin et al. (2013), Favier and Van der Schee (2014), Gobert et al. (2012), Kim and Bednarz (2013a), Simmons et al. (2008), Songer (2010)	–	Demirci (2011), Kim and Bednarz (2013b), Lee and Bednarz (2009), Liu, Bui, Chang, and Lossman (2010)	**11**
Non-experimental	Bodzin et al. (2014), Lei et al. (2009), Perkins, Hazelton, Erickson, and Allan (2010), Srivastava & Tait (2012, Wang, Lee, & Sun (2013)	Doering and Veletsiano (2007), Kulo and Bodzin (2011), Madsen et al. (2014), Madsen and Rump (2012), Shin (2007)	Clark et al. (2007), Demirci et al. (2013), Shin (2006)	**13**
Total	**13**	**5**	**8**	**26**

This bold values indicate is the number (and total sum) of study per category.

randomization, instead working with the encountered groups of participants and studying their individual differences over time (Centre for Reviews and Dissemination, 2009; Döring & Bortz, 2016).

Table 6 presents a summary of the reviewed studies' main characteristics in terms of their stated research interest, respective study design, population and sample size, type of intervention, duration and type of instruction, GIS software and data used, and reported effects (Cohen's *d*).

The assessment of the general quality of the studies in relation to the individual study results occurs in an aggregated manner (Centre for Reviews and Dissemination, 2009; Waddington et al., 2012). To this end, the present review study uses a checklist with easy-to-determine quality criteria of empirical education research, for example, the formulation of the research question, the explanation of the study population and sample size, and the description of the intervention, methods used, and survey instruments (Roberts et al., 2006). To avoid a subjective rating, the checklist comprises 11 equally weighted items with normalized values "Yes," "No," and "Unclear" (Van den Berg, Schoones, & Vlieland, 2007). Each study has been individually checked for these 11 items, which were assigned on the basis of the reported study design and interventions, further methodological descriptions, and documented observations of the learning situations.

TABLE 6 Summary of the studies' main characteristics

Reference, year, country	Research interest	Study design	Population and sample size	Intervention; duration; type of instruction	Software used and data	Reported effects (Cohen's *d*)
Aladag (2010), Turkey	Effectiveness of GIS-based learning *(EG)* on students' academic achievement and motivation compared to traditional learning with maps *(CG)*	qE, randomly selected classes	7th grade students in social study lesson (n = 44); public coeducational primary/secondary school	Lecture: "Population in Our Country"; 3 weeks with 3-h lessons each; teacher demonstration and manual-based GIS exercise	ArcGIS 9.2; ArcMap file, ArcScene file; no further description	No
Bodzin et al. (2013), USA	Effects of geospatial curriculum *(EG)* on promoting energy literacy compared with conventional curriculum approach *(CG)*	qE, comparative design	8th grade students (n = 1,044) and teacher (n = 13); middle school, year 2009/2010	Energy resources curriculum with 6 GIS units, 5 units on digital globes, 1-week GIS project; 8 weeks in total; teacher-led	My World GIS, Google Earth; vector and raster files, KMZ files	Overall energy resources knowledge = 1.27, for only *(EG)* = 1.23; overall energy attitudes and behavior = 0.20, for only *(EG)* = 0.20; subscales are not shown
Bodzin et al. (2014), USA	Effects of geospatial curriculum on energy content knowledge and geospatial thinking and reasoning, and the influence of personal factors on curriculum enactment	nE, case study	8th grade students (n = 1,049) and teacher (n = 13); middle school, year 2010/2011	Energy resources curriculum with 6 units GIS, 5 units on virtual globes, 1-week GIS project; 8 weeks in total; teacher-led	My World GIS + Google Earth; vector and raster files, KMZ files	Geospatial thinking and reasoning = 0.63; energy content knowledge = 0.88; overall energy achievement = 0.86
Clark et al. (2007), USA	Does web-based learning improve student performance over traditional teaching methods in a GIS course?	nE, case study	Undergraduate students in an introductory GIS course in geography (n = 199)	Change in the instructional mode from traditional lecture to WBL; three offerings of semester course sessions in 2002 and 2003; lecture and labs	ArcInfo; different "real-world" GIS applications; vector and raster files, TIN files	No

(Continues)

TABLE 6 (Continued)

Reference, year, country	Research interest	Study design	Population and sample size	Intervention; duration; type of instruction	Software used and data	Reported effects (Cohen's *d*)
Demirci (2011), Turkey	Effectiveness of GIS-based exercise demonstrated with only one computer *(EG)* compared to students' self-paced learning in a computer lab *(CG)*	qE	9th grade high-school students in geography course (n = 30)	Exercise: "Why do earthquakes occur frequently in Turkey?"; <90 min; teacher demonstration with computer and handouts vs. self-paced computer work with handouts	ArcView 9.2; ArcMap document with feature sets, satellite imagery	No
Demirci et al. (2013), Turkey	Evaluation whether or not Google Earth is an effective methodology to support learning in geography lessons	nE, case study, pre/post-test	9th grade students from three different high schools (n = 3 × 25)	Exercise on types of coastal landforms; 2 h; partly teacher-led, partly self-paced learning	Google Earth; KMZ files containing text, videos, and photos	No
Doering and Veletsiano (2007), USA	What are the students' experiences when learning geography with digital globes and real-time authentic data?	nE, case study	Middle-school students (n = 65)	3 ArcExplorer (AEJEE) lessons, 1 Google Earth lesson from the GoNorth! ANWR 2006 expedition transect; no further description	AEJEE + Google Earth; GPX files, satellite images, map-layer, hot-linked digital photos, KMZ files	No
Edsall and Wentz (2007), USA	Benefits of teaching with GIS-based visualization *(EG)* compared to hands-on paper-map-based exercises *(CG)* for understanding concepts in geomorphology	E	Undergraduate students in an introductory physical geography course (n = 304)	Self-contained exercises on coastal landforms; 2 weeks with 3 h of lecture and 3 h of lab	ArcView; feature layer, scanned topographic maps	No

(Continues)

TABLE 6 (Continued)

Reference, year, country	Research interest	Study design	Population and sample size	Intervention; duration; type of instruction	Software used and data	Reported effects (Cohen's *d*)
Favier and Van der Schee, (2014), The Netherlands	Effects of students' WebGIS use *(EG)* on geospatial relational thinking and perceptions of learning effects compared with conventional lesson series *(CG)*	qE	9th grade secondary-school students from 5 schools (n = 287)	Lesson series with geospatial technologies on water-related spatial planning in the Netherlands; 3 weeks, each with 45-min lessons; teacher-led	EduGIS; map layer and different digital maps	Overall geospatial relational thinking *(EG)* = 0.38; *(CG)* = 0.04; overall self-efficacy on knowledge gain *(EG)* = 0.64; *(CG)* = 0.34; subscales are not shown
Gobert et al. (2012), USA	Two separate studies on testing the efficacy of learning with Google Earth during introduction geosciences lab with regard to students' gender and their prior knowledge from coursework	qE	Geoscience majors *(EG)* and non-science majors *(CG)* in geoscience lecture and lab, Study 1 (n = 225), Study 2 (n = 138)	Lab activities on geological/geographical knowledge of Iceland (Study 1) and Tonga (Study 2); 2-h lab period; self-paced learning, only technical help by instructors	Google Earth; standard view, virtual block diagrams; 3D COLLADA models/4D animations	No
Huang (2011), Taiwan	Impacts of explorative learning with a GIS-based website *(EG)* compared to a structured learning website *(CG)* on spatial cognition and geographic knowledge gain	E, post-test only	5th grade elementary-school students (n = 40)	Online unit: "My Hometown"; <25 min; self-paced web-based learning	Website with GIS interface, digital maps on the structure of the school community, local services, hometown historical sites, etc	No

(Continues)

TABLE 6 (Continued)

Reference, year, country	Research interest	Study design	Population and sample size	Intervention; duration; type of instruction	Software used and data	Reported effects (Cohen's *d*)
Kim and Bednarz (2013a), South Korea	Exploration of the relationship between GIS learning and the development of critical spatial thinking	qE	Upper-level undergraduates in "Introductory GIS" (*n* = 41) *(EG)*, "Economic Geography" (*n* = 43) *(CG)*, and "non-GIS/ Geography" (*n* = 84) *(CG)*	Semester course, two lectures and one hands-on lab session per week; textbook *GIS fundamentals*, 3rd edn	ArcGIS; no further description	Components of critical spatial thinking for *(EG)*: (i) data reliability = 1.35; (ii) spatial reasoning = 1.16; (iii) problem-solving validity = 2.44
Kim and Bednarz (2013b), South Korea	Development of an assessment tool to measure students' self-assessment of their spatial habits of mind after GIS learning	qE	Upper-level undergraduates in "Introductory GIS" (*n* = 41) *(EG)*, "Economic Geography" (*n* = 43) *(CG)* and "non-GIS/ Geography" (*n* = 84) *(CG)*	Semester courses, two lectures and one hands-on lab session per week; textbook *GIS fundamentals*, 3rd edn	ArcGIS; no further description	Components of spatial habits of mind for *(EG)*: (i) pattern recognition = 0.78; (ii) spatial description = 0.56; (iii) visualization = 0.46; (iv) spatial concept use = 0.51; (v) spatial tool use = 0.10
Kulo and Bodzin (2011), USA	Design-based research of a GIS-based unit on the world's energy resources and fostering the spatial thinking skills of middle-school students	nE, case study	8th grade students (*n* = 110) and 1 teacher; middle school	Interdisciplinary geospatially supported energy unit; 29 days in total, 12 days GIS-based working; teacher-led	My World GIS, Google Earth; datasets, satellite images, KMZ files	No
Lee and Bednarz (2009), South Korea	Investigation of the relationship between GIS learning and spatial thinking ability by analyzing students' performance on a spatial-skills test	qE	University students in "Introductory GIS" (*n* = 17) *(EG)*, "GIS & Cartography" (*n* = 10) *(EG)*, and "Cartography" (*n* = 18) *(EG)*; "Economic Geography" (*n* = 35) *(CG)*	Semester courses, no further description; lectures and hands-on lab exercises	ArcGIS; basic data models (raster, vector); choropleth maps, dot maps, proportional circle maps, flow maps, and cartograms	No

(Continues)

TABLE 6 (Continued)

Reference, year, country	Research interest	Study design	Population and sample size	Intervention; duration; type of instruction	Software used and data	Reported effects (Cohen's *d*)
Lei et al. (2009), Taiwan	Investigation of differences in students' cognitive reasoning while performing a geographical landmark search with Google Earth	nE, case study, randomly selected classes	7th grade junior high-school students (*n* = 153)	Landmark search with Google Earth; one 50-min session after training; self-paced working with worksheets	Google Earth standard view, disabled search functions; only rotation and zoom allowed	No
Liu et al. (2010), Australia	Evaluation as to whether PBL and GIS *(EG)* as an instructional method compared to only PBL geography learning *(CG)* results in higher-order learning outcomes	qE, pre-treatment diagnostic test post-treatment project report	Secondary-school students from the year 2008 (*n* = 24) and 2007 (*n* = 25)	Three PBL activities on human population dynamics; no further description; decreasing teacher-led scaffolding	ArcGIS 9; feature datasets and satellite imagery	No
Madsen et al. (2014), Denmark	Ethnographic study on students' conceptions/strategies for creating GIS as their personal instrument for learning geography and improving spatial thinking	nE, case study	First-year undergraduate geography students in "GIS and cartography" (*n* = 79), course teachers (*n* = no data)	"GIS and cartography" course; 9 weeks, twice-weekly lectures plus twice-weekly, 2-h labs; hands-on exercises with GIS manual	ArcGIS 9.1; no further description; examples on GIS data are documented within interview sections	No
Madsen and Rump (2012), Denmark	Understanding of students' different engagement in GIS courses in higher-education geography due to the theoretical perspective, shared and personal desiderata	nE, case series	Undergraduate students in "Planning and Management" (*n* = 8)	7-week hands-on and problem-based course; no further description	ArcGIS 9.1; application; datasets, no further description	No

(Continues)

TABLE 6 (Continued)

Reference, year, country	Research interest	Study design	Population and sample size	Intervention; duration; type of instruction	Software used and data	Reported effects (Cohen's *d*)
Perkins et al. (2010), USA	Understanding students' geographic conceptions of scale and distance after GPS data collection, map production with Desktop GIS and graphical methods	nE, case study, pre/post-test	Students from 8 different middle schools (n = 156)	Place-based and hands-on schoolyard tree inventory curriculum; three lessons in 3 days; teacher-led	My World GIS, GPS; JPEG2000 orthophoto, shape files; blank data layer with pre-sets for GPS data entry	No
Shin (2006), USA	Effectiveness of using GIS in improving geographic content knowledge and mapping skills in an elementary classroom	nE, case study, pre/post sketch map comparison	4th grade elementary-school students (n = 18) and one teacher	GIS instructional module, four lessons on population and transportation change; 3 weeks, 13 class sessions with 40 to 75 min each; teacher-led	ArcGIS 3.2; feature sets, 3D-maps	No
Shin (2007), USA	Effectiveness of using GIS in improving geographic understanding and sense of place in an elementary classroom	nE, case study, partly randomly selected students for working groups	4th grade elementary-school students (n = 18) and one teacher	GIS instructional module, 4 lessons on population and transportation change; 3 weeks, 13 class sessions with 40 to 75 min each; teacher-led	ArcGIS 3.2; feature sets, 3D-maps	No
Simmons et al. (2008), USA	Effects of students' attitudes and knowledge gain after working in an ecology field lab with GIS experience *(EG)* compared to field lab without GIS *(CG)*	qE	Undergraduate students of "Fundamentals of Ecology Laboratory" fall 2004 (n = 100), fall 2005 (n = 102)	Field-based inquiry lab with 5 h of traditional sessions and 5 GIS-based interventions; one 3-h lab period for field-based data collection and analysis	ArcView 3.2; 1,300 squirrel point locations, aerial photo image of campus; database exchange to MS Excel	Total conceptual knowledge for *(EG)* year 1 < 0.2, year 2 > 0.8; attitude survey covering all 5 subdimensions for *(EG)* year 1 between 0 and 0.3; year 2 between −0.2 and 0.4

(Continues)

TABLE 6 (Continued)

Reference, year, country	Research interest	Study design	Population and sample size	Intervention; duration; type of instruction	Software used and data	Reported effects (Cohen's *d*)
Songer (2010), USA	Effectiveness of using web-based GIS maps *(EG)* in place of paper maps *(CG)* on students' geography content knowledge and self-efficacy in introductory human geography	qE	Students from "Introductory Human Geography" course from a university (n = 121) and a community college (n = 50)	Four map-based activities on urbanization, geo-demographics, crime & religion, and migration; teacher-led instruction with take-home assignments, in-class work, and discussion	ArcIMS viewer; data layer	No
Srivastava & Tait (2012, Australia	Examination of students' competence development in understanding basic GIS concepts by relating their qualitative performance to their quantitative performance	nE, case study	Multidisciplinary university students in "Introductory GIS" course (n = 109)	6-week sequence of interlocked learning activities with formative and summative assessment, lecture and hands-on lab with open discussion groups in Blackboard	Google Earth/ Google Maps, ArcGIS; georeferenced hand-drawn maps GeoJPEG/BMP	No
Wang et al. (2013), Taiwan	Examination of the effects of students' different thinking styles and spatial abilities on their spatial anchoring activities with Google Earth	nE, case study	High-school freshmen (n = 66)	Performing spatial search tasks while reading web-based articles on earth science and history; 2 weeks, each with a 45-min session after training; self-paced working	Google Earth; KMZ files	No

Note: The abbreviations given in brackets are EG = experimental group, CG = comparison group. The study design is indicated as the following: E = experimental study, qE = quasi-experimental study, nE = non-experimental study.

Only 8 of the 286 verifications carried out were ambiguous and, therefore, were labeled as "Unclear." Furthermore, a threshold value was set, and study quality where more than two-thirds of the items were fulfilled was considered adequate (cf. Van den Berg et al., 2007). Table 7 shows the summarized rating results. Ultimately, about 70% of the studies demonstrate an adequate methodological quality; that is, they positively fulfill at least 7 of the 11 items. None of the studies clearly fulfill all the criteria. In absolute numbers, only Items 3, 6, and 8 were positively fulfilled by fewer than half of the individual studies. Likewise, low values were recorded for Items 7 and 11.

3.3 | Synthesis procedure, qualitative content analysis, coding

For analyzing and aggregating the multiple research studies' findings in terms of the variables and factors that influence the effective implementation of learning GIS, narrative synthesis was used. This approach provides a generic assembly of methods for processing heterogeneous individual studies' findings and the different data levels and values towards a comparable level of text-based aggregation (Rodgers et al., 2009; Snilstveit et al., 2012). This approach is used when other forms of synthesis, like statistical meta-analysis or meta-ethnography, are not feasible—however, it significantly differs from just narratively describing and summarizing research findings (Popay et al., 2006). To face the criticism of the impact of a lack of transparency and lack of clarity on the tools and techniques applied to conduct a narrative synthesis (Snilstveit et al., 2012), the present study applied the well-structured application framework *Guidance on the Conduct of Narrative Synthesis in Systematic Reviews*, by Popay et al. (2006). Hence, this study considers four main elements in approaching a narrative synthesis: developing a theory of how the intervention works; why, and for whom; developing a preliminary synthesis; exploring relationships within and between studies; and assessing the robustness of the synthesis. Figure 2 shows the schema of the synthesis process used within the present study, its included elements, and the tools and techniques used.

There are several suitable descriptive and interpretative tools and techniques for integrating multiple data from the primary level of investigation into a consistent measure and language at the synthesis level. For example, textual descriptions and thematic summaries, tabulations, groupings and clustering, subgroup analyses, transformative data rubrics, conceptual mapping, validity assessment, and critical reflection are all used (Popay et al., 2006; Pope et al., 2007; Snilstveit et al., 2012). Out of this, the present study uses thematic and content analysis to "translate" data from empirical GIS education research in terms of the main factors and variables that effect the learning of GIS (Q2). Furthermore, this work seeks to identify and summarize the main conceptual facets of competence-based GIS learning (Q3). For this reason, Mayring's (2014) qualitative content analysis (QCA) is

TABLE 7 Criteria for assessing the quality of studies and the absolute number of positive assignments

Items	Number of individual studies (n = 26)
1. *Reference to theoretical aspects in the field of study*	26
2. *Formulation of research questions*	23
3. *Formulation of hypotheses or assumptions of the investigation*	11
4. *Explanation of population and sample size*	25
5. *Description of the sampling procedure of the participants*	17
6. *Documentation of the random assignment of the participants*	5
7. *Description of the participants' prior experiences in working with GIS*	16
8. *Documented pre-tested study design*	5
9. *Description of the methods used and survey instruments*	26
10. *Discussion of the results and findings*	26
11. *Methods discussed/limitations of findings*	14

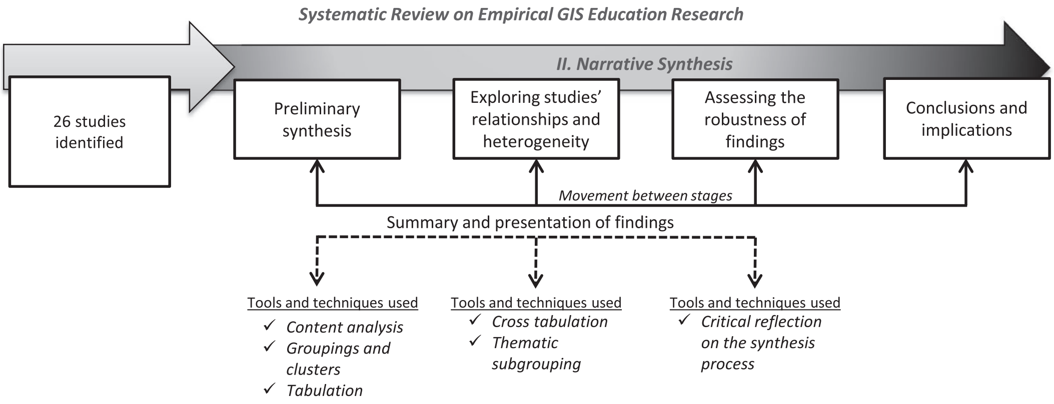


FIGURE 2 Narrative synthesis process (Source: Authors' sketch adapted from Popay et al., 2006)

used. From the perspective of qualitative social research, this method of systematic and rule-based interpretative text analysis of various communicative materials (Neuendorf, 2002) allows for the abstract conceptualization and category-based summary of the similarities and differences of study findings in the form of text-based data transformation upon an equivalent level of categorical information. For that purpose, all the research articles were electronically encoded, analyzed, and further categorized with *MAXQDA 12* (Verbi-GmbH Berlin).

Of the specific QCA techniques, the present study uses inductive category formation in parallel with deductive category assignment. Inductive category formation aims at "summarizing categories directly, which are coming from the material itself, not from theoretical considerations" (Mayring, 2014, p. 79). Although this procedure is comparable to the open coding procedure in grounded theory (Strauss & Corbin, 1998), within QCA, it follows a more rigorous process of text coding and category development. Hence, the single research articles on GIS education research—each treated as a separate instance of communication material in the field of empirical GIS education research and thus as a context unit—were subject to a fixed sequence of line-by-line coding of content-bearing text units based on a prior defined level of abstraction and classification of evolving themes. Coding units were defined as complete statements about the application and context-related visible impact/value of dealing with GIS in a specific learning situation/process. Data extraction was carried out considering two levels of information based on the research interests formulated in Q2 and Q3. First, all of the reported numerical data and findings, as well as abstract statements on the efficiency of GIS teaching and learning that either result from quantitative procedures (such as assessments or cognitive testing) or from qualitative investigations (like observations or interviews), were considered. Second, this includes recording information on the related contexts and conditions of GIS teaching and learning as well as the reported interactions and strategies of the involved actors (here, the teacher and students).

For the classification of the addressed knowledge dimensions and cognitive levels through GIS learning, deductive category assignment was utilized. This approach is based on using theoretically derived concepts and priorly defined categories for material passage (Mayring, 2014). For the coding procedure, a fixed coding agenda was developed, including predefined coding rules, anchor samples, and rules for the revision of categories where required. The used category system includes the two-dimensional construct of the "knowledge dimension" and "cognitive process domain" derived from Anderson & Krathwohl (2001). While the former dimension includes subcategories of factual, conceptual, procedural, and metacognitive knowledge, the latter dimension contains the subcategories of remembering, understanding, applying, analyzing, evaluating, and creating. As coding units, all content-bearing text units that describe a concrete situation or context in which the cognitive requirement is directly connected to the use of GIS as part of specific learning tasks, or to assessment tasks as part of the study's intervention, were defined. For example, if a study reports that students utilize buffer functionality on a certain learning task, the resulting classifications are “procedural knowledge” and “applying.” If learners were asked to find and name cities on a data layer during an assessment, the resulting classifications are “factual knowledge” and “remembering.”

4 | RESULTS

The results are organized according to the research questions. They begin with an overall summary. The findings on the approached method designs for investigating GIS learning (Q1), the factors and variables effecting it (Q2), and the examined facets of competence addressed so far (Q3) are characterized by great variety, which is caused by the heterogeneity of the involved single studies.

4.1 | What study designs and methods for the investigation of GIS-based learning have been used?

The diversity of the studies is evident by looking at the single studies' method designs (Table 5). The results indicate that only Studies Edsall and Wentz (2007) and Huang (2011) can be classified as experimental studies. Another 11 studies used quasi-experimental designs for their research; that is, working without randomization of the participants. Half of all the studies used non-experimental study designs. Except for Study Madsen and Rump (2012), all the non-experimental studies document research conducted in the form of case studies, meaning that there are no control groups or comparative resulting. In contrast, Study Madsen and Rump (2012) has been classified as a case series, as it reports on the reasons for students' different engagements in GIS, based on observations over eight individual instances. Moreover, most of the quantitative study approaches were limited in the extent to which they showed results from “real” experimental or quasi-experimental studies with interfering factors that needed to be controlled. In addition to the variability of the single studies' designs, as well as the different number of study participants, the high variability in the form and duration of the individual interventions (see Table 6) must also be mentioned as a cause of the strong heterogeneity of GIS education research. The differences in the duration of intervention ranged from the completion of a 25-min online learning unit within the context of one experiment (Huang, 2011) to multi-week lessons and learning units of 45 min or more, to a comparison of GIS courses over multiple semesters and years (Clark, Monk, & Yool, 2007). A similar situation is found for the overall number of study participants considered. The lowest number of study participants, with n = 8 students, is found in the qualitative Study Madsen and Rump (2012). In comparison, the greatest number of participants with n> 1,000 occurred with middle-school student studies (Bodzin et al., 2013, 2014).

4.2 | What factors or variables effect GIS learning in terms of technology use, major subject contents, learning contexts, and didactic and pedagogical aspects?

4.2.1 | Type of GIS and GIS pedagogy

The application of different types of GIS in relation to the predominant approach of GIS pedagogy in terms of teaching and learning *about* vs. *with* GIS is closely related to educational level, as presented in Table 8.

Regarding GIS pedagogy, learning *with* GIS in hands-on learning situations but without lectures was the overall dominating approach of the interventions carried out at the school level. In contrast, learning *about* GIS only appeared in higher education, mainly in introductory GIS courses with lectures. Only four studies documented that teaching and learning *about* and *with* GIS were equally part of the learning environment. The primary GIS application used within the reported studies is DesktopGIS (n = 16). While two studies also report integrating GPS-based

TABLE 8 Educational level, type of GIS used, and GIS pedagogy

	Type of GIS				GIS pedagogy		
Educational level	Desktop GIS	Digital globe	Other WebGIS	Additional GPS use	With GIS	About GIS	With and about GIS
Elementary school	Shin (2006, 2007)	–	Huang (2011)	–	Huang (2011), Shin (2006, 2007)	–	–
Middle school	Bodzin et al. (2013, 2014), Perkins et al. (2010)	Bodzin et al. (2013, 2014), Doering and Veletsiano (2007), Kulo and Bodzin (2011)	–	Doering and Veletsiano (2007), Perkins et al. (2010)	Bodzin et al. (2013, 2014), Doering and Veletsiano (2007), Kulo and Bodzin (2011), Perkins et al. (2010)	–	–
Secondary school	Aladag (2010), Demirci (2011), Liu et al. (2010)	Demirci et al. (2013), Lei et al. (2009), Wang et al. (2013)	Favier and Van der Schee (2014)	–	Aladag (2010), Demirci (2011), Favier and Van der Schee (2014), Liu et al. (2010)	–	Demirci et al. (2013), Lei et al. (2009), Wang et al. (2013)
Higher education (university or college)	Clark et al. (2007), Edsall and Wentz (2007), Kim and Bednarz (2013a, 2013b), Lee and Bednarz (2009), Madsen et al. (2014), Madsen and Rump (2012), Simmons et al. (2008), Srivastava & Tait (2012)	Gobert et al. (2012), Srivastava & Tait (2012)	Songer (2010)	–	Edsall and Wentz (2007), Gobert et al. (2012), Simmons et al. (2008), Songer (2010)	Clark et al. (2007),Kim and Bednarz (2013a, 2013b), Lee and Bednarz (2009), Madsen etal.(2014), Srivastava & Tait (2012)	Madsen and Rump (2012)

data collection into the learning activity, no study reports utilizing mobile GIS applications. Further, it is interesting to note that with more than 70% of the used DesktopGIS, there is a dominance of the software family *ArcGIS* by *ESRI©*. In contrast, only four studies at the secondary education level reported the use of *My World GIS* software, which is specially designed for classroom application. A comparable picture can be drawn regarding the use of digital globes for geobrowsing data; out of the studies that have used *Google Earth©* (n = 9), only one study (Doering & Veletsiano, 2007) also used *ArcExplorer Java Education for Educators* by *ESRI©*. The use of WebGIS was limited to local applications, with *EduGIS* being a current national school GIS platform in the Netherlands. Regarding the related spectrum of specific GIS functions and tools for data handling and analysis as a means for students to use GIS for information processing and knowledge construction, no valid summary and further subgrouping of the studies is possible due to inconsistencies in the studies' reporting. However, GIS applications mainly comprise the use of basic tools for data display and layer handling, that is, functions such as opening and saving data, using the standard tools for zooming and identifying, working with attribute tables and legend settings, and viewing data in a standard data overlay. Advanced GIS tool usage, for example, for spatial statistics, map algebra, or network analysis, was not reported.

4.2.2 | Curriculum and subject matter

It is worthwhile to look at the various curriculum-specific and content-specific fields of learning for which GIS was utilized in terms of the respective studies' interventions. As Table 9 shows, at the level of higher education, 7 of 11 studies are related to mostly conventional, semester-long undergraduate introductory course settings containing lectures and hands-on laboratory sessions (involving teaching and learning *about* GIS). In contrast, only four studies report on short and self-contained learning activities in different subjects (learning *with* GIS). Looking at GIS use at the school level, it is evident that GIS has been used as an educational tool for understanding and analyzing mostly geography-related aspects and contents.

TABLE 9 Subgrouping of curriculum connection and subject-specific knowledge areas

Thematic reference of intervention	Studies
Higher education (curriculum/course)	
Introductory GIS course (geography, multi-disciplinary)	Clark et al. (2007), Kim and Bednarz (2013a, 2013b), Lee and Bednarz (2009), Srivastava & Tait (2012
Introductory human geography	Songer (2010)
Introductory physical geography	Edsall and Wentz (2007)
GIS and cartography (geography)	Madsen et al. (2014)
GIS in planning and management (geography and geoinformatics)	Madsen and Rump (2012)
Fundamentals of ecological laboratory	Simmons et al. (2008)
Geoscience lab on plate tectonics	Gobert et al. (2012)
School level (subject-specific)	
Human geography	Aladag (2010), Liu et al. (2010), Shin (2006, 2007)
Physical geography	Demirci (2011), Demirci et al. (2013)
Energy resources curriculum	Bodzin et al. (2013, 2014), Kulo and Bodzin (2011)
Topographical knowledge	Huang (2011), Lei et al. (2009), Wang et al. (2013)
Issues on man and environment	Doering and Veletsiano (2007), Favier and Van der Schee (2014)
Ecological understanding	Perkins et al. (2010)

4.2.3 | Knowledge dimensions and cognitive domain

To find out to what extent and on what cognitive level GIS has been used in the respective learning contexts, all the research studies were analyzed by structuring each of their documented learning outcomes regarding the application of GIS (Table 10).

The results show that GIS learning is relatively uniformly distributed according to the dimensions of factual, conceptual, and procedural knowledge. A majority of the studies deal with geography-related content knowledge by either employing basic learning activities to foster understanding or activities to foster learning through analysis. Only five studies focus on procedural knowledge application in terms of training GIS knowledge and skills in higher education GIS-course environments. Two studies did not report on the cognitive process level sufficiently, making categorical assignment impossible. Two further studies are respectively concerned with developing an instrument for assessing students' spatial habits of mind and aspects of their critical spatial thinking. Although both of these studies can, therefore, be classified as methodological, rather than theoretical or empirical studies on subject-specific competences in the field of geography and GIS in terms of each documented learner's knowledge application, they were both classified as promoting metacognitive knowledge. Finally, only one study was classified at the highest cognitive level of creating. This is because this study focuses on the cognitive processes that are related to students' spatial anchoring behavior in terms of creating geographic references on a map while mentally connecting textual information to specific geographic locations. Interventions that were based on the pedagogical approach of learning *with* GIS comprise DesktopGIS, WebGIS, and digital globes for learning. Their utilization was mostly connected to the cognitive processes of understanding and analyzing geography-related factual and conceptual knowledge (see Table 11).

4.3 | What facets of knowledge, process skills, and affect in terms of competence-based GIS learning have been investigated?

The previous results sections presented synthesized findings from the content analysis and from further thematically grouping and clustering the information from the text codings in the form of different tabulations. This procedure was frequency analytical and descriptive by nature. However, to answer Q3 in terms of interpretative synthesis, it seems helpful to briefly recite and explain QCA category building as a process before presenting the final results as a product within a comprehensive table.

4.3.1 | The process of category formation

During the qualitative content analytical aggregation of the individual studies' findings, numerous descriptive aspects and respective categories emerged from the text material, providing detailed information and data of subject-specific knowledge and skills in action, cognitive processes of reasoning through GIS, and affective and motivational facets of GIS learning. These themes and concepts closely relate to the context-bearing pedagogical aspects and approaches of instruction as well as the design of GIS-learning environments that were investigated within the single research studies. To indicate the type of empirical evidence of these individual findings for further comparison, the classification of the empirical validation comprised three levels of evidence: (*) significant findings (results with $p < .05$); (#) non-significant findings (resulting from observation); and (+) general findings or conclusions from empirical research. After nearly half of all the studies were coded, an initial 27 thematic categories emerged out of the text-material. The following is a brief example of the paraphrased codings of the emerging main theme of “Subject-specific knowledge and skills (A).”

TABLE 10 Grouping of studies referring to knowledge dimensions and cognitive domain

Knowledge dimension	Cognitive domain						
	Remembering	Understanding	Applying	Analyzing	Evaluating	Creating	No documentation
Factual	–	Demirci et al. (2013), Edsall and Wentz (2007), Gobert et al. (2012), Huang (2011)	Lei et al. (2009)	Aladag (2010), Songer (2010)	–	–	–
Conceptual	–	Favier and Van der Schee (2014), Shin (2006, 2007)	Simmons et al. (2008)	Bodzin et al. (2013, 2014), Demirci (2011), Doering and Veletsiano (2007), Kulo and Bodzin (2011)	–	Wang et al. (2013)	–
Procedural	–	Srivastava & Tait (2012)	Perkins et al. (2010)	Lee and Bednarz (2009), Liu et al. (2010), Madsen and Rump (2012)	–	–	Clark et al. (2007), Madsen et al. (2014)
Meta cognitive	–	Kim and Bednarz (2013b)	–	–	Kim and Bednarz (2013a)	–	–

TABLE 11 GIS pedagogy, type of GIS, and reference to the cognitive domain

	Type of GIS			Cognitive domain						
GIS pedagogy	DesktopGIS	Digital globe	Other WebGIS	Remembering	Understanding	Applying	Analyzing	Evaluation	Creating	No documentation
With GIS	Aladag (2010), Bodzin et al. (2013, 2014), Demirci (2011), Edsall and Wentz (2007), Kulo and Bodzin (2011), Liu et al. (2010), Perkins et al. (2010), Shin (2006, 2007), Simmons et al. (2008)	Bodzin et al. (2013, 2014), Doering and Veletsiano (2007), Gobert et al. (2012), Kulo and Bodzin (2011)	Favier and Van der Schee, (2014), Huang (2011), Songer (2010)	–	Edsall and Wentz (2007), Favier and Van der Schee (2014), Gobert et al. (2012), Huang (2011), Shin (2006, 2007)	Perkins et al. (2010), Simmons et al. (2008)	Aladag (2010), Bodzin et al. (2013, 2014), Demirci (2011), Doering and Veletsiano (2007), Kulo and Bodzin (2011), Liu et al. (2010), Songer (2010)	–	–	–
About GIS	Clark et al. (2007), Kim and Bednarz (2013a, 2013b), Lee and Bednarz (2009), Madsen et al. (2014), Srivastava & Tait (2012	Srivastava & Tait (2012)	–	–	Kim and Bednarz (2013b), Srivastava & Tait (2012)	–	Lee and Bednarz (2009)	Kim and Bednarz (2013a)	–	Clark et al. (2007), Madsen et al. (2014)
About & with GIS	Madsen and Rump (2012)	Demirci et al. (2013), Lei et al. (2009), Wang et al. (2013)	–	–	Demirci et al. (2013)	Lei et al. (2009)	Madsen and Rump (2012)	–	Wang et al. (2013)	–

(A) "Subject-specific knowledge and skills"

- **A: Importance of foreknowledge**

(*) Learners with more computer familiarity do not show greater improvement in learning coastal geomorphology and concepts in physical geography than those with less computer familiarity. **Edsall and Wentz (2007)**

- **A: Improvement of understanding**

(*) Google Earth supports understanding of geography and basic geology knowledge regardless of the level of prior coursework and regardless of gender. **Gobert, Wild, and Rossi (2012)**

- **A: GIS provides information on demand**

(+) Just-in-time association of maps with non-spatial facts in instruction media facilitates subject matter comprehension. **Huang (2011)**

- **A: Construction of placed-based meaning**

(#) Building an understanding of place starts with familiar places by making connections between what one sees on the GIS map and personal experiences; dots on the map suddenly became meaningful through personal experiences. **Shin (2007)**

- **A: GIS-specific knowledge and skills**

(#) Compared to learners in non-GIS courses, the learners in a GIS course can explicitly use and verbalize GIS-specific technical terms such as spatial concepts and related vocabulary (like buffer, projection, and attribute). **Kim and Bednarz (2013b)**

The further processing of the remaining articles was based on a revision and reduction of the preliminary 27 categories to a final number of 17 thematic categories. The including paraphrased statements of the different studies' single findings were further aggregated as well as assigned to the respective different educational levels (the corresponding 12-page result table is not part of this article). In addition, they were summarized for synthesis by a meaningful abstract (Sandelowski & Barroso, 2006). Finally, the 17 thematic categories were conclusively grouped under four main themes that have evolved and were continuously described throughout the category formation procedure: (A) "Subject-specific knowledge and skills"; (B) "Cognitive skills and processes"; (C) "Motivational and affective aspects"; and (D) "Pedagogical aspects for GIS teaching and learning."

The following demonstrates the previously explained procedure of aggregated category formation, taking again the example of Theme (A) and the detailed description of Category (A1). Afterwards, Table 12 presents the synthesized findings on competence-based GIS teaching and learning (Section 4.3.2).

(A): "Subject-specific knowledge and skills"

Description: This category describes the influence of teaching and learning through GIS on the development of the learner's subject-specific knowledge and skills. This involves different types of knowledge, including factual, conceptual, and procedural knowledge. Skills are understood as the ability to apply knowledge in practice; thus, they are linked to procedural knowledge. Research related to the development of knowledge and skills through GIS learning can be summarized within the four subcategories of "Geographic knowledge gain" (A1); "Construction of meaning" (A2); "Information 'on-demand'" (A3); and "GIS knowledge and skills" (A4).

A1: Geographic knowledge gain

Summarized findings:

TABLE 12 Synthesized findings on competence-based GIS teaching and learning

Main theme and individual categories	Summarizing abstracts
(A) Subject-specific knowledge and skills. This category describes the influence of teaching and learning through GIS on the development of the learner's subject-specific knowledge and skills. This involves different types of knowledge, namely, factual, conceptual, and procedural knowledge. Skills are understood as the ability to apply knowledge in practice; thus they are linked to procedural knowledge.	
A1 Geographic knowledge gain (*m*, *s*, *h*)	GIS teaching and learning has proved to have a positive impact on the formation of the learner's geography-related content knowledge and understanding (i.e., factual and conceptual knowledge)
A2 Construction of meaning (*p*, *m*, *s*)	Abstract geospatial data become "meaningful artifacts" of digital information and knowledge for a learner if the learner is already familiar with the mapped places within the provided datasets. Developing meaning of place and space is associated with a modification of a learner's "common view" of the world and the concepts of space by dynamically changing data views through zooming. Thus, authentic and place-based data affect GIS teaching and learning, helping to create and foster a sense of place as well
A3 Information "on demand" (*p*, *m*, *s*)	GIS has proved to enhance geographic learning efficiency due to its capacity to dynamically display and connect spatial information of current interest. Map manipulation within GIS is key to identifying relevant information for spatial inquiry. Therefore, in comparison to learning with paper-based maps and pre-structured learning content, teaching and learning through GIS fosters the construction of geographical content knowledge by providing the learner with information "on demand," thereby reducing cognitive load
A4 GIS knowledge and skills (*s*, *h*)	Only a few studies referred to the role of GIS-specific content knowledge as well as technical/methodical skills (i.e., procedural knowledge). However, in summary, learning *about* GIS enhances the conceptual understanding of GIS with regard to data reliability, the use of technical terminology, and data models. Further, there is a semantic difference between "using" ready-to-use GIS like Google Earth and effectively "operating" these systems, which requires sufficient computer skills as well as geo-technological knowledge, skills, and practice
(B) Cognitive skills and processes. This category summarizes the findings on learners' cognitive skills and processes related to working with GIS. This category is closely related to category (A) "subject-specific knowledge and skills," since the development of knowledge and skills involves different cognitive process levels.	
B1 Enhanced spatial thinking (*m*, *s*, *h*)	Teaching and learning *with* and *about* GIS have been found to enhance learners' skills of spatial thinking in different contexts of short-term as well as long-term application of GIS. However, there are different approaches as to how "spatial thinking" is operationalized in current research. Consequently, to interpret findings on spatial thinking and GIS, it appears necessary to closely look at the respective definitions as well as the underlying terms and concepts
B2 Cognitive process levels (*p*, *s*, *h*)	In terms of a learner's cognitive processing, GIS teaching and learning has been shown to result in enhanced knowledge gain due to the intensified in-depth observations of geographical aspects in terms of analyzing and evaluating
B3 Visual stimulation (*p*, *m*, *s*)	Graphical representations of information within GIS foster learning efficiency regarding geographical aspects. However, visual learning with digital globes can result in surface learning, which has been described as understanding geographical facts and content without active memorization and disengagement in using certain analysis tools

(Continues)

TABLE 12 (Continued)

Main theme and individual categories	Summarizing abstracts
B4 Prior knowledge and abilities (*p*, *m*, *s*, *h*)	Effective learning with GIS places great value on the learner's prior knowledge and reasoning skills and abilities
B5 Learners' cognitive differences (*m*, *s*, *h*)	GIS teaching and learning does not take place within an arena of uniform learners. On the contrary, the learner's individual engagement with GIS has been shown to depend on different cognitive thinking styles, learning strategies, and spatial abilities. Thus, it should be kept in mind that diverse GIS-learners need different ways of instruction and scaffolding to be able to create a form of GIS to use as their personal learning medium for effective geographic inquiry and spatial thinking
(C) Motivational and affective aspects. This category summarizes the empirical findings on the learners' motivational and affective aspects related to GIS teaching and learning.	
C1 Motivation and interest (*p*, *m*, *s*, *h*)	Working with GIS and digital globes, in particular, increases learners' motivation and interest in geography lessons and in working with geospatial technology
C2 Self-efficacy (*s*, *h*)	Working with GIS reinforces a learner's positive perception of achieving substantial learning outcomes
C3 GIS is "gaming & fun" (*p*, *m*, *s*, *h*)	GIS, but especially WebGIS and Google Earth, has been demonstrated to be fun to use and entertaining for learners. However, this raises the question of what the fun activity actually is. Is it "GIS learning" or rather "web-based playing with the computer" in class?
C4 Exploration activities (*p*, *m*, *s*)	Learning with GIS and particularly with Google Earth is accompanied by the learner's intrinsic motivation and curiosity of (a) virtually exploring geographical locations of personal interest such as local neighborhoods along with (b) testing the technical functions and possibilities to manipulate data with the respective GIS application
(D) Pedagogical aspects for GIS teaching and learning. This category summarizes the findings from empirical GIS education research on the pedagogical and didactical aspects of teaching and learning to support the effective engagement with GIS.	
D1 Inquiry and problem-based learning (*p*, *s*, *h*)	Problem-based teaching and learning with GIS in well-designed hands-on learning environments is a worthwhile experience for learners in terms of "doing research" related to real-world situations and authentic problems. This supports learners' inquiry skills, problem-solving abilities, as well as their self-paced direction of the learning process
D2 Learning orchestration (*p*, *m*, *s*, *h*)	Effective GIS teaching and learning are not only attributed to technology use alone but to the appropriate design, scaffolding, and instruction of GIS-based learning arrangements. In particular, this is true because GIS-learning orchestration is challenging with regard to addressing different learning styles, learning strategies for coping with GIS, and the different simultaneous learning activities in the classroom. Learning orchestration should, therefore, emphasize learning processes rather than fixed learning outcomes by (a) designing clear and appropriate GIS learning tasks, (b) realizing mindful teacher-led instruction, (c) allowing learners' individual constructions of GIS as a personal learning medium, (d) considering various forms of support for GIS learning, and (e) enabling self-paced learning approaches, such as in WBL environments, allowing for collaborative learning and sharing troublesome experiences with others

(Continues)

TABLE 12 (Continued)

Main theme and individual categories	Summarizing abstracts
D3 Teachers' professional competences (*p*, *m*, *s*)	Teachers should be aware that their professional GIS knowledge and skills affect learners' visible outcomes. As a result, besides technological content knowledge, teachers need sufficient content knowledge and pedagogical content knowledge as well. Furthermore, effectively implementing GIS-based curricula requires a great amount of time for teachers to develop their pedagogical design capacity, to create appropriate learning materials, and to perceive the learners' needs related to geospatial learning
D4 Temporal progression of GIS learning (*p*, *m*, *s*, *h*)	Accumulating and transferring students' competences through GIS-based geography learning takes an extended amount of time—often more time than anticipated. Research indicates that the positive development of specific knowledge and skills, such as map skills or spatial thinking, is linked to long-term engagement with GIS, rather than being a result of a singular learning occurrence. Therefore, from the perspective of GIS teaching and learning, two different temporal perspectives of GIS learning have to be taken into account: (a) "operational time," such as short and episodic engagement with GIS as part of a single lesson or course unit; and (b) "progression competence development," such as long-term, periodic engagement with GIS as part of a lesson series or a university lecture

- Compared to traditional non-GIS teaching and learning methods, GIS-supported teaching and learning results with a significant increase in content knowledge. Aladag (2010), Bodzin et al. (2013, 2014), Songer (2010)
- A significant increase in factual geographic knowledge after only working with Google Earth has been verified. Demirci, Karaburun, and Kılar (2013), Gobert et al. (2012)
- A positive, but not significant knowledge gain for geographic content knowledge has been verified. Demirci (2011), Kulo and Bodzin (2011)
- Conceptual understanding related to landmark representation (that is, acquiring basic spatial information on certain places together with prior geographic knowledge) significantly accounts for more about the outcomes of ordinary geographical learning than transformations of complex spatial information, which is more closely associated with hands-on experiences and knowledge construction. Lei, Kao, Lin, and Sun (2009)
- GIS-based learning significantly improves comprehension of declarative knowledge in physical geography; however, no significant improvement in contrast to paper-based learning was measured. Edsall and Wentz (2007)
- Computer familiarity (like owning a computer) is not related to significant improvements in learning physical geography contents. Edsall and Wentz (2007)
- However, facilitating GIS in a fieldwork-based ecology lab does not show a significant increase in conceptual knowledge (population sampling techniques) in contrast to field exercise and traditional lecture without GIS. Simmons, Wu, Knight, and Lopez (2008)
- Although GIS only have marginal benefit as a teaching tool for small scale and simple spatial phenomena, it is important to note that GIS did not negatively affect the performance or attitude of learners. Simmons et al. (2008)

Summarizing abstract: GIS teaching and learning have proved to have a positive impact on the formation of the learner's geography-related content knowledge and understanding, such as factual and conceptual knowledge.

4.3.2 | The product of content analytical synthesis

To answer Q3 in terms of what facets of competence-based GIS teaching and learning have been investigated in the analyses research literature, Table 12 presents the findings of the narrative synthesis. A short summary statement describes the four main themes of competence-based GIS teaching and learning first. The subcategories are characterized by meaningful abstracts that result from the described thematic and content analytical working. The included levels of education are encoded as (*p*) primary school, (*m*) middle school, (*s*) secondary school, and (*h*) higher education.

Overall, the synthesized findings presented in Sections 4.2 and 4.3 need to be interpreted in more detail to further integrate the discovered personal and technical variables and factors as well as the social interactions and situational contexts of GIS learning. This is especially important for those studies that report small to large effect sizes (Cohen's *d*) for GIS learning in relation to knowledge gain (Bodzin et al., 2013, Bodzin et al., 2014, Simmons et al., 2008), improvement of spatial thinking (Bodzin et al., 2014, Favier & Van der Schee, 2014; Kim, & Bednarz, 2013a, 2013b), the change in students' attitudes (Simmons et al., 2008), behavior (Bodzin et al., 2013), and self-efficacy (Favier & Van der Schee, 2014). These findings do not allow for conclusions to be made about the large-scale effectiveness of GIS-based learning based only on statistical power (Cohen, 1992). Rather, they should also be subjected to an evaluation with regard to the size and direction of the measured learning effects, as is required in a comparable manner for evaluating the subjective distortions of the results of the qualitative studies (Doering & Veletsiano, 2007, Kulo & Bodzin, 2011; Madsen, Christiansen, & Rump, 2014; Madsen & Rump, 2012; Shin, 2007). In addition, a detailed interpretation of the distribution of the study participants with reference to their level of education would also be of major interest in determining to what extent there are age-dependent differences in GIS learning. This is because the present aggregation of the individual studies' findings comprises all educational levels from primary school up to higher education. However, a detailed subgrouping analysis that aims to investigate the possible internal or external factors interfering with the central study variables, as well as to identify major moderators regarding GIS learning, such as a student's foreknowledge, level of education, intrinsic motivation, or gender, cannot be undertaken here due to the studies' heterogeneity.

5 | DISCUSSION

This section is organized around the three focal points of: (1) the state of added knowledge on GIS in education; (2) the quality and limitations of this review study; and (3) implications for future GIS education research.

5.1 | State of added knowledge on GIS education

The integration of individual studies' findings from empirical GIS education resulted in a number of meaningful statements about a learner's construction of: (a) subject-specific knowledge and skills; (b) cognitive skills and processes; (c) motivational-affective aspects of GIS learning; along with (d) various pedagogical and curricula issues. However, this review study is neither a proponent of a theory of GIS learning based upon hypothesis-based testing of cause and effect in GIS learning in geography nor suggesting that large-scale conclusions can be made about the actual effects of GIS-based learning. Rather, it provides a new framework for systematic and structured summary and aggregation of empirically investigated indicators of the phenomenon “GIS learning,” which have been investigated so far by the international GIS-education research community. Thus, from the perspective of social theory (Blumer, 1954), the presented categories and synthesized statements are not “definitive concepts” that could serve as fixed benchmarks on the effectiveness of GIS education. Instead, this review has generated those “sensitizing concepts” that help explain GIS learning in terms of the social action of the involved parties. However, it needs to be emphasized that the most driving question on how, why, and for whom GIS works on a large scale cannot be answered conclusively here (cf. Popay et al., 2006). As shown in Section 4, the main reason for this is the empirically verified heterogeneity of the examined studies. This refers to the study's population samples, the total learning time in class, social learning formats of individual vs. peer-based vs. group-based working, and the use of different types of GIS and geospatial datasets. Also, different forms of instruction, such as frontal instruction and lecturing, “trouble-shooting” through the teacher or researcher, independent or accompanying use of a technical or learning manual, or even no instruction at all, have a significant impact on the students' visible learning outcomes in dealing with GIS. Incomparable study designs are simply based on each different subject-related or thematic reference as to *why* GIS has been used for interventions in class. However, the studies' heterogeneity should not be read as a global deficit in the research landscape of GIS education. Instead, the arduous research behind it should be critically appreciated, regardless of whether it is for exploratory research, design and implementation studies, or scaled-up research asking about effectiveness (Baker et al., 2015). Without this research and its different questions and perspectives, method designs, study participants, GIS applications, and, finally, empirical outcomes, it would not be possible to debate research gaps, fragmented knowledge, and blank spots in the theory and practice of GST and learning.

On the one hand, this points to the fact that empirical GIS education research is not sufficiently linked to general educational research, as Baker et al. (2012) reported. A situation that is also true for geography education research in terms of applying scientific educational research for engaging in systematic efforts to investigate the characteristics of students' effective learning—as well as ways of effective teaching—to think geographically (Bednarz et al., 2013). This argument is especially related to the fields of computer-based learning (Cook, 2005; Davis, Bagozzi, & Warshaw, 1989; King & He, 2006), self-regulated learning (Boekaerts, 1999; Dinsmore, Alexander, & Loughlin, 2008; Pintrich, 2004; Zimmermann, 1990), and the emerging field of educational technology (Bedenlier, Bond, Buntins, Zawacki-Richter, & Kerres, 2020). Although they are closely linked to the very nature of GIS and learning, these fields do not play any role in current empirical GIS education research. This finding is worthy of consideration since it would offer pivotal aspects to the present discussion on the students' *computer*-based learning through GIS (Winters, Greene, & Costich, 2008). The same applies to general meta-analytical education research. For example, Hattie (2009) shows that working with computers in school is effective (average d = 0.37). This is true if there is, for example, a diversity of teaching strategies and multiple learning opportunities (namely, the computer as a supplement, and not as a substitute, for teachers); when the learner and not the teacher is in “control” of the learning (regulation of technology); or when computer work takes place in pairs instead of singly or in large groups.

On the other hand, the discovered shortcomings of the synthesized findings also arise from the quality of the reporting and the documentation of the respective research. Although the criteria-based valuation of the individual studies' methodological quality has shown that most of the investigated studies show adequate empirical research, the weakest points of documentation are the formulation of basic hypotheses or assumptions concerning the investigation, how the (random) assignment of the study participants was carried out, whether or not the used methods of data gathering were pre-tested, and the critical discussion of the used methods, along with the limitations of findings. While the formulation of hypothesis- or theory-based presumptions and a concluding discussion of the used methods are general quality criteria for empirical research, the random selection of study participants and the pre-testing of survey instruments are particularly relevant for (quasi-)experimental study designs and for quantitative test methods (Centre for Reviews and Dissemination, 2009; Döring & Bortz, 2016). The last aspect mentioned should, therefore, be critically viewed in terms of the quality of the studies examined here, because quantitative study designs mainly utilized standardized procedures such as assessments, tests, or surveys. Relevant information on the determination of the reliability of the survey instruments used, such as the construct validity of the test instrument, would be desirable in this regard to fully provide the transparency of the research. This also applies to the qualitative study designs regarding the credibility of the respective research from a circular-iterative research design (Sandelowski & Barroso, 2006). It is not only the post-hoc evaluation of and reflection on the research process that is addressed here critically, but also an accompanying verification of one's own research process in the interest of process validity (Morse, Barrett, Mayan, Olson, & Spiers, 2002). Neither aspect is adequate in the qualitative studies examined; these are frequently based on recorded field observations in class, different forms of interviews with students (such as group discussion), and content or document analysis of those interviews, as well as on students' assignments and assessments.

5.2 | Quality of the current review study research

Since the general reliability of systematic reviews depends on the validity of the used methods to transparently minimize results bias (such as over- or underestimation of related findings), the limitations of this study need to be critically discussed (De Vet et al., 2005; Roberts et al., 2006). First and foremost, this pertains to the selection of studies, the coding, as well as the aggregation of the individual study results, which were completed according to the sole judgment of the author of this review. Despite the author's many years of experience in the field of GIS education at university level, as well as experience in the field of content analysis, an additional evaluation of the coding consistency of the synthesis procedure in terms of inter-rater reliability would have been desirable to counteract the so-called "garbage in, garbage out" effect and any possible subjective distortion of the aggregated individual study results (Rosenthal & DiMatteo, 2001). However, due to the high need for personnel and time that an additional evaluation would require, it was not realizable within the framework of this study. Instead, the category formation resulting from the content analysis was discussed by means of peer debriefing and joint coding sessions with experienced colleagues in qualitative research (Morse et al., 2002; Spall, 1998). It should also be noted that this review only includes peer-reviewed articles that were published between 2005 and 2014. This limitation runs the risk of publication bias (Centre for Reviews and Dissemination, 2009; De Vet et al., 2005). Thus, it would be desirable to extend the review to include research results that have not yet been considered. This would include publications that were published outside of the considered period, non-peer-reviewed publications, and primary research such as doctoral studies (cf. Baker et al., 2012). Finally, it must be noted that despite the methodological standardization in evidence-based research, systematic literature reviews should always be original and, therefore, unstandardized research. This means that ideal-typical descriptions of the process of a systematic review, as found in the recommendations largely used here, can only function as a guideline and not as a stiff methodological corset. As Rosenthal and DiMatteo (2001) put it: there is no "single correct way to perform a meta-analysis" (p. 68). This also applies to systematic literature reviews and is particularly true for those reviews in areas where empirical education research is employed and in which a variety of personal, social, and technical factors, interdependencies, and contexts must be considered (Berliner, 2002). In this context, the content-related validity of this review is limited to the scope of the documented results of the respective individual studies.

5.3 | Implication for future GIS education research

The results of this review study provide a range of directions to systematically look at for future research on GIS education based on "evidence gained" at the level of synthesized empirical validation for student learning on outcomes and learning GST (Baker et al., 2015).

First, it appears worthwhile to work on validating the reported impacts of GIS for teaching and learning to arrive at a formulation of evident moderator variables, such as gender, cognitive process, and type of instruction, which can guide the effective implementation of GIS in certain learning environments. The development of a web of cause and effect relationships that reflects the contexts and conditions, as well as the strategies, for the interaction of those learning with GIS and of those who teach GIS is a decisive component in changing in the long term from a purely normative design of GIS curricula to GIS pedagogies that are also empirically based.

Second, empirical GIS educational research needs to be more systematic in terms of generating consistent, replicable, and applicable results across studies (cf. Baker et al., 2012). In this connection, with reference to the inner and outer forms of empirical studies on GIS teaching and learning processes, it can be noted that the attributes necessary to carry out evidence-based research synthesis—namely, accuracy, simplicity, and clarity (Rosenthal & DiMatteo, 2001)—should also be kept in mind for the subject examined here. This is an important prerequisite for applying methods of meta-analysis to evidence-based research on empirical GIS education in the future. In this context, this systematic literature review represents a comprehensive piece of work showing evidence-based aggregation of the state of research in competence-based GIS learning—however, it is only one piece of the puzzle.

Finally, future research needs to focus more on the very essence of learning through *geographic* information systems. Looking at the themes of GST education research (Baker et al., 2015), thus adjusting the pure technology focus of teaching and learning *about* vs. *with GIS* towards computer-based learning *through GST* for educating "critical spatial thinkers" (Bearman, Jones, André, Cachinho, & DeMers, 2016) would represent a second paradigm shift. The argument made here is that the genuine educational aspect in dealing with GST in terms of a cultural technology of (mass media) communication of geospatial information (Ash, Kitchin, & Leszczynski, 2016; Felgenhauer & Gäbler, 2018; Kanwischer, 2014; Sui & Goodchild, 2011) is in developing people's competence in critiquing the increasing geomedia-based spread of diverse and competing perspectives of our world and its various power relations. Hence, learning *through* GST should focus on context-based learning and reasoning, allowing for reflectively dealing with geospatial technology, geospatial data, and its multiple representations in society (Pokraka, Gryl, Schulze, Kanwischer, & Jekel, 2017; Schulze, Gryl, & Kanwischer, 2015). Baker et al. (2012, pp. 271f) already implicitly announced the small differences in the prepositions *with* vs. *through*, discussing questions of learning "with and about GIS" and of "citizenship formation through GIS." This discussion is of great importance for the perception of the general educational value of GST for future geography education (Kerski, 2015) and, more specifically, for realizing effective teaching and learning in the upcoming field of digital geography (Ash, Kitchin, & Leszczynski, 2019), which is another challenging task for educational research in this field.

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CONFLICT OF INTEREST

There are not conflicts of interest.

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ENDNOTE

[1] The author conducted major parts of this review study in 2015 and 2016 during their dissertation. An extended manuscript can be found within the author's thesis on competence-based GIS education in higher education (Schulze, 2017).

REFERENCES

Abend, P. (2013). *Geobrowsing. Google Earth & Co. - Nutzungspraktiken einer digitalen Erde* [Geobrowsing. Google Earth & Co., Practices of Use of a Digital Earth]. Berlin, Germany: De Gruyter.

Anderson, L. W., & Krathwohl, D. R. (2001). *A taxonomy for learning, teaching, and assessing: A revision of Bloom's Taxonomy of Educational Objectives* (Complete ed.). New York, NY: Longman.

Ash, J., Kitchin, R., & Leszczynski, A. (2016). Digital turn, digital geographies? *Progress in Human Geography*, *42*(1), 25–43.

Ash, J., Kitchin, R., & Leszczynski, A. (2019). Introducing digital geographies. In J. Ash, R. Kitchin, & A. Leszczynski (Eds.), *Digital geographies* (pp. 1–10). London, UK: Sage.

Bailey, J. E., Whitmeyer, S. J., & De Paor, D. G. (2012). The application of Google Geo Tools to geoscience education and research. In S. J. Whitmeyer, J. E. Bailey, D. G. De Paor, & T. Ornduff (Eds.), *Google Earth and virtual visualisation in geoscience education and research* (Geological Society of America Special Paper No. 492, pp. vii–xix). Boulder, CO: Geological Society of America.

Baker, T. R., Battersby, S., Bednarz, S. W., Bodzin, A. M., Kolvoord, B., Moore, S., ... Uttal, D. (2015). A research agenda for geospatial technologies and learning. *Journal of Geography*, *114*, 118–130.

Baker, T. R., & Bednarz, S. W. (2003). Lessons learned from reviewing research in GIS education. *Journal of Geography*, *122*, 231–233.

Baker, T. R., Kerski, J., Huynh, N. T., Viehrig, K., & Bednarz, S. W. (2012). Call for an agenda and center for GIS education research. *Review of International Geographical Education Online*, *2*, 254–288.

Bakri, A., Sugiarti, Y., & Wahyudin, D. (2019). Context integration GIS of education relevant in secondary school TVET. *Journal of Physics: Conference Series*, *1375*, 012081.

Bearman, N., Jones, N., André, I., Cachinho, H. A., & DeMers, M. (2016). The future role of GIS education in creating critical spatial thinkers. *Journal of Geography in Higher Education*, *40*(3), 394–408.

Bedenlier, S., Bond, M., Buntins, K., Zawacki-Richter, O., & Kerres, M. (2020). Learning by doing? Reflections on conducting a systematic review in the field of educational technology. In O. Zawacki-Richter, M. Kerres, S. Bedenlier, M. Bond, & K. Buntins (Eds.), *Systematic reviews in educational research: Methodology, perspectives and application* (pp. 111–127). Wiesbaden, Germany: Springer VS.

Bednarz, S. W., Heffron, S., & Huynh, N. T. (2013). *A road map for 21st century geography education: Geography education research* (A report from the Geography Education Research Committee of the Road Map for 21st Century Geography Education Project). Washington, DC: Association of American Geographers.

Bednarz, S. W., & Van der Schee, J. (2006). Europe and the United States: The implementation of geographic information systems in secondary education in two contexts. *Technology, Pedagogy & Education*, *15*, 191–205.

Berliner, D. C. (2002). Comment: Educational research, the hardest science of all. *Educational Researcher*, *31*, 18–20.

Blumer, H. (1954). What is wrong with social theory? *American Sociological Review*, *19*, 3–10.

Bodzin, A. M., Fu, Q., Kulo, V., & Pfeffer, T. (2014). Examining the effect of enactment of a geospatial curriculum on students' geospatial thinking and reasoning. *Journal of Science Education & Technology*, *23*, 562–574.

Boekaerts, M. (1999). Self-regulated learning: Where we are today. *International Journal of Educational Research*, *31*, 445–457.

Brown, J. S., Collins, A., & Duguid, P. (1989). Situated cognition and the culture of learning. *Educational Researcher*, *18*(1), 32–42.

Bryant, L. M. P., & Favier, T. (2015). Professional development focusing on inquiry-based learning using GIS. In O. M. Solari, A. Demirci, & J. Van der Schee (Eds.), *Geospatial technologies and geography education in a changing world* (pp. 127–138). Tokyo, Japan: Springer.

Butler, D. (2006). Virtual globes: The web-wide world. *Nature*, *439*, 776–778.

Centre for Reviews and Dissemination. (2009). *Systematic reviews: CRD's guidance for undertaking reviews in health care*. Retrieved from https://www.york.ac.uk/crd/SysRev/!SSL!/WebHelp/SysRev3.htm

Çepni, O. (2013). The use of Geographic Information Systems (GIS) in geography teaching. *World Applied Sciences Journal*, *25*(12), 1684–1689.

Cohen, J. (1992). Statistical power analysis. *Current Directions in Psychological Science*, *1*, 98–101.

Cook, D. A. (2005). The research we still are not doing: An agenda for the study of computer-based learning. *Academic Medicine*, *80*(6), 541–548.

Cooper, H. M. (2010). *Research synthesis and meta-analysis: A step-by-step approach* (4th ed.). Thousand Oaks, CA: Sage.

Davis, F. D., Bagozzi, P., & Warshaw, P. R. (1989). User acceptance of computer technology: A comparison of two theoretical models. *Management Science*, *35*(8), 982–1003.

Demirci, A. (2015). The effectiveness of geospatial practices in education. In O. M. Solari, A. Demirci, & J. Van der Schee (Eds.), *Geospatial technologies and geography education in a changing world* (pp. 141–153). Tokyo, Japan: Springer.

De Vet, H. C. W., Verhagen, A. P., Logghe, I., & Ostelo, R. W. J. G. (2005). Literature research: Aims and design of systematic reviews. *Australian Journal of Physiotherapy*, *51*, 125–128.

Dewa, P., Mulyanti, B., & Widiaty, I. (2020). Geographic information system in education. *IOP Conference Series: Materials Science & Engineering*, *830*, 042097.

DiBiase, D., Foote, K. E., Tate, N. J., & Unwin, D. J. (2012). Ways forward for GIS&T education. In D. J. Unwin, K. E. Foote, N. J. Tate, & D. DiBiase (Eds.), *Teaching geographic information science and technology in higher education* (pp. 453–467). Chichester, UK: Wiley-Blackwell.

Dinsmore, D. L., Alexander, P. A., & Loughlin, S. M. (2008). Focusing the conceptual lens on metacognition, self-regulation, and self-regulated learning. *Educational Psychology Review*, *20*, 391–409.

Döring, N., & Bortz, J. (2016). *Forschungsmethoden und Evaluation in den Sozial- und Humanwissenschaften* [Research methods and evaluation in the social sciences and humanities]. Berlin, Germany: Springer.

Felgenhauer, T., & Gäbler, K. (Eds.). (2018). *Geographies of digital culture*. New York, NY: Routledge.

Foote, K. (2012). Scope and sequence in GIS&T education: Learning theory, learning cycles and spiral curriculum. In D. J. Unwin, K. E. Foote, N. J. Tate, & D. DiBiase (Eds.), *Teaching geographic information science and technology in higher education* (pp. 81–95). Chichester, UK: Wiley-Blackwell.

Gerstenmeier, J., & Mandl, H. (1995). Wissenserwerb unter konstruktivistischer Perspektive [Knowledge acquisition from a constructivist perspective]. *Zeitschrift für Pädagogik*, *41*(6), 867–888.

Hammersley, M. (2020). Reflections on the methodological approach of systematic reviews. In O. Zawacki-Richter, M. Kerres, S. Bedenlier, M. Bond, & K. Buntins (Eds.), *Systematic reviews in educational research: Methodology, perspectives and application* (pp. 23–40). Wiesbaden, Germany: Springer VS.

Hattie, J. (2009). *Visible learning: A synthesis of over 800 meta-analyses relating to achievement*. London, UK: Routledge.

Heyvaert, M., Maes, B., & Onghena, P. (2013). Mixed methods research synthesis: Definition, framework, and potential. *Quality & Quantity*, *47*, 659–676.

Kanwischer, D. (2014). Digitale Geomedien und Gesellschaft. Zum veränderten Status geographischen Wissens in der Bildung. [Digital geomedia and society. On the changing status of geographic knowledge in education]. *Geographische Rundschau*, *66*(6), 12–17.

Kanwischer, D., Reudenbach, C., & Schulze, U. (2009). Wie kommt der Transrapid nach Marburg? GIS und problembasiertes Lernen in der Hochschule. [How can the Transrapid get connected to the city of Marburg? GIS and problem-based learning in higher education]. In T. Jekel, K. Donert, & A. Koller (Eds.), *Learning with Geoinformation IV – Lernen mit Geoinformation IV* (pp. 200–211). Heidelberg, Germany: Wichmann Verlag.

Kennedy, D., Hyland, A., & Norma, R. (2006). Writing and using learning outcomes: A practical guide. In E. Froment, J. Kohler, L. Purser, & L. Wilson (Eds.), *EUA Bologna handbook: Making Bologna work* (pp. 3.4-1–3.4-28). Berlin, Germany: Raabe.

Kerski, J. (2008). Geographic information systems in education. In J. P. Wilson & A. S. Fotheringham (Eds.), *The handbook of geographic information science* (pp. 540–556). Oxford, UK: Blackwell.

Kerski, J. (2015). Geo-awareness, geo-enablement, geotechnologies, citizen science, and storytelling: Geography on the world stage. *Geography Compass*, *9*(1), 14–26.

King, W. R., & He, J. (2006). A meta-analysis of the technology acceptance model. *Information & Management*, *43*(6), 740–755.

Klieme, E., Avenarius, H., Blum, W., Döbrich, P., Gruber, H., Prenzel, M., … Vollmer, H. J. (2004). *The development of national educational standards: An expertise*. Berlin, Germany: Federal Ministry of Education and Research.

Koeppen, K., Klieme, E., & Leutner, D. (2008). Current issues in competence modeling and assessment. *Journal of Psychology*, *216*(2), 61–73.

Lane, R., & Bourke, T. (2019). Assessment in geography education: A systematic review. *International Research in Geographical and Environmental Education*, *28*(1), 22–36.

Mayring, P. (2014). *Qualitative content analysis: Theoretical foundation, basic procedures and software solution*. Retrieved from https://qualitative-content-analysis.org/wpcontent/uploads/Mayring2014QualitativeContentAnalysis.pdf

Milson, A. J., Demirci, A., & Kerski, J. (Eds.). (2012). *International perspectives on teaching and learning with GIS in secondary schools*. Dordrecht, Germany: Springer.

Morse, J. M., Barrett, M., Mayan, M., Olson, K., & Spiers, J. (2002). Verification strategies for establishing reliability and validity in qualitative research. *International Journal of Qualitative Methods*, *1*(2), 13–22.

National Research Council. (2006). *Learning to think spatially: GIS as a support system in the K-12 curriculum*. Washington, DC: National Academies Press.

Neuendorf, K. C. (2002). *The content analysis guide book*. London, UK: Sage.

Newman, M., & Gough, D. (2020). Systematic reviews in educational research: Methodology, perspectives and application. In O. Zawacki-Richter, M. Kerres, S. Bedenlier, M. Bond, & K. Buntins (Eds.), *Systematic reviews in educational research: Methodology, perspectives and application* (pp. 3–22). Wiesbaden, Germany: Springer VS.

Pintrich, P. R. (2004). A conceptual framework for assessing motivation and self-regulated learning in college students. *Educational Psychology Review*, *16*, 385–407.

Pokraka, J., Gryl, I., Schulze, U., Kanwischer, D., & Jekel, T. (2017). Promoting learning and teaching with geospatial technologies using the spatial citizenship approach. In L. Leite, L. Dourado, A. S. Afonson, & S. Morganda (Eds.), *Contextualizing teaching to improving learning: The case of science and geography* (pp. 223–344). Hauppauge, NY: Nova Science Publishers.

Popay, J., Roberts, H., Sowden, A., Petticrew, M., Arai, L., Rodgers, M., & Britten, N. (2006). *Guidance on the conduct of narrative synthesis in systematic reviews: A product from the ESRC methods programme*. Lancaster, UK: Lancaster University.

Pope, C., Mays, N., & Popay, J. (2007). *Synthesising qualitative and quantitative health evidence: A guide to methods*. Maidenhead, UK: McGraw Hill Open University Press.

Roberts, P. D., Stewart, G. B., & Pullin, A. S. (2006). Are review articles a reliable source of evidence to support conservation and environmental management? A comparison with medicine. *Biological Conservation*, *132*(4), 409–423.

Rodgers, M., Sowden, A., Petticrew, M., Arai, L., Roberts, H., Britten, N., & Popay, J. (2009). Testing methodological guidance on the conduct of narrative synthesis in systematic reviews: Effectiveness of interventions to promote smoke alarm ownership and function. *Evaluation*, *15*(1), 49–73.

Rosenthal, R., & DiMatteo, M. (2001). Meta-analysis: Recent developments in quantitative methods for literature reviews. *Annual Review of Psychology*, *52*, 59–82.

Rustenbach, J. S. (2003). *Metaanalyse: eine anwendungsorientierte Einführung* [Metaanalysis: An application-oriented introduction]. Bern, Switzerland: Verlag Hans Huber.

Sandelowski, M., & Barroso, J. (2006). *Handbook for synthesizing qualitative research*. New York, NY: Springer.

Schultz, R. B. (2012). Active pedagogy leading to deeper learning: Fostering metacognition and infusing active learning into the GIS&T classroom. In D. J. Unwin, K. E. Foote, N. J. Tate, & D. DiBiase (Eds.), *Teaching geographic information science and technology in higher education* (pp. 133–143). Chichester, UK: Wiley-Blackwell.

Schulze, R. (2004). *Meta-analysis. A comparison of approaches*. Cambridge, MA: Hogrefe & Huber.

Schulze, U. (2017). *Geoinformationsausbildung in der Hochschule. Kompetenzen, curriculare Anforderungen und empirische Befunde* [Geographic information systems in higher education: Competences, curriculum, empirical findings] (Unpublished PhD dissertation). Johann-Wolfgang Goethe-Universität zu Frankfurt am Main.

Schulze, U., Gryl, I., & Kanwischer, D. (2015). Spatial citizenship education and digital geomedia: Composing competences for teacher education and training. *Journal of Geography in Higher Education*, *39*, 369–385.

Schulze, U., Kanwischer, D., & Reudenbach, C. (2013). Essential competences for GIS learning in higher education: A synthesis of international curricular documents in the GIS&T domain. *Journal of Geography in Higher Education*, *37*(2), 257–275.

Sinton, D. (2012). Making the case for GIS&T in higher education. In D. J. Unwin, K. E. Foote, N. J. Tate, & D. DiBiase (Eds.), *Teaching geographic information science and technology in higher education* (pp. 17–36). Chichester, UK: Wiley-Blackwell.

Snilstveit, B., Oliver, S., & Vojtkova, M. (2012). Narrative approaches to systematic review and synthesis of evidence for international development policy and practice. *Journal of Development Effectiveness*, *4*, 409–429.

Spall, S. (1998). Peer debriefing in qualitative research: Emerging operational models. *Qualitative Inquiry*, *4*(2), 280–292.

Steiger, E., de Albuquerque, J. P., & Zipf, A. (2015). An advanced systematic literature review on spatiotemporal analyses of Twitter data. *Transactions in GIS*, *19*(6), 809–834.

Strauss, A. L., & Corbin, J. (1998). *Basics of qualitative research: Techniques and procedures for developing grounded theory*. Thousand Oaks, CA: Sage.

Sui, D. Z. (1995). A pedagogic framework to link GIS to the intellectual core of geography. *Journal of Geography*, *94*(6), 578–591.

Sui, D. Z., & Goodchild, M. F. (2011). The convergence of GIS and social media: Challenges for GIScience. *International Journal of Geographical Information Science*, *25*(11), 1737–1748.

Tan, G. C. I., & Chen, Q. F. J. (2015). An assessment of the use of GIS in teaching. In O. M. Solari, A. Demirci, & J. Van der Schee (Eds.), *Geospatial technologies and geography education in a changing world* (pp. 155–168). Tokyo, Japan: Springer.

Tate, N. J. (2012). GIS is dead, long live GIS&T: An educational commentary on the opening of Pandora's box. In D. J. Unwin, K. E. Foote, N. J. Tate, & D. DiBiase (Eds.), *Teaching geographic information science and technology in higher education* (pp. 345–358). Chichester, UK: Wiley-Blackwell.

Tate, N. J., & Jarvis, C. H. (2017). Changing the face of GIS education with communities of practice. *Journal of Geography in Higher Education*, *41*(3), 327–340.

Van den Berg, M., Schoones, J., & Vlieland, V. T. (2007). Internet-based physical activity interventions: A systematic review of the literature. *Journal of Medical Internet Research*, *9*(3), e26.

Waddington, H., White, H., Snilstveit, B., Hombrados, J. G., Vojtkova, M., Davies, P., ... Tugwell, P. (2012). How to do a good systematic review of effects in international development: A tool kit. *Journal of Development Effectiveness*, *4*, 359–387.

Winters, F. I., Greene, J. A., & Costich, C. M. (2008). Self-regulation of learning within computer-based learning environments: A critical analysis. *Educational Psychology Review*, *20*, 429–444.

Zadrozny, J., McClure, C., Lee, J., & Jo, I. (2016). Designs, techniques, and reporting strategies in geography education: A review of research methods. *Review of International Geographical Education Online*, *6*(3), 216–233.

Zawacki-Richter, O., Kerres, M., Bedenlier, S., Bond, M., & Buntins, K. (Eds.). (2020). *Systematic reviews in educational research: Methodology, perspectives and application*. Wiesbaden, Germany: Springer VS.

Zimmermann, B. J. (1990). Self-regulated learning and academic achievement: An overview. *Educational Psychologist*, *25*(1), 3–17.

Zwartjes, L., de Lázaro, M. L., Donert, K., Sánchez, I. B., De Miguel González, R., & Wołoszyńska-Wiśniewska, E. (2017). *Literature review on spatial thinking* (Project report). Retrieved from http://www.gilearner.ugent.be/wpcontent/uploads/GI-Learner-SpatialThinkingReview-3.pdf

SYNTHESIZED STUDIES

Aladag, E. (2010). The effects of GIS on students' academic achievement and motivation in seventh-grade social studies lessons in Turkey. *International Research in Geographical & Environmental Education*, *19*, 11–23.

Bodzin, A. M., Fu, Q., Peffer, T., & Kulo, V. (2013). Developing energy literacy in US middle-level students using the geospatial curriculum approach. *International Journal of Science Education*, *35*, 1561–1589.

Bodzin, A. M., Fu, Q., Kulo, V., & Pfeffer, T. (2014). Examining the effect of enactment of a geospatial curriculum on students' geospatial thinking and reasoning. *Journal of Science Education & Technology*, *23*, 562–574.

Clark, A. M., Monk, J., & Yool, S. R. (2007). GIS pedagogy, web-based learning and student achievement. *Journal of Geography in Higher Education*, *31*, 225–239.

Demirci, A. (2011). Using Geographic Information Systems (GIS) at schools without a computer laboratory. *Journal of Geography*, *110*, 49–59.

Demirci, A., Karaburun, A., & Kılar, H. (2013). Using Google Earth as an educational tool in secondary school geography lessons. *International Research in Geographical & Environmental Education*, *22*, 277–290.

Doering, A., & Veletsiano, G. (2007). An investigation of the use of real-time, authentic geospatial data in the K-12 classroom. *Journal of Geography*, *106*, 217–225.

Edsall, R., & Wentz, E. (2007). Comparing strategies for presenting concepts in introductory undergraduate geography: Physical models vs. computer visualization. *Journal of Geography in Higher Education*, *31*, 427–444.

Favier, T. T., & Van der Schee, J. (2014). The effects of geography lessons with geospatial technologies on the development of high school students' relational thinking. *Computers & Education*, *76*, 225–236.

Gobert, J., Wild, S. C., & Rossi, L. (2012). Testing the effects of prior coursework and gender on geoscience learning with Google Earth. In S. J. Whitmeyer, J. E. Bailey, D. G. De Paor, & T. Ornduff (Eds.), *Google Earth and virtual visualisation in geoscience education and research* (Geological Society of America Special Paper No. 492, pp. 453–468). Boulder, CO: Geological Society of America.

Huang, K. H. (2011). A GIS-interface web site: Exploratory learning for geography curriculum. *Journal of Geography*, *110*, 158–165.

Kim, M., & Bednarz, R. (2013a). Effects of a GIS course on self-assessment of spatial habits of mind (SHOM). *Journal of Geography*, *112*, 165–177.

Kim, M., & Bednarz, R. (2013b). Development of critical spatial thinking through GIS learning. *Journal of Geography in Higher Education*, *37*, 350–366.

Kulo, V. A., & Bodzin, A. M. (2011). Integrating geospatial technologies in an energy unit. *Journal of Geography*, *110*, 239–251.

Lee, J., & Bednarz, R. (2009). Effect of GIS learning on spatial thinking. *Journal of Geography in Higher Education*, *33*, 183–198.

Lei, P.-L., Kao, G. Y.-M., Lin, S. S. J., & Sun, C.-T. (2009). Impacts of geographical knowledge, spatial ability and environmental cognition on image searches supported by GIS software. *Computers in Human Behavior*, *25*, 1270–1279.

Liu, Y., Bui, E. N., Chang, C.-H., & Lossman, H. G. (2010). PBL-GIS in secondary geography education: Does it result in higher-order learning outcomes? *Journal of Geography*, *109*, 150–158.

Madsen, L. M., Christiansen, F., & Rump, C. (2014). Students individual engagement in GIS. *Journal of Geography in Higher Education*, *38*, 251–265.

Madsen, L. M., & Rump, C. (2012). Considerations of how to study learning processes when students use GIS as an instrument for developing spatial thinking skills. *Journal of Geography in Higher Education*, *36*, 97–116.

Perkins, N., Hazelton, E., Erickson, J., & Allan, W. (2010). Place-based education and geographic information systems: Enhancing the spatial awareness of middle school students in Maine. *Journal of Geography*, *109*, 213–218.

Shin, E.-K. (2006). Using Geographic Information System (GIS) to improve fourth graders' geographic content knowledge and map skills. *Journal of Geography*, *105*, 109–120.

Shin, E.-K. (2007). Using Geographic Information System (GIS) technology to enhance elementary students' geographic understanding. *Theory & Research in Social Education*, *35*, 231–255.

Simmons, M. E., Wu, X. B., Knight, S. L., & Lopez, R. R. (2008). Assessing the influence of field- and GIS-based inquiry on student attitude and conceptual knowledge in an undergraduate ecology lab. *CBE-Life Science Education*, *7*, 338–345.

Songer, L. C. (2010). Using web-based GIS in introductory human geography. *Journal of Geography in Higher Education*, *34*, 401–417.

Srivastava, S. K., & Tait, C. (2012). An activity-based learning approach for key Geographical Information Systems (GIS) concepts. *Journal of Geography in Higher Education*, *36*, 527–545.

Wang, D.-Y., Lee, M.-H., & Sun, C.-T. (2013). Effects of thinking style and spatial ability on anchoring behavior in Geographic Information Systems. *Educational Technology & Society*, *16*(3), 1–13.

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