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Map Skills in Education: A Systematic Review of Terminology, Methodology and Influencing Factors

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Abstract

For a few decades, map skills stay at the forefront of not only geographers' and geographic educators' research interest. To identify what has already been accomplished, where the research currently stands and where the potential for future studies lies, a review of the literature was carried out. Specifically, this comprehensive synthesis of map skill research focuses on three perspectives: terminology, methodological approaches, and mainly on investigated factors affecting the map skill level. As non-uniformity in terminology is apparent, an integrative framework of map skill types based on theoretical works and previous studies is proposed. Similarly, methods that can be more suitable and beneficial for future research than now prevailing non-standardized test are presented. These suggestions are mainly based on a variety of identified scarcely used methodological approaches. Furthermore, the synthesis shows that the number of factors which influence on the level of map skills has been tested is substantial. But that, frequently investigated categories of factors are identifiable. In addition, current gaps in map skill research are identified and insufficiently studied, yet potentially important factors are suggested for future studies.

Keywords
Map Skill; Map Reading; Map Use; Geography Education; Systematic Review

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The current period can be characterised as spatial information age. The development and increased accessibility of modern technology mean that we are confronted every day with a huge amount of information about objects, phenomena and processes, and their spatial perspective. This would have been unthinkable just one hundred years ago (LaSpina, 1998).

One of the frequent methods used to visualise spatial information is a map. Its popularity is largely due to its potential for visualising spatial distribution of selected information which can put the information in a completely new perspective (van Dijk, van der Schee, Trimp, & van der Zijpp, 1994). The ever-present popularity of maps has risen to such an extent that it is possible to find them almost everywhere, as the World Wide Web has dramatically transformed the way in which they are created and distributed (Ooms et al., 2015). Publicly accessible geographic applications and geographic information systems have also been of great significance for the dissemination of maps in recent years. As such, the public not only uses maps, but also frequently creates them (Hamerlinck, 2015; Hurst & Clough, 2013; Pedersen, Farrell, & McPhee, 2005).

The increasing popularity of maps together with the development of cartography as a science has led to a greater need to develop students' map skills, i.e. skills associated with use and drawing of maps. The more skilful people are in using maps, the better they will be able to interpret spatial information about both the globe itself and the place where they live. Consequently, it will also be easier for them to make sense of the world (Catling, 2005; Gökçe, 2015; Hanus & Havelková, 2019; Harte & Dunbar, 1994).

Moreover, map skills are a substantial part of geographical competence that can address many employers' needs in the business, government, and non-profit sectors, as well as in the geospatial technology industry (DiBiase et al., 2010; Schulze, Kanwischer, & Reudenbach, 2011; Solem, 2017; Solem, Cheung, & Schlemper, 2008). Map skills and related spatial thinking together with GIS use are three of the four areas of geographical skills most needed at work according to geography alumni (Schlemper, Adams, & Solem, 2014; Solem, 2017; Solem et al., 2008).

The need for the development of map skills, inter alia, has increased pressure on research in the field. In approx. the last 40 years, a number of studies have been published describing the level of map skills and identifying independent variables (hereinafter referred to as factors) that affect this level. These studies, however, are characterized by a considerable variety of terminology and a quite unsystematic (from the perspective of the overall state of knowledge in the field) selection of methodological approaches, sample characteristics and factors investigated. This causes difficulties for the generalisability of knowledge, the planning and implementation of further research aiming at providing a comprehensive understanding of the current level of map skills, and for an understanding of map development processes.

Therefore, the main goal of this study is firstly to address these difficulties and to synthesise prior research in the field of map skills, as it reveals the current state and the main trends; and, secondly to offer guidance to researchers who are seeking suitable unanswered questions regarding map skills and the factors affecting their level of development. As there has been no systematic review of the literature focusing on map skills in general, the following research questions are addressed:

- How are map skills defined by individual researchers?
- What types of map skills and what specific operations with maps are commonly investigated?
- What methodological approaches are used to identify the level of map skills?
- What factors have been most frequently tested as potentially affecting the level of map skills?
- Does the research attention dedicated to these factors correspond to the overall results of the studies?
- What potentially relevant factors have not yet been (sufficiently) studied or have an influence which has yet to be well understood?

A systematic review of literature published from 1980 to 2016 was carried out and a narrative synthesis of the results is employed to address these questions. To make the synthesis systematic and comprehensive, an elementary framework of map skills classification and of types of factors influencing map skills is discussed.

Theoretical Framework

Map Work and Map Skills

Map work consists of the understanding of map concepts and the practising of map skills which people employ when working with or drawing maps (Hanus & Havelková, 2019). However, a study of the literature has shown specification of map skills to be problematic. Authors (Board, 1978; Herrmann & Pickle, 1996; Keates, 1996; Kimerling, Buckley, Muehrcke, & Muehrcke, 2009; McClure, 1992; van Dijk et al., 1994; Wiegand, 2006) differ on which operations should be included among map skills. However, it can generally be stated that map skills can be broadly differentiated into activities associated with map use and activities associated with map drawing (Drumheller, 1968; Gerber, 1984; Harwood & Usher, 1999). Map use can be further specified based on operations corresponding to the reading, analysis and interpretation of maps (Carter, 2005; Kimerling et al., 2009; Liebenberg, 1998; van Dijk et al., 1994; Wiegand, 2006).

The individual types of map use skills have been appropriately described by (Wiegand, 2006, p. 111):

> Map reading is characterised as simply extracting information from the map. Map features are identified and named and their attributes noted. Map analysis involves processing that information in order, for example, to describe patterns and relationships or to measure distances between places. Map interpretation goes beyond what is shown on the map and involves the application of previously acquired information in order to solve problems or make decisions.

Hanus & Marada (2014) in association with Board (1984) have, moreover, emphasized the fact that higher-order (more complex) map skills incorporate those from lower levels (less complex, with lower cognitive demands). Specific operations representing the subject of research in the studies reviewed have been assigned to the above-defined map skills to narrowly specify them (see Figure 1). This approach to map skill categorization fully reflects the current concept of working with maps as tools for developing geographic thinking (Hanus & Havelková, 2019). Therefore, it is used to categorize studies and interpret the results of this systematic review.

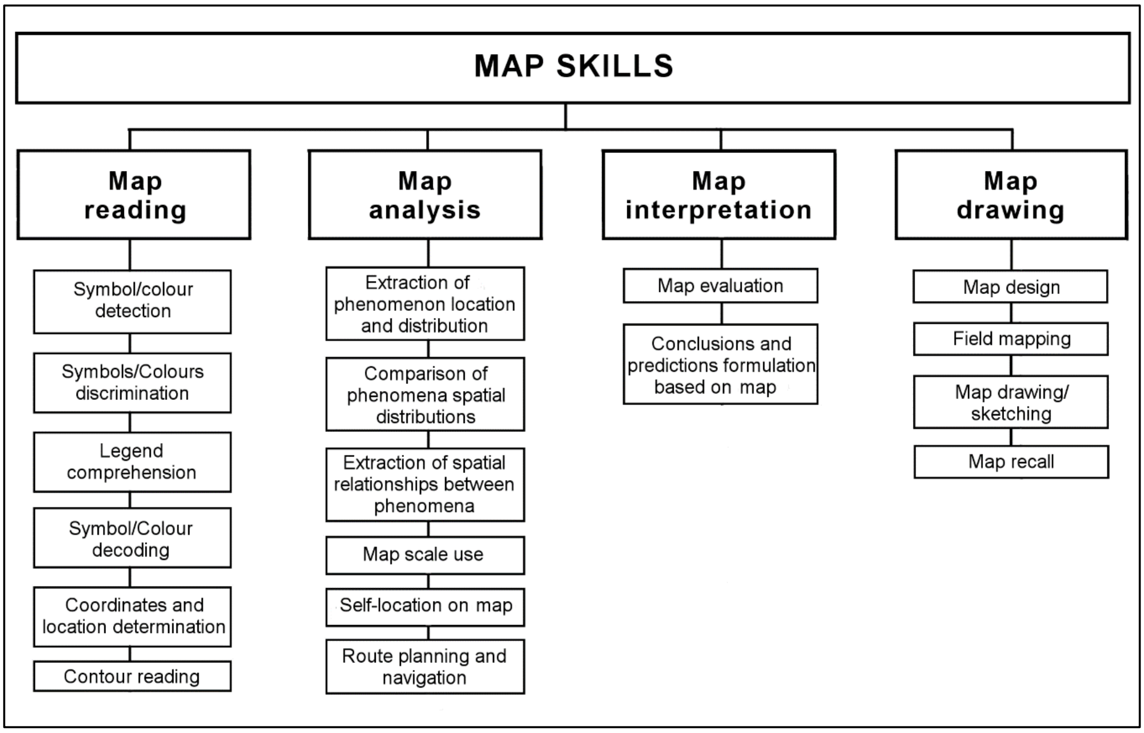

Figure 1. Map skill categorization.

Source: compiled on the basis of Drumheller (1968); Hanus & Marada (2014); Herrmann & Pickle (1996); Keates (1996); Kimerling et al. (2009); Riding & Boardman (1983); Rittschof, Griffin, & Custer (1998); Robinson (1995); Wiegand (2006).

Factors Affecting Map Skill Level

It is possible to designate basic categories of factors (i.e., independent variables) which may influence map skill level and its development based on the concept of cartographic communication (Koláčný, 1969; Wood, 1972) or eventually on the concept of cartographic interaction (Roth, 2012). Although the concept of cartographic communication has already been superseded in terms of the mediation of cartographic information, the categorization of factors influencing map skills is still appropriate.

This involves factors associated with the map itself (map characteristics) on the one hand and factors, i.e., attributes, associated with the map user (user characteristics) on the other hand. These two categories should be supplemented with a third, which includes the characteristics of the social, learning, etc. environment (external factors). As the cartographer's creation of a map and, particularly, the map user's work with a map can be impeded or promoted by them (e.g., home environment, familiarity with the area, teacher's learning style).

Methodology

Research Design

This study reviewed both experimental and correlational empirical studies which have tested map skill level and its dependence on an independent variable (factor). The review intentionally concentrated on studies with participants of school age (including university and college students), older than five years, as a high degree of variance in the tested and significant factors is to be expected in the case of preschool children due to their level of cognitive development and due to the frequent fundamental differences in research design (e.g., Blades et al., 1998; Liben & Yekel, 1996; Sowden, Stea, Blades, Spencer, & Blaut, 1996). For the same reason, studies which specifically only concentrate on participants with special educational needs, i.e., participants with learning disabilities, blind/deaf participants, participants with behavioural disorders etc. were not considered (e.g., Fox & Avramidis, 2003; McKissick, Spooner, Wood, & Diegelmann, 2013; Pike, Blades, & Spencer, 1992).

Literature Search

A broad literature search was carried out for peer-reviewed articles which tested map skill level and investigated at least one factor which could explain differences in this level between individual participants or groups of participants. The systematic review was performed according to the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) criteria, a systematic and explicit method for identifying, selecting, and critically appraising relevant research. PRISMA consists of a 27-item checklist and a four-phase (Identification, Screening, Eligibility, Included) flow diagram (Moher, Liberati, Tetzlaff, Altman, & The PRISMA Group, 2009).

Keywords, titles and abstracts of peer-reviewed articles published in English between 1980[3] and 2016 were searched for in two major electronic bibliographic databases most relevant to the investigated research field, namely Scopus and the Education Resources Information Center (ERIC). The following keyword combinations were used:

("map skill" OR "map reading" OR "cartographic skill" OR "map interpretation" OR "map understanding" OR "map use skill" OR "mapping skill") AND ("testing" OR "level" OR "children" OR "pupil" OR "student").

Due to the focus on map skills and its educational aspects, the Scopus search was further refined by subject area, specifically to the Arts and Humanities, Computer Science, Earth and Planetary Sciences, Environmental Science, Mathematics, Psychology and the Social Sciences. The search process resulted in 563 potentially relevant articles after excluding 59 duplicates (Figure 2). A subsequent search of reference lists was not conducted as retrieving literature by scanning reference lists may produce a biased sample of studies (Higgins & Green, 2011).

[3]The studies published prior to the year 1980 were not taken into consideration as the preliminary search had shown their prevailing different research aims and perspectives. Specifically, the found empirical studies were more focused on a map and its design than a map user and map user's skills. Alternatively, the articles concentrated on suggesting effective development and learning of map skills without conducting (rigorous) research.

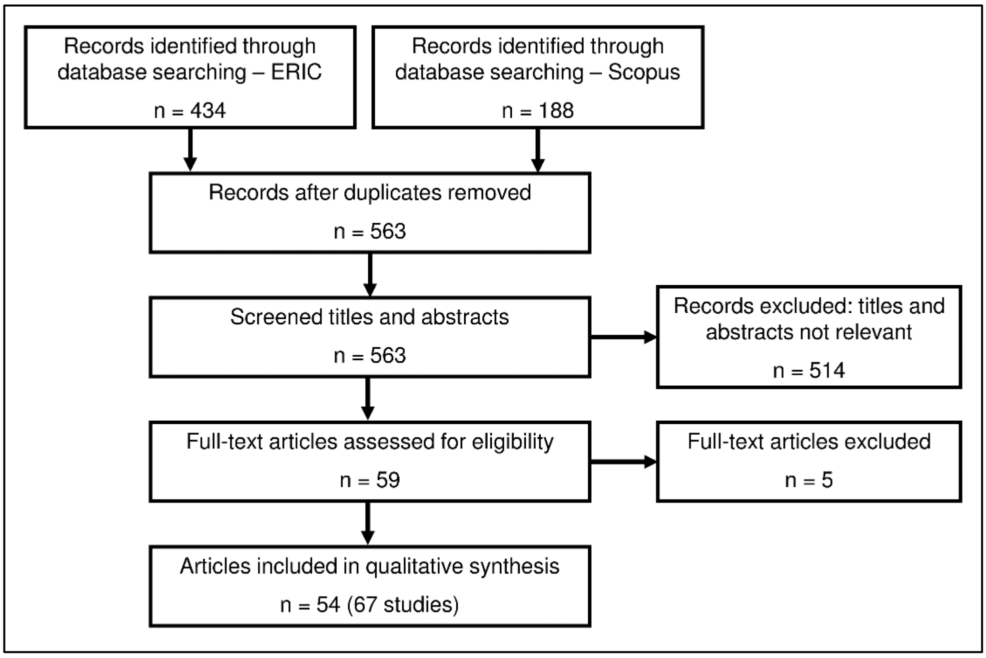

Figure 2. Flow of the studies for inclusion in the review.

In the second stage, both authors independently inspected the identified article titles and abstracts and confirmed that the selected articles:

(1) did not involve participants younger than 6 years of age or participants with special educational needs;
(2) tested the level of at least one map skill and the influence of at least one factor on it;
(3) provided empirical evidence or evaluation;
(4) were written in English.

In the case of conflict of the criteria or disagreement, the full paper was obtained and independently inspected and the inclusion criteria were applied. Any disagreement between the authors was resolved through discussion and consensus. In the end, 54 papers were identified as the research sample pool for this review (see Figure 2). Noticeably, some papers involved more than one study. In order to differentiate between the variants of empirical approach (choice of type of map skills and factors tested), each study was counted separately. As a result, a further 13 studies were identified for a total of 67 studies, of which 38 were correlational studies and 29 were experimental studies (see Appendix). A more detailed description of the electronic database searches can be obtained from the authors.

Data Extraction

A structured data extraction form was used onto which both authors abstracted data from each included article The authors abstracted data concerning the main characteristics of the empirical studies relevant to the aims of the review: sample size, participant age, map skill(s) tested, research methods, factor(s) considered to affect map skill(s) level, and main outcomes concerning statistically significant factor(s) and how it/they influenced map skill level. An extensive table showing the data abstracted from each reviewed paper is listed in the Appendix.

Data Synthesis

The aim of the data synthesis process was to integrate, based on the stated research goals, the results from the various types of primary research (i.e., from the perspective of the definition of map skills, the methodological approach, the map skill(s) tested, and the factor(s) considered). However, statistical synthesis of the results was prevented by the excessive heterogeneity of the experimental and correlational studies and sometimes insufficiently described methodology and results, described in more detail below. Narrative synthesis is therefore employed.

Table 1
Main categories, Subcategories and Number of Identified Factors

Main category	Subcategory	# Factors
User characteristics	age	2
	ethnicity and culture	4
	gender	1
	geographical knowledge and skills	15
	individual disabilities	3
	leisure and hobbies	7
	non-geographical abilities and skills	10
	psychological factors	14
Map characteristics	cartographic means of representation	6
	complexity	7
	other	5
External factors	education	3
	family	3
	tested map skill	1
	residence	1
	teaching	11

In addition to summary narrative text and tables, data were also synthesized into conceptual maps, i.e., diagrams depicting relations between concepts and, eventually, the strength of these relations. In this article, the conceptual maps describe and clearly show the major factors influencing map skill levels and the relations between factor influence and type of map skill tested. Therefore, the number of studies testing a given factor's influence was counted for each factor, as was the number of studies in which the factor's influence was statistically significant/or tested but not statistically significant.

Furthermore, the factors were categorised as relating to one of user characteristics, map characteristics or external factors. The categories were further divided by the authors into subcategories representing and characterizing the different types of factors, more suitable for conceptual maps and synthesis of results (see Table 1). Given the chosen synthesis process and the main aim of this review, the conceptual maps omit any identified factor not proven to be significant in at least one study (see Table 2).

Table 2
Not Statistically Significant Factors

Factor	Main category
Colour blindness	User characteristics
Dyslexia	User characteristics
Feeling of task importance	User characteristics
Hemisphericity	User characteristics
Hobby preferences	User characteristics
Interest in maps	User characteristics
Possibility of teaching career	User characteristics
Reading of geographical magazines	User characteristics
Score in language test	User characteristics
TV viewing	User characteristics
Watching geography programmes	User characteristics
Youth club membership	User characteristics
Digital/paper map	Map characteristics
Symbol type	Map characteristics
Familiarity of materials	External factors
Parental education	External factors
Parents travelling abroad	External factors

The conceptual maps were created using Gephi graph visualization and manipulation software. More specifically, Gephi's ForceAtlas layout was used as it can cluster related nodes, and move strongly connected nodes to the centre of the conceptual map and less connected nodes to its boundaries. Nodes represent the significant factors, the subcategories and categories they fall under, and the type of map skill tested. The weight of each node (its size) is based on the number of studies in which the influence of the factor on map skill level was proven to be significant. The same applies to edges (links) representing the existence and strength of a relation between two nodes (based on the number of studies in which the relation has been found significant). The clarity of the conceptual maps has been increased by colourising nodes and links according to the aforementioned categorisation of the factors.

Findings and Results

Differences in Terminology and Definition of Map Skills

Synthesizing current research base from the point of view of the terminology used for the skills participants employs when using or drawing maps has proven difficult. Some authors do not use any specific terms at all, because they place these skills within a broader group of skills, e.g., geographical skills, geospatial thinking skills, spatial (reasoning) skills (Battersby, Golledge, & Marsh, 2006; Beatty & Tröster, 1987; Kelly, Kelly, & Miller, 1987; Liben, Myers, Christensen, & Bower, 2013; Logan, Lowrie,

& Diezmann, 2014). Other authors admittedly distinguish between these skills, but do not further specify their terminology, making comparisons impossible (Bein, 1990; Bein, Hayes, & Jones, 2009; Henrie, Aron, Nelson, & Poole, 1997; Lim, 2005; Livni & Bar, 2001; Nelson, Henrie, Aron, & Poole, 1996; Scevak & Moore, 1998; Shin, 2007).

Nevertheless, it was quite clear from the other studies that authors differ even in their overall designations of these skills. In addition to the term “map skills”, there can also be found in the literature, for example, “mapping skills (abilities)” (Aksoy, 2013; Baker, Petcovic, Wisniewska, & Libarkin, 2012; Matthews, 1986; Trifonoff, 1995) and “cartographic skills” (Grofelnik & Pap, 2013). An even greater variety of terms arises in the case of individual operations. As mentioned in the introduction to this review, authors do not agree on which operations fall under “map skills” or even on how to categorise them. In addition to the division into “map reading”, “map analysis”, “map interpretation” and “map drawing”, other terms are used, such as “map understanding/comprehension” (Allen, Miller Cowan, & Power, 2006; Clark et al., 2008), "wayfinding/navigation skills" (Alhosani & Yagoub, 2015; Johnson, Johnson, Stanne, & Garibaldi, 1990; Malinowski & Gillespie, 2001) and "map learning/recall" (Postigo & Pozo, 1998, 2004; Winn & Sutherland, 1989). However, these terms refer to specific operations with maps which can be assigned to the types of map skills mentioned above.

From a researcher’s perspective, the number of terms used impedes the search for relevant published studies and increases the definitional redundancy of some terms. For example, a substantial number of authors use “map reading (skill)” for all map use skills, including map analysis and map interpretation (Barker, Hailstone, & Simmonds, 1986; Chang & Antes, 1987; Ishikawa, 2016; Ooms et al., 2015; Riding & Boardman, 1983; Umek, 2003).

Map Skills Tested

It is apparent from the previous text that it was necessary to re-categorise studies included in the review by map skill(s) tested in order to answer the research questions. Wiegand’s (2006) definition of map skill types and the detailed schema of individual operations with maps (Figure 1) were used to unify the terms. Studies focusing on multiple types of map skills were assigned to all types tested in it.

Thanks to this synthesis, it was discovered that the studies most frequently tested the ability to read a map (59% of studies) followed by map analysis (47%) and map drawing (27%), while studies testing map interpretation were rarest (19%). No study was oriented solely towards this ability. Map interpretation was tested in participants in association with their ability to read or analyse maps (Allen et al., 2006; Chang & Antes, 1987; Hanus & Marada, 2016; Ishikawa, 2016; Liebenberg, 1998; Pedersen et al., 2005). This connection is also apparent from Figure 5 which depicts factors with significant influence on given types of map skills.

Of the specific operations, the most popular were without doubt route planning, navigation and self-location on a map (Aksoy, 2013; Alhosani & Yagoub, 2015; Griffin, 1995; Griffin & Griffin, 1996; Hemmer et al., 2013; Lim, 2005; Logan et al., 2014;

Malinowski & Gillespie, 2001), which fall under map analysis skills. In contrast, numeric map scale use, another map analysis skill, was rarely tested (Aksoy, 2013; Grofelnik & Pap, 2013; Hanus & Marada, 2016; Hemmer et al., 2013). The individual operations constituting map interpretation and drawing skills (see Figure 1) have been researched similarly often.

Although map reading skills were most frequently researched, substantial differences are apparent in the frequency of research into individual map reading skill. For example, ability to determine geographic coordinates was researched only by Aksoy (2013) and Grofelnik & Pap (2013). While, in contrast, research focused very frequently on symbol and colour discrimination and decoding (Alhosani & Yagoub, 2015; Barker et al., 1986; Gilmartin & Shelton, 1989; Ishikawa, 2016; Liebenberg, 1998; Ooms et al., 2015) and on the locating objects on a map (Beatty & Tröster, 1987; Clark et al., 2008; Eve, Price, & Counts, 1994; Hemmer et al., 2013; Kastens & Liben, 2010).

Some authors do not take differences between individual subsets of map skills into account in their empirical studies and state that their goal is to identify general level of map skills (Bein, 1990; Bein et al., 2009; Grofelnik & Pap, 2013; Henrie et al., 1997; Kelly et al., 1987; Livni & Bar, 2001; Nelson et al., 1996). Nevertheless, their research tasks are sometimes closely associated with one specific type of map skill or even only a few specific operations. The failure to differentiate between individual skills may arise from the different research focuses of the authors, as a result, sufficient awareness of map skill diversity may be lacking. This substantially precludes identification of overall map skill level other than via a single robust research tool or the combination of several research tools.

Methodological Approaches to Map Skill Testing

As with the map skill concepts, not all studies give sufficient information about methodological approaches chosen to test the level of the map skills and identify factors influencing (Bein, 1990; Bein et al., 2009; Gerber, 1984; Nelson et al., 1996). As such, these insufficient descriptions indicate a high risk of bias and therefore substantially reduce not only the methodological but also overall quality, even when the studies make use of a suitable approach and create a valuable research instrument(s).

The absence of a used research instrument is also problematic not only for evaluating the quality of the studies, but also for research continuity with previous studies and comparing results (Matthews, 1986; Postigo & Pozo, 2004; Riding & Boardman, 1983; Umek, 2003). Instead of a used instrument, the articles often include examples of tested items, either only a few or an entire battery of questions, but without the maps which participants were supposed to use to answer them (Alhosani & Yagoub, 2015; Henrie et al., 1997; Kelly et al., 1987; Pedersen et al., 2005; Postigo & Pozo, 1998).

Generally, however, there are no substantial differences in the research instruments used, because suitable use of tests or questionnaires consisting of tasks/questions and maps usually suffices to identify most map skills and it is therefore not surprising that they predominate (e.g., Chang & Antes, 1987; Clark et al., 2008; Michaelidou, Nakos, & Filippakopoulou, 2004; Ooms et al., 2015; Teck, 1989; Trifonoff, 1995; van Dijk et al., 1994). Tests and questionnaires are often created by the authors based on theoretical knowledge or curriculum requirements, but there are also studies which have made use of preexisting and therefore tested tools (Aksoy, 2013; Hemmer et al., 2013; Sholl & Egeth, 1982; Ugodulunwa & Wakjissa, 2015; van der Schee & van Dijk, 1999).

The only case where tests do not prevail involves identification of map drawing level. Instead, participants were required to draw a map ranging from a sketch (mental) map (Harwood & Usher, 1999; Matthews, 1986; Postigo & Pozo, 1998; Shin, 2007) to a contour map (Wiegand & Stiell, 1997) and on to a map of a real environment base on field research (Baker et al., 2012). Exceptionally, studies were found which made use of audio or video recordings or the interview or think-aloud method to identify map skill level (Leinhardt, Stainton, & Bausmith, 1998; Logan et al., 2014; Ungar, Blades, & Spencer, 1997). These methods were mainly used in combination with other aforementioned methods (test, map drawing).

The distribution of research methods used to identify factors influencing map skill levels is highly similar to the above. Factors characterising map users are ascertained almost exclusively using questionnaires (e.g., gender, age, grade, liking for geography and marks for school subjects) or tests (e.g., spatial ability, maths skills, cognitive/learning style and drawing ability). The influence of factors falling under map characteristics (e.g., map type or figure-ground contrast) and external factors (e.g., teaching method or type of pre-test instruction) is predominantly verified in experimental studies (Barker et al., 1986; Bausmith & Leinhardt, 1998; Griffin, 1995; Johnson et al., 1990; Ungar et al., 1997; van der Schee & van Dijk, 1999). The method of identifying them therefore corresponds directly with the methodological approach selected for testing map skill level.

The designated research sample is also important for interpreting the influence of the chosen factors on map skill level. The studies differ crucially in size of research sample. The sample size (just like the sample structure) is substantially influenced by the research method and the focus of the study. As such, there are studies (24% of studies) which ascertained map skill level and verified the influence of researched factors in less than 50 participants (e.g., Bausmith & Leinhardt, 1998; Hirsch & Sandberg, 2013; Ishikawa, 2016; Kastens & Liben, 2010; Liben et al., 2013; Shin, 2007; Ungar et al., 1997). The transferability and generalisability of the results ascertained are therefore substantially limited because both map skill level and influence of researched factors could be substantially influenced by unascertained specifics of individual participants. Nevertheless, these studies can still be of great importance for the research field when they use qualitative research methods and aim to study students' development and level of a specific map skill in depth.

Moreover, a high number of participants (more than 600) does not necessarily mean simpler interpretation and greater transferability of results from the point of view of map skills and factors influencing them. As for example in case when the selected research tool is insufficiently described or contains only a few test items associated with map skills because it is more widely focussed, e.g., on geographical skills generally

(Beatty & Tröster, 1987; Bein, 1990; Gerber, 1984; Henrie et al., 1997). The sample size is stated for all studies in the Appendix.

Factors Affecting Map Skill Level

As most of the studies investigated the influence of more than one factor, a total of 93 different factors were identified. The influence of most factors (66%) was, however, investigated only once. The substantial variety of selected factors and particularly the considerable representation of factors tested only once contributes to the number of factors (18) which influence has not been proven in any study (see Table 2). These factors are not included in Figures 3 and 5 as they display only the factors affecting map skills (i.e., 75 factors)[4].

As far as the main categories of factors are concerned, authors most frequently verified the dependency of map skill level on factors characterising map users (81% of the studies), followed by external factors (64%), with the influence of map characteristics investigated least frequently (25%). The distinct predominance of factors characterizing map users is even more apparent if their weights are totalled, i.e., the number of studies in which their influence has been proven (see Figure 3). This high degree of representation is caused substantially by the higher number of identified factors aiming to describe participants (57 out of 93). By comparison, the number of factors aiming to describe map characteristics is almost the same as the number of external factors (17 vs 19), yet the number of studies focused on them and verifying their influence differs substantially (see Figure 3).

Figure 3 also clearly shows which identified factors have been most frequently proven as affecting level of map skills (gender, age, map skill tested, grade, expertise in geography, spatial ability and teaching method) and similarly which of the subcategories created for the purposes of this review (geographical knowledge and skills, teaching, non-geographical abilities and skills, age, gender and psychological factors).

A substantial variety of statistically significant factors is noticeable particularly in the subcategory of psychological factors (see Figure 3). Not only have the previous studies verified the influence of certain types and parts of intelligence (verbal, nonverbal, general verbal reasoning), they have proven other mental processes to be influential (e.g., motivation, emotion, memory).

[4] The specifics of influence of individual factors as well as for example the specific age group for which the factors have been proven to be significant is not in detail described in the article. As its aims are different and it is out of scope of single article to do so. Nevertheless, this information are part of the Appendix which comprehensively sum up main outcomes of reviewed studies.

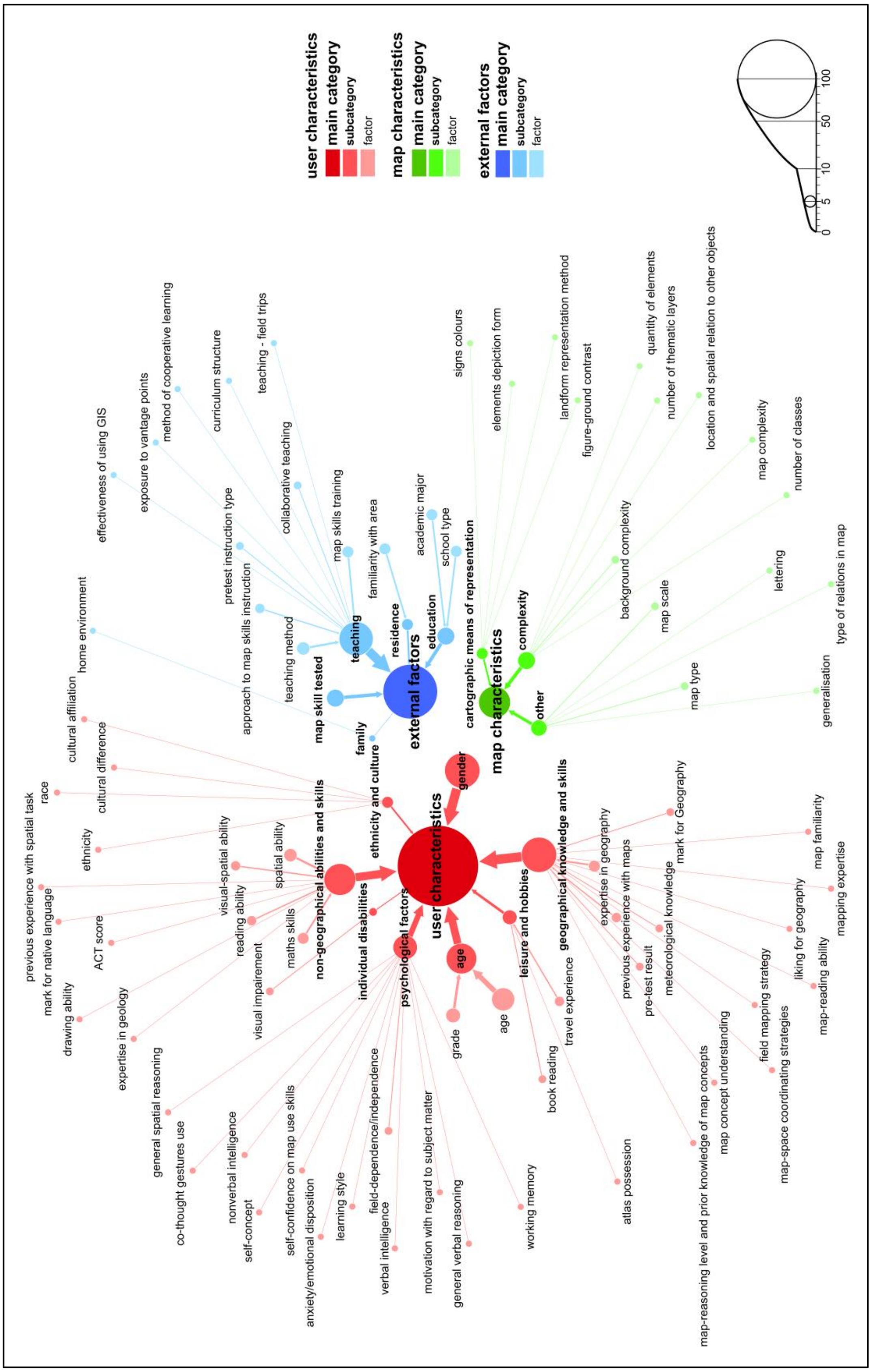

Figure 3. Factors affecting level of map skills. Note: Radius of node (circle) and thickness of edge represents the number of studies proving influence of factor(s) represented.

On the contrary, the subcategory of geographical knowledge and skills is rather uniform despite the number of factors it includes. The majority of them characterize knowledge and skills directly linked to cartography. Meteorological knowledge is the only proven (and also tested) specific factor related directly to one of the main geographical branches. Similarly, the math-related abilities and skills prevail among the statistically significant factors belonging to non-geographical abilities and skills.

Clarity of factors influence. Nevertheless, the unequivocal nature of the influence of the researched factors cannot be evaluated simply upon the basis of the number of studies which demonstrate the dependency of map skill level on them. After all, this number is substantially influenced by the number of authors who have decided to verify the influence of the given factors in their research. As such, factors, which are easy to identify within the framework of a study, or factors which influence is debatable from the point of view of previous theoretical and empirical studies, may appear relatively frequently.

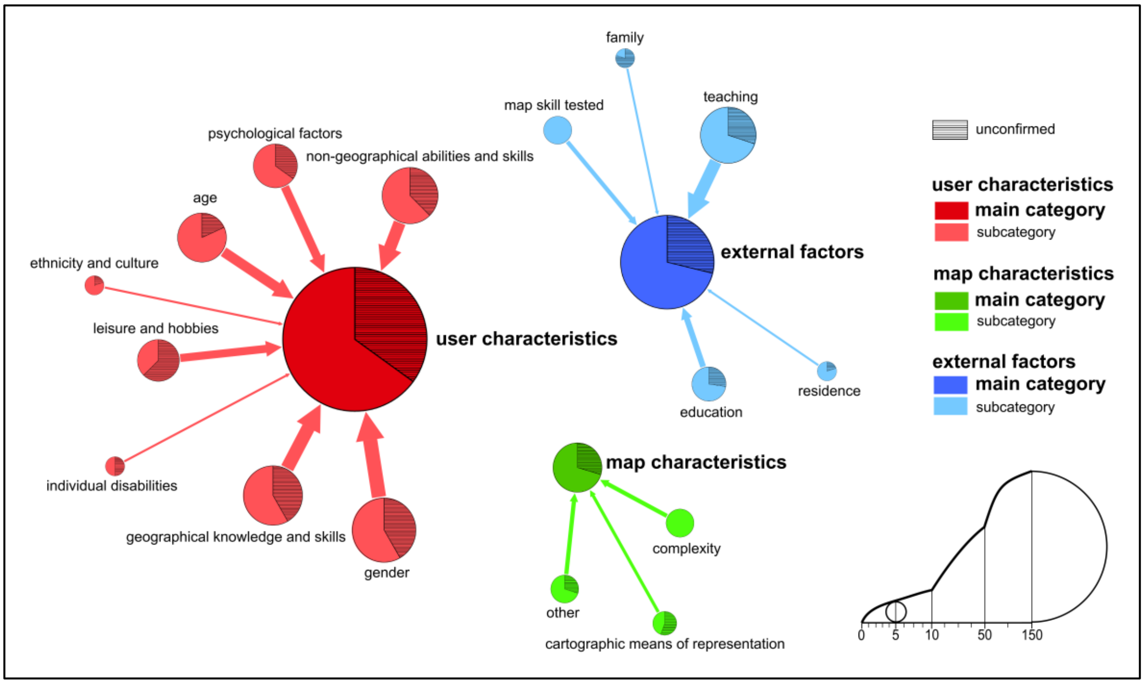

Figure 4. Structure of factor categories according to demonstration of their influence.

Note: Conceptual map includes all 93 identified factors. Radius of node (circle) represents the number of studies testing influence of factor(s) represented. Thickness of edge represents the number of studies proving influence of factor(s) represented.

Gender is a suitable example of such a factor. See Figure 4 above, which depicts in diagrams (using a grid) the share[5] of studies per identified subcategory which have not proven the influence of factors on map skill level. As is already clear from Table 3, the

[5]This share of the studies is not related to the overall number of studies in which the influence of the given factors was verified. In some studies, the influence of the given factor was only partially proven (e.g. only for one map type, only for some test tasks) and these cases were included among both the statistically significant and statistically insignificant factors (it was counted twice; see Table 3).

influence of gender on map skill level has been only partially proven in the large share of studies dealing with it. For example, the results of Chang & Antes (1987) study show that males performed significantly better than females in reference and topographic map use, but not in street map use. At odds with many other studies which found that male participants had a higher level of map skills than female participants (Eve et al., 1994; Hemmer et al., 2013; Lim, 2005; Malinowski & Gillespie, 2001), Aksoy (2013) found either no differences between male and female participants or that some operations falling under map reading were significantly in favour of female participants. Considered together, therefore, the results of the studies show that gender interacts with other factors which should be taken into account both when designing the study and when interpreting and comparing the results.

It is also apparent from Figure 4 that the debatable nature of factors' influence does not involve only the factor of gender. Subcategories of factors with an even higher share of studies in which their influence at the level of map skills is not significant can be found (leisure and hobbies, cartographic means of representation and individual disabilities). Nevertheless, unlike gender, they involve factors which have been investigated less frequently.

Table 3
Factors Which Influence Has Been Proven in 5 or More Studies

Factor (Main Category)	# Studies	# Significant	# Unconfirmed	Subcategory
Gender (U)	27	18	15	Gender
Age (U)	13	12	3	Age
Tested map skill (E)	8	8	0	Map skill tested
Spatial ability (U)	7	5	4	Non-geographical abilities and skills
Grade (U)	6	6	1	Age
Teaching method (E)	5	5	2	Teaching

Note: In some studies, the influence of the given factor was only partially proven (e.g., only for one map type, only for some test tasks) and these cases were included among both the statistically significant and not statistically significant (unconfirmed) factors. Legend: U – User characteristics, E – External.

On the other hand, the individual factors which influence has been investigated most frequently in the reviewed empirical studies include factors upon which participant map skill level depends quite significantly (see Table 3). As is apparent in the case of the tested map skill which was statistically proven to affect map skill level in all eight studies where it was taken into account (Grofelnik & Pap, 2013; Hanus & Marada, 2016; Ishikawa, 2016; Michaelidou et al., 2004; Ooms et al., 2015; Postigo & Pozo, 2004; Umek, 2003; van Dijk et al., 1994).

The difference in influence of identified factors based on map skill type. This finding points not only to the already discussed substantial diversity of individual map skills, but also indirectly to the importance of taking into account the type of map skills which level is investigated when selecting individual factors as independent variables for empirical study. Thanks to visual depiction of the synthesized study results (see Figure 5), clusters of influencing factors which seem to be characteristic for level of individual map skill types can be identified.

The factors which are particularly characteristic for maps, such as figure-ground contrast, number of classes in a choropleth map, form of element depiction etc., have only been investigated and proven as significant in the case of ability to read maps (Barker et al., 1986; Gilmartin & Shelton, 1989; Winn & Sutherland, 1989).

Only map background complexity has been proven to significantly influence the ability to analyse maps (Michaelidou et al., 2004). It can be said that map analysis especially involves factors which can be generally summarised as being associated with spatial abilities and skills or spatial imagination (general spatial reasoning, previous experience of a spatial task and the method of landform representation) (Hemmer et al., 2013; Ishikawa, 2016; Liben et al., 2013; Malinowski & Gillespie, 2001; van Dijk et al., 1994).

Factors specific to map drawing also correspond to the characteristics of this type of map skill. Map drawing especially involves factors associated with experience of mapmaking and with the cartographic expertise of the participants in general (field mapping strategy, mapping expertise, map-reasoning level and prior knowledge/understanding of the map concept) (Baker et al., 2012; Gerber, 1984; Harwood & Usher, 1999; Shin, 2007).

Map drawing tends to be omitted in some theoretical and also empirical works when individual map skill types are distinguished and described (e.g., Kimerling et al., 2009; Liebenberg, 1998; van Dijk et al., 1994; Wiegand, 2006). Presumably, their focus on the use of an already created map is the cause. Moreover, as already mentioned, the reviewed studies identifying map drawing skills frequently substantially differ in methodological approaches chosen. Notwithstanding the difference, a considerable amount of factors has been verified to influence both the map drawing skills and some of the skills related to the map use (e.g., spatial ability, teaching method) as is apparent from Figure 5.

Even factors which according to the reviewed studies significantly influence all four types of map skill can be identified. These include gender, age, grade, expertise in geography, and possession of an atlas (from user characteristics); map type (map characteristics); map skill training, collaborative teaching and the academic major (external factors). Given the generally high number of studies verifying the influence of gender and age, it is no surprise that these factors have stronger links to individual types of map skills (Figure 5).

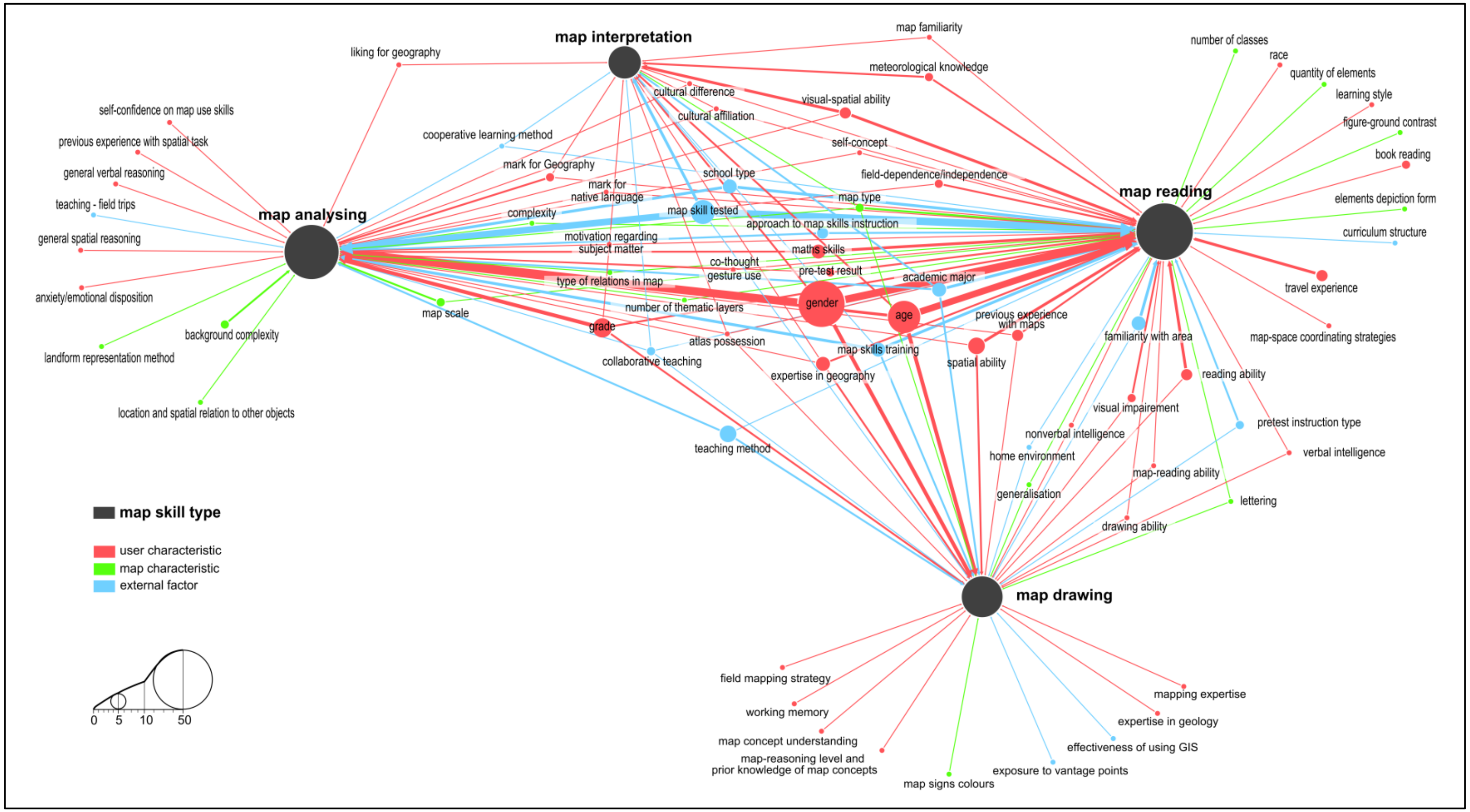

Figure 5. Factor effects in relation to tested map skill type.

Note: Radius of node (circle) represents the number of studies proving factor significance. Thickness of edge between factor and map skill type represents the number of studies proving factor significant influence on given map skill type.

Discussion

The paper has employed a literature review in order to provide researchers interested in the topic of map skills with a general overview of the current state of knowledge in the field. Specifically, the review has focused on three perspectives, i.e., terminology, methodological approaches, and factors and their effect on map skill level.

The strengths and limitations of this review and its implications for future research are discussed with a focus on gaps in the field of map skill research.

Strengths and Limitations

The authors are unaware of any other systematic review synthesising empirical studies focusing on map skills. The previous thematically close reviews focused specifically on only one or a few specific aspects of these skills (from the perspective of an independent variable tested or a methodological approach used). Or on the contrary, they pursued more general aim in terms of research topic covered (e.g., Gilmartin & Patton, 1984; Krassanakis & Cybulski, 2019; Lauer, Yhang, & Lourenco, 2019; Zadrozny, McClure, Lee & Jo, 2016).

Despite the fact that a relatively substantial number of empirical studies has been identified and analysed in this review, it is possible that other suitable studies missed the criteria of the literature search and have therefore not been included. This may be due to the chosen bibliographical databases, the limitation of the review to only peer-reviewed articles written in English or the keywords used during the searches.

As described above, substantial diversity exists in the terms used for the skills which the user employs when using or designing maps. This diversity increased the difficulty of searching for relevant studies. Despite the authors' endeavours to include as keywords all of the terms commonly used for these skills (map skill, map reading, cartographic skill, map interpretation, map understanding, map use skill and mapping skill), subsequent analysis of the discovered studies has shown that this list is far from being exhaustive.

The terminological diversity has probably been caused substantially by the different research focuses of the individual researchers, as map skills are a substantially interdisciplinary topic which is of interest to psychologists, educators, geographers, geographic didactics, cartographers and many other experts. The area of map skills therefore attracts the theoretical (and methodological) starting points of a substantial number of scientific disciplines. Moreover, the map skills research is less or more connected with the even broader research field of spatial abilities, spatial skills and spatial thinking that is not primarily linked to geography as map skills are. As examples of studies focused on these skills from a geography education perspective, see Huynh & Sharpe (2013), Lee & Bednarz (2012), and Jo, Hong, & Verma (2016).

Another aim of this review has been to assist researchers to focus on investigating or, on the other hand, eliminating the influence of significant factors within their selected research design. And moreover, to guide them towards research into those factors which influence has yet to be sufficiently investigated, or indeed investigated at all (see below Suggestions for future research).

Unfortunately, it has not been possible to conduct a meta-analysis of the reviewed studies and calculate average effect sizes of individual factors. This is due not only to the distinct heterogeneity of the studies but also to insufficient reports on methodologies and results in a considerable number of studies. In order to provide at least a partial overview of factors investigated, particularly those statistically confirmed as affecting map skills, synthesised conceptual maps were created. These maps clearly depict both the individual factors, their categorisation from the point of view of the main variables entering cartographic communication and the frequency of confirmation of their influence.

The number of factors identified (93) substantially outnumbered the number of studies identified (67) and once more indicated the overall breadth and associated problematic nature of this research topic. Many factors were investigated in only one study and it is therefore probable that the inclusion of a given factor among those which do or do not influence map skills partially depends on the research design selected by the authors. Given this, it is not possible to generalise and it is necessary to become more closely acquainted with each specific study (see the Appendix, where the main outcomes for each study are stated together with the study's basic characteristics).

It is similarly impossible to unambiguously assess factors' influence based merely on the number of studies in which that influence has been proven to be significant. The frequency reflects the "popularity" of the individual factors among authors to a certain extent. It is therefore also important to look at how many studies investigated the factor but did not prove the influence of the factor on map skill level, especially in the case of frequently investigated factors. As such, Figure 4 and Table 3 indicate that, unlike age/grade and map skill tested, which influence is relatively unambiguous, gender (the most frequently investigated factor) is a highly debatable factor (see also Gilmartin & Patton, 1984; Wiegand, 2006).

Similarly, it is impossible to unequivocally designate which factors must be included in the research design when testing only some or even one specific map skill based on our analysis. This is especially true of skills falling under map interpretation because no empirical study has independently investigated them. Nevertheless, clusters of factors appear in the case of the remaining three types of map skills, despite the connectedness and non-specific nature of some research with regard to the tested types of map skills. These clusters may be at least partially typical for these skill types (see Figure 5) and therefore serve as a guide to researchers when designing future empirical studies.

Despite these limitations, this review provides a number of important findings and conclusions, thanks to which it is possible to propose recommendations for further empirical studies into map skills.

Suggestions for Future Research

As already stated, the area of map skills is wide-ranging, both in specific skills needed for working with maps and in factors entering into the process of the development and/or use of these skills. It is therefore not possible to encompass this topic fully in a single empirical study, let alone identify the level of all specific map skill operations and verify the influence of all potential factors.

Suggestions related to map skills investigated and terms referring to them. This review illustrates a need to use clear terminology and distinguish individual operations with a map based on their cognitive complexity and typology of map skills when planning research. Map work as such can be divided into understanding of map concepts and map skills, which are further divided into four types (of differing cognitive difficulty): reading, analysing, interpreting, and drawing. This proposed typology that is based on both theoretical works and empirical studies should be used to specify the research subject enabling comparability of results.

With respect to the map skill tested, a relatively low number of studies aim to verify level of map interpretation skills (e.g., to critically evaluate a map and to formulate conclusions and predictions based on a map). As such, map skills imposing the least cognitive demands are investigated most frequently (map reading – recognition, understanding and evaluation of symbols and determination of locations) along with those considered important in everyday life (map analysis – way-finding, navigation). Nevertheless, it is the map interpretation that is becoming more and more important in today's world where we are facing a huge amount of (irrelevant and even false) information that can be also depicted on maps of differing cartographic quality. Therefore, research specifically devoted to the students' level of map interpretation skills and factors influencing them is of great importance.

In general, individual studies would be of greater benefit if they focused more closely on specific (types of) map skills or if they at least considered differences in the map skills tested when analysing results and verifying the influence of the factors under investigation. Thereby testing the existence of this dependency separately for different (types of) map skills as factor influence varies by map skill. For the same reason, it is very important for authors to explicitly define the skills investigated or refer to the literature on which the definition concepts are based.

Suggestions related to methodological approaches chosen. Just as it is necessary to theoretically frame the researched map skills and the factors influencing them, so it is essential to report methodologies and results clearly and in detail in order to build a base for future research grounded in previous research designs and findings (similarly Downs (1994) in terms of geography education and National Research Council (2006) in terms of spatial thinking). No matter how much this may seem a matter of course, our analysis has shown many articles fail to meet this standard. In order to lessen the risk of bias in empirical studies and, furthermore, to enable investigation of the same research questions using the same methodologies, but with different participants in different geographical and educational settings, it is necessary for authors to publish their complete research tool in their papers or appendices, provided the publisher and the nature of the research instrument so allow.

Our synthesis also shows that authors have preferred quantitative methods of data collection. Specifically, they make frequent use of tests mostly created by themselves comprising multiple-choice questions and maps based on which the questions are answered to identify level of map skills. Map skill research, particularly its international comparability, would be improved by the creation of standardized tests of map skills suitable for use in different national or international contexts (similarly Downs (1994); National Research Council (2006)). The inspiration can be found in recent endeavours to design a standardized test for measuring (geo) spatial thinking (Huynh & Sharpe, 2013; Lee & Bednarz, 2012).

Moreover, as Zadrozny, McClure, Lee & Jo (2016, p. 229) have stated, "collecting and analysing both quantitative and qualitative data proves to be beneficial in improving various aspects of research in the field of geography education" in general. A mixed methodology (e.g., questionnaire with follow-up interviews, map sketching with think-aloud method, and video recording or eye-tracking experiment with retrospective think-aloud protocol) would enable researchers to acquire both an overview of the general level of the map skills in the given population and a deeper insight into the topic. Specifically, there is a substantial lack of studies focused on bottlenecks or misconceptions which hamper map skill development, or strategies used when solving tasks with maps or drawing a map. For these research questions, the use of eye-tracking technology that is already substantially popular in cartographic research in general can be of particular benefit (for examples of relevant research see Çöltekin, Fabrikant, & Lacayo, 2010; Havelková & Hanus, 2019; Kim, Kim, Shin, & Ryu, 2015).

Suggestions related to factors tested. A further possibility for the development of knowledge in this research area can involve the abandonment of "traditional" factors such as age and gender. With exception of cases where the influence of these, otherwise most frequently selected, factors has not yet been investigated and researchers intend to study map skills from an as yet insufficiently described point of view. On the basis of this review of individual types of map skills, factors which have been considered in only a small number of studies, but which influence, based on the conclusions of these studies, would appear to be significant, include:

- map reading: familiarity with mapped area, factors describing map design, factors related to teaching – teaching method used in geography education or specifically for map-skill development;
- map analysis: factors characterising spatial ability and imagination, maths skills, factors describing map complexity;
- map interpretation: factors falling under geographical knowledge and skills;
- map drawing: factors related to teaching – teaching method used in geography education or specifically for map-skill development, previous experience with maps and prior cartographic knowledge.

Moreover, it is possible to focus on further studies concerning factors which influence has so far been verified for only some map skills and to verify whether the level of the remaining map skills also depends upon them. Such possibilities based on this review include, for example:

- map analysis: factors falling under geographical knowledge and skills, familiarity with area;
- map interpretation: previous experience with maps and prior cartographic knowledge, spatial abilities and skills, familiarity with area;
- map drawing: the type of school (e.g., school specialization, type of educational programme), spatial ability, math skills.

It would also be incorrect to assume that all factors which may cause differing levels of map skills have been identified in the studies. Based on theoretical studies, empirical research from related fields and factors identified in this review, the following factors present themselves in this review as ones to which experts in this field should devote their research:

- User characteristics:
  - Analytical and statistical reasoning,
  - Strategy used for problem-solving,
  - Graphicacy,
  - Misconceptions in cartography,
- Map characteristics:
  - Comprehensibility/presence of legend,
  - Map composition,
  - Map cartographic/content accuracy,
  - Degree of abstraction of theme/phenomenon/means of expression,
  - Orientation of map in relation to cardinal directions,
  - The selected cartographic projection,
- External factors:
  - Curricular requirements,
  - Time limit,
  - Teacher's learning and teaching style.

Conclusion

As the results have shown, level of map skills is affected by a wide range of factors. The majority of factors identified relate to the map user. Moreover, some are also among the most frequently proved to be significant factors (gender, age and grade). Nevertheless, there are also external factors and factors relating to the map characteristics which also have an effect on map skills (e.g., map skill tested, teaching method and map complexity). As map skill tested is one of the key factors, it is not surprising that several factors which seem to be specific to particular map skill types have been identified.

The results of this review could be of benefit not only as an overview of existing research in the map skill field but also as a guide to formulate the research design concept of future studies. The results can be of particular assistance when designating research goals. Specifically, they can be helpful in selection of map skills to be tested, i.e., with regard to awareness of cognitive and content differences between individual map operations. And moreover, in selection of factors to be investigated as independent variables explaining differences in map skill levels. Furthermore, the review of the used methodological approaches can be an inspirational resource for experts when selecting and creating their own research instruments.

Besides its benefits for researchers devoted to the issue of map skills, this review can be of use to journal editors. Eligible reviewers for newly submitted manuscripts aiming to investigate map skills can be found among the authors of reviewed studies. Moreover, the editors can efficiently check if the authors of the manuscript are well acquainted with the current state of art. And, specifically, if their study builds upon the results of the previous ones and focuses on yet to be sufficiently investigated perspectives. Besides that, the recommendations of this study related to the methodological approaches, research design, and research tools are of use for journal editors during evaluation of manuscript innovativeness and merits from the methodological point of view.

Even for the (geography) teachers, the results of the review can be beneficial as they indirectly provide several suggestions. The one of the most important is to incorporate in lessons activities comprising of use and design of maps that are diverse in every perspective (e.g., map type used, map skill developed, geography topic taught, etc.). This variety can enable any student to discover pleasure in working with maps. The teachers should as well be cautious of factors that can unnecessarily impede students' use of maps (e.g., lack of required math skills, high map complexity, and unfamiliarity with the depicted area). Additionally, knowledge of factors that can influence the process of map skill development or can have different impact on each student (i.e., resulting in different level of map skill among students in one class or school), can be critical and helpful in increasing the effectivity of teaching and in achieving the educational goals.

Finally, in concordance with the suggestions for researchers, teachers should devote more attention to developing map skills that are essential in today's world. Therefore, to cognitively demanding skills (map interpretation) besides others, e.g., critical evaluation of information depicted on a map, formulation of generalizations, conclusions, and predictions based on map(s).

References

Aksoy, B. (2013). Investigation of mapping skills of pre-service teachers as regards to various parameters. *Educational Research and Reviews*, *8*(4), 134–143.

Alhosani, N. M. D., & Yagoub, M. M. (2015). Geographic skills: a case study of students in the United Arab Emirates. *International Research in Geographical and Environmental Education*, *24*(1), 95–102.

Allen, G. L., Miller Cowan, C. R., & Power, H. (2006). Acquiring information from simple weather maps: Influences of domain-specific knowledge and general visual–spatial abilities. *Learning and Individual Differences*, *16*(4), 337–349.

Baker, K. M., Petcovic, H., Wisniewska, M., & Libarkin, J. C. (2012). Spatial signatures of mapping expertise among field geologists. *Cartography and Geographic Information Science*, *39*(3), 119–132.

Barker, P., Hailstone, M., & Simmonds, M. (1986). An experimental study of some effects of figure-ground contrast on the use of street maps. *Information Design Journal*, *4*(3), 212–220.

Battersby, S. E., Golledge, R. G., & Marsh, M. J. (2006). Incidental learning of geospatial concepts across grade levels: map overlay. *Journal of Geography*, *105*(4), 139–146.

Bausmith, J. M., & Leinhardt, G. (1998). Middle-school students' map construction: understanding complex spatial displays. *Journal of Geography*, *97*(3), 93–107.

Beatty, W. W., & Tröster, A. I. (1987). Gender differences in geographical knowledge. *Sex Roles*, *16*(11–12), 565–590.

Bein, F. L. (1990). Baseline geography competency test: administered in Indiana universities. *Journal of Geography*, *89*(6), 260–265.

Bein, F. L., Hayes, J. J., & Jones, T. G. (2009). Fifteen year follow-up geography skills test administered in Indiana, 1987 and 2002. *Journal of Geography*, *108*(1), 30–36.

Blades, M., Blaut, J. M., Darvizeh, Z., Elguea, S., Sowden, S., Soni, D., … Uttal, D. (1998). A cross-cultural study of young children's mapping abilities. *Transactions of the Institute of British Geographers*, *23*(2), 269–277.

Board, C. (1978). Map reading tasks appropriate in experimental studies in cartographic communication. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *15*(1), 1–12.

Board, C. (1984). Higher order map-using tasks: geographical lessons in danger of being forgotten. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *21*(1), 85–97.

Carter, J. R. (2005). The many dimensions of map use. *Proceedings of the XXII International Cartographic Conference*, (A Coruña), 1–9.

Catling, S. J. (2005). Developing children's understanding and use of maps. In C. Lee & C. C. Hung (Eds.), *Primary Social Studies: Exploring Pedagogy and Content* (pp. 220– 250). Singapore: Marshall Cavendish Education.

Chang, K. T., & Antes, J. R. (1987). Sex and cultural differences in map reading. *American Cartographer*, *14*(1), 29–42.

Clark, D., Reynolds, S., Lemanowski, V., Stiles, T., Yasar, S., Proctor, S., … Corkins, J. (2008). University students' conceptualization and interpretation of topographic maps. *International Journal of Science Education*, *30*(3), 377–408.

Çöltekin, A., Fabrikant, S. I., & Lacayo, M. (2010). Exploring the efficiency of users' visual analytics strategies based on sequence analysis of eye movement recordings. *International Journal of Geographical Information Science*, *24*(10), 1559–1575.

DiBiase, D., Corbin, T., Fox, T., Francica, J., Green, K., Jackson, J., … Van Sickle, J. (2010). The new geospatial technology competency model: bringing workforce needs into focus. *Journal of the Urban & Regional Information Systems Association*, *22*(2), 55–72.

Downs, R. M. (1994). The need for research in geography education: it would be nice to have some data. *Journal of Geography*, *93*(1), 57–60.

Drumheller, S. J. (1968). Conjure up a map – A crucial but much neglected skill. *Journal of Geography*, *67*(3), 140–146.

Eve, R. A., Price, B., & Counts, M. (1994). Geographic illiteracy among college students. *Youth & Society*, *25*(3), 408–427.

Fox, P., & Avramidis, E. (2003). An evaluation of an outdoor education programme for students with emotional and behavioural difficulties. *Emotional and Behavioural Difficulties*, *8*(4), 267–283.

Gerber, R. (1984). Factors affecting the competence and performance in map language for children at the concrete level of map-reasoning. *Cartography*, *13*(3), 205–213.

Gilmartin, P. P., & Patton, J. C. (1984). Comparing the sexes on spatial abilities: map-use skills. *Annals of the Association of American Geographers*, *74*(4), 605–619.

Gilmartin, P. P., & Shelton, E. (1989). Choropleth maps on high resolution CRTs, the effects of number of classes and hue on communication. *Cartographica*, *26*(2), 40–52.

Gökçe, N. (2015). Social studies in improving students' map skills: teachers' opinions. *Educational Sciences: Theory and Practice*, *15*(5), 1345–1362.

Griffin, M. M. (1995). You can′t get there from here: situated learning transfer, and map skills. *Contemporary Educational Psychology*, *20*(1), 65–87.

Griffin, M. M., & Griffin, B. W. (1996). Situated cognition and cognitive style: effects on students' learning as measured by conventional tests and performance assessments. *The Journal of Experimental Education*, *64*(4), 293–308.

Grofelnik, H., & Pap, I. (2013). Mastery of long-term cartographic knowledge and skills of new entry secondary level pupils. *Kartografija i Geoinformacije (Cartography and Geoinformation)*, *12*(19), 86–102.

Hamerlinck, J. D. (2015). Whither goes the "maps" course? Maintaining map-use concepts, skills, and appreciation in GIS&T curricula. *Cartography and Geographic Information Science*, *42*(1), 11–17.

Hanus, M., & Havelková, L. (2019). Teachers' concepts of map skill development. *Journal of Geography*, *118*(3), 101–116.

Hanus, M., & Marada, M. (2014). Mapové dovednosti: vymezení a výzkum. *Geografie*, *119*(4), 406–422.

Hanus, M., & Marada, M. (2016). What does a map-skills-test tell us about Czech pupils? *Geografie*, *121*(2), 279–299.

Harte, J., & Dunbar, C. (1994). *Skills in Geography*. Cambridge: Cambridge University Press.

Harwood, D., & Usher, M. (1999). Assessing progression in primary children's map drawing skills. *International Research in Geographical and Environmental Education*, *8*(3), 222–238.

Havelková, L., & Hanus, M. (2019). Research into map-analysis strategies: theory- and data-driven approaches. *Geografie*, *124*(2), 187–216.

Hemmer, I., Hemmer, M., Kruschel, K., Neidhardt, E., Obermaier, G., & Uphues, R. (2013). Which children can find a way through a strange town using a streetmap? – results of an empirical study on children's orientation competence. *International Research in Geographical and Environmental Education*, *22*(1), 23–40.

Henrie, R. L., Aron, R. H., Nelson, B. D., & Poole, D. A. (1997). Gender-related knowledge variations within geography. *Sex Roles*, *36*(9), 605–623.

Herrmann, D., & Pickle, L. W. (1996). A cognitive subtask model of statistical map reading. *Visual Cognition*, *3*(2), 165–190.

Higgins, J. P. T., & Green, S. (2011). *Cochrane handbook for systematic reviews of interventions*. Hoboken, N.J.: Wiley.

Hirsch, P. L., & Sandberg, E. H. (2013). Development of map construction skills in childhood. *Journal of Cognition and Development*, *14*(3), 397–423.

Hurst, P., & Clough, P. (2013). Will we be lost without paper maps in the digital age? *Journal of Information Science*, *39*(1), 48–60.

Huynh, N. T., & Sharpe, B. (2013). An Assessment Instrument to Measure Geospatial Thinking Expertise. *Journal of Geography*, *112*(1), 3–17.

Ishikawa, T. (2016). Spatial thinking in geographic information science: Students' geospatial conceptions, map-based reasoning, and spatial visualization ability. *Annals of the American Association of Geographers*, *106*(1), 76–95.

Jo, I., Hong, J. E., & Verma, K. (2016). Facilitating spatial thinking in world geography using web-based GIS. *Journal of Geography in Higher Education*, *40*(3), 442–459

Johnson, D. W., Johnson, R. T., Stanne, M. B., & Garibaldi, A. (1990). Impact of group processing on achievement in cooperative groups. *The Journal of Social Psychology*, *130*(4), 507–516.

Kastens, K. A., & Liben, L. S. (2010). Children's strategies and difficulties while using a map to record locations in an outdoor environment. *International Research in Geographical and Environmental Education*, *19*(4), 315–340.

Keates, J. S. (1996). *Understanding maps*. Harlow: Longman.

Kelly, J. T., Kelly, G. N., & Miller, R. B. (1987). Logo experience: Effects on map skills. *Computers in the Schools*, *4*(2), 57–64.

Kim, K., Kim, M., Shin, J., & Ryu, J. (2015). Eye-movement analysis of students' active examination strategy and its transfer in visuospatial representations. *Journal of Geography*, *114*(4), 133–145.

Kimerling, A. J., Buckley, A. R., Muehrcke, P. C., & Muehrcke, J. O. (2009). *Map Use: Reading and Analysis*. Redlands: ESRI Press Academic.

Koláčný, A. (1969). Cartographic information – a fundamental concept and term in modern cartography. *The Cartographic Journal*, *6*(1), 47–49.

Krassanakis, V., & Cybulski, P. (2019). A review on eye movement analysis in map reading process: The status of the last decade. *Geodesy and Cartography*, *68*(1), 191–209.

LaSpina, J. A. (1998). *The visual turn and the transformation of the textbook*. Mahwah, NJ: Routledge.

Lauer, J. E., Yhang, E., & Lourenco, S. F. (2019). The development of gender differences in spatial reasoning: A meta-analytic review. *Psychological Bulletin*, *145*(6), 537–565.

Lee, J., & Bednarz, R. (2012). Components of spatial thinking: evidence from a spatial thinking ability test. *Journal of Geography*, *111*(1), 15–26.

Leinhardt, G., Stainton, C., & Bausmith, J. M. (1998). Constructing maps collaboratively. *Journal of Geography*, *97*(1), 19–30.

Liben, L. S., & Yekel, C. A. (1996). Preschoolers' understanding of plan and oblique maps: the role of geometric and representational correspondence. *Child Development*, *67*(6), 2780–2796.

Liben, L. S., Myers, L. J., Christensen, A. E., & Bower, C. A. (2013). Environmental-scale map use in middle childhood: links to spatial skills, strategies, and gender. *Child Development*, *84*(6), 2047–2063.

Liebenberg, E. C. (1998). Teaching map use in a multicultural environment. *South African Geographical Journal*, *80*(2), 111–117.

Lim, K. Y. T. (2005). Augmenting spatial intelligence in the geography classroom. *International Research in Geographical and Environmental Education*, *14*(3), 187–199.

Livni, S., & Bar, V. (2001). A controlled experiment in teaching physical map skills to grade 4 pupils in elementary schools. *International Research in Geographical and Environmental Education*, *10*(2), 149–167.

Logan, T., Lowrie, T., & Diezmann, C. M. (2014). Co-thought gestures: supporting students to successfully navigate map tasks. *Educational Studies in Mathematics*, *87*(1), 87–102.

Malinowski, J. C., & Gillespie, W. T. (2001). Individual differences in performance on a large-scale, real-world wayfinding task. *Journal of Environmental Psychology*, *21*(1), 73–82.

Matthews, M. H. (1986). Gender, graphicacy and geography. *Educational Review*, *38*(3), 259–271.

McClure, R. W. (1992). *A conceptual model for map skills curriculum development based upon a cognitive field theory philosophy* (Unpublished PhD Dissertation). Oklahoma State University, Oklahoma.

McKissick, B. R., Spooner, F., Wood, C. L., & Diegelmann, K. M. (2013). Effects of computer-assisted explicit instruction on map-reading skills for students with autism. *Research in Autism Spectrum Disorders*, *7*(12), 1653–1662.

Michaelidou, E., Nakos, B., & Filippakopoulou, V. (2004). The ability of elementary school children to analyse general reference and thematic maps. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *39*(4), 65–88.

Moher, D., Liberati, A., Tetzlaff, J., Altman, D. G., & The PRISMA Group. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *PLOS Medicine*, *6*(7), 1–28.

National Research Council. (2006). *Learning to Think Spatially*. Retrieved from http://www.nap.edu/catalog/11019

Nelson, B. D., Henrie, R. L., Aron, R. H., & Poole, D. A. (1996). Academic achievement variations in geography: A public-parochial comparison. *Great Lakes Geographer*, *3*(2), 51–56.

Ooms, K., De Maeyer, P., Dupont, L., Van der Veken, N., Van de Weghe, N., & Verplaetse, S. (2015). Education in cartography: what is the status of young people's map-reading skills? *Cartography and Geographic Information Science*, *43*(2), 134–153.

Pedersen, P., Farrell, P., & McPhee, E. (2005). Paper versus Pixel: effectiveness of paper versus electronic maps to teach map reading skills in an introductory physical geography course. *Journal of Geography*, *104*(5), 195–202.

Pike, E., Blades, M., & Spencer, C. (1992). a comparison of two types of tactile maps for blind children. *Cartographica*, *29*(3–4), 83–88.

Postigo, Y., & Pozo, J. I. (1998). The learning of a geographical map by experts and novices. *Educational Psychology*, *18*(1), 65–80.

Postigo, Y., & Pozo, J. I. (2004). On the road to graphicacy: The learning of graphical representation systems. *Educational Psychology, 24*(5), 623–644.

Riding, R. J., & Boardman, D. J. (1983). The relationship between sex and learning style and graphicacy in 14- year- old children. *Educational Review*, *35*(1), 69–79.

Rittschof, K. A., Griffin, M. M., & Custer, W. L. (1998). Learner differences affecting schemata for thematic maps. *International Journal of Instructional Media*, *25*(2), 179–199.

Robinson, A. H. (1995). *Elements of Cartography*. New York: Wiley.

Roth, R. E. (2012). cartographic interaction primitives: framework and synthesis. *The Cartographic Journal*, *49*(4), 376–395.

Scevak, J. J., & Moore, P. J. (1998). Levels of processing effects on learning from texts with maps. *Educational Psychology*, *18*(2), 133–155.

Schlemper, M. B., Adams, J. K., & Solem, M. (2014). Geographers in business, government, and nonprofit organizations: skills, challenges, and professional identities. *The Professional Geographer*, *66*(3), 480–492.

Schulze, U., Kanwischer, D., & Reudenbach, C. (2011). Competence dimensions in a Bologna-oriented GIS education. In T. Jekel, A. Koller, AGIT-Symposium, & Geoinformatics Forum (Eds.), *Learning with GI 2011*. Berlin: Wichmann.

Shin, E. K. (2007). Using geographic information system (GIS) technology to enhance elementary students' geographic understanding. *Theory & Research in Social Education*, *35*(2), 231–255.

Sholl, M. J., & Egeth, H. E. (1982). Cognitive correlates of map-reading ability. *Intelligence*, *6*(2), 215–230.

Solem, M. (2017). Geography education, workforce trends, twenty-first-century skills, and geographical capabilities. In D. Richardson, N. Castree, M. F. Goodchild, A. Kobayashi, W. Liu, & R. A. Marston (Eds.), *The International Encyclopedia of Geography* (pp. 1–9).

Solem, M., Cheung, I., & Schlemper, M. B. (2008). Skills in professional geography: an assessment of workforce needs and expectations. *The Professional Geographer*, *60*(3), 356–373.

Sowden, S., Stea, D., Blades, M., Spencer, C., & Blaut, J. M. (1996). Mapping abilities of four-year-old children in York, England. *Journal of Geography*, *95*(3), 107–111.

Teck, L. B. (1989). Effects of practical experience and sequential skills in map reading. *Singapore Journal of Education*, *10*(1), 55–59.

Trifonoff, K. M. (1995). Going beyond location: Thematic maps in the early elementary grades. *Journal of Geography*, *94*(2), 368–374.

Ugodulunwa, C., & Wakjissa, S. (2015). Use of Portfolio Assessment Technique in Teaching Map Sketching and Location in Secondary School Geography in Jos, Nigeria. *Journal of Education and Practice, 6*(17), 23–30.

Umek, M. (2003). A comparison of the effectiveness of drawing maps and reading maps in beginning map teaching. *International Research in Geographical and Environmental Education*, *12*(1), 18–31.

Ungar, S., Blades, M., & Spencer, C. (1997). Strategies for knowledge acquisition from cartographic maps by blind and visually impaired adults. *Cartographic Journal*, *34*(2), 93–110.

van der Schee, J. A., & van Dijk, H. (1999). The effect of student freedom of choice in learning map skills. *International Research in Geographical and Environmental Education*, *8*(3), 256–267.

van Dijk, H., van der Schee, J., Trimp, H., & van der Zijpp, T. (1994). Map skills and geographical knowledge. *International Research in Geographical and Environmental Education*, *3*(1), 68–80.

Wiegand, P. (2006). *Learning and Teaching with Maps*. New York: Routledge.

Wiegand, P., & Stiell, B. (1997). children's relief maps of model landscapes. *British Educational Research Journal*, *23*(2), 179–192.

Winn, W. D., & Sutherland, S. W. (1989). Factors influencing the recall of elements in maps and diagrams and the strategies used to encode them. *Journal of Educational Psychology*, *81*(1), 33–39.

Wood, M. (1972). Human factors in cartographic communication. *The Cartographic Journal*, *9*(2), 123–132.

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.

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Appendix I.

Main characteristics and outcomes of reviewed studies.
Note: Only the research instruments used for map skill testing are stated. The explanation of used abbreviations: N – size of research sample, U – university students (i.e., approx. 18 years and older), CO – correlational study, EI – study with experimental design including intervention, E – study with experimental design (intervention not included), C – confirmed independent variable, NC – non-confirmed independent variable, C&NC – partially confirmed independent variable.

Study	Country	N	Age	Study design	Research instrument	Map skills tested	Investigated factors	Main outcomes
Aksoy (2013)	Turkey	199	U	CO	Achievement test	Reading, analysis, interpretation, drawing	C: department of student's study, academic major; C&NC: gender, possession of atlas	Understanding and evaluation of symbols went significantly in favour of female students. Gender was not a significant factor in the other tested map skills. Students possessing atlas scored significantly higher in all tested map skills except scaling skills. Geography and social studies pre-service teachers showed higher map skill level than primary education pre-service teachers. There were significant differences in map skill level in favour of pre-service teachers studying oral fields over those studying numerical fields.
Alhosani & Yagoub (2015)	UAE	80	U	CO	Test – drawing sketch map, questions with maps	Reading, analysis, interpretation, drawing	C: university grade, gender	Geographic skills of senior students were measurably better than those of freshmen and male students performed better than female students.
Allen, Miller Cowan, & Power (2006) – study 1	USA	89	U	CO	Achievement test	Reading, interpretation	C&NC: geographical knowledge, meteorological knowledge, visual-spatial ability; NC: gender	Meteorological knowledge was crucial to success in acquiring information from weather maps. The most important visual-spatial abilities for successful acquisition of weather information were spatial scanning and closure speed. Other visual-spatial abilities such as visual memory and closure flexibility did not impact performance significantly.
Allen, Miller Cowan, & Power – study 2	USA	61	U	CO	Achievement test	Reading, interpretation	C: meteorological knowledge, map familiarity, visual-spatial ability	Individuals with higher level meteorological knowledge outperformed those with lower-level knowledge. Participants had better results with weather maps of a familiar country. Level of visual-spatial ability correlated with performance.
Baker et al. (2012)	USA	67	U	CO	Field map drawing; GPS tracking	Drawing	C: expertise in geology, mapping expertise; C&NC: field mapping strategy, spatial ability, working memory	Both mapping and geological expertise correlated with quality of drawn maps (field mapping skills). Map accuracy correlated strongly with field thoroughness (time in field, distance walked, per cent of field area seen). Working memory and spatial ability significantly correlated with success for novices only.

Barker, Hailstone, & Simmonds (1986)	New Zealand	288	U	E	Achievement test	Reading	C: figure-ground contrast in street maps	Variations in map format (concerning figure-ground contrast) significantly influenced performance in the various map-reading tasks. Low contrast maps proved most difficult overall.
Battersby, Golledge, & Marsh (2006) – study 1	USA	148	11–12, 14–18, U	CO	Achievement test	Analysis	C: grade	University students were most successful, while middle school students were least successful.
Battersby, Golledge, & Marsh – study 2	USA	100	11–12, 14–18, U	CO	Achievement test	Analysis	C: grade	University and high school students performed significantly better than middle school students.
Bausmith & Leinhardt (1998)	USA	12	12–14	E	Map drawing; tape and video recording	Drawing	C: map-reasoning level and prior knowledge of useful map concepts; NC: collaborative teaching	Prior knowledge and experience played a role in success at map enlargement. Students with some knowledge of fundamental geographic principles (nature of longitude and latitude lines) showed some advantage when drawing maps. Results indicated that a relationship exists between student's recognition of map element interconnections and subsequent map accuracy.
Beatty & Tröster (1987) – study 1	USA	1257	U	CO	Fargo Map Test (FMT)	Drawing	C: gender, distance from home region	Males more accurately located places on maps of the United States or its various regions than females did.
Beatty & Tröster (1987) – study 2	USA	95	U	CO	Fargo Map Test (FMT)	Drawing	C: gender	Males more accurately located places on maps of the United States or its various regions than females did.
Beatty & Tröster (1987) – study 3	USA	128	U	CO	Fargo Map Test (FMT)	Drawing	C: gender; NC: working memory	Males more accurately located places on maps of the United States or its various regions than females did. Ability to learn a map was not correlated with performance on the localisation of places on maps of the United States.

Beatty & Tröster (1987) – study 4	USA	134	U	CO	Fargo Map Test (FMT)	Drawing	C: gender, expertise in geography, travel experience; NC: interest in maps	Performance on the localisation of places on maps of the United States was positively correlated with students' expertise in geography and travel experience.
Beatty & Tröster (1987) – study 5	USA	157	U	CO	Fargo Map Test (FMT)	Drawing	C: gender, visual-spatial ability; NC: handedness	Performance on the localisation of places on maps of the United States was positively correlated with students' visual-spatial ability.
Bein (1990)	USA	3382	U	CO	Competency based geography test	Not specified	C: age, travel experience, gender, academic major	Men scored higher than women. Scores increased with age of respondent and increased travel experience. Arts and science students scored significantly higher than students majoring in business, education and other disciplines.
Bein, Hayes, & Jones (2009)	USA	2278	U	CO	Competency based geography test	Not specified	C: travel experience, gender, ethnicity, prior education in geography NC: age	Significant performance differences persisted between gender and ethnic groups. Arts and science students performed significantly higher than students from education, business and other disciplines. Map skill level was positively affected by travel experience.
Chang & Antes (1987)	USA, Taiwan	202	U	E	Achievement test	Reading, analysis, interpretation	C&NC: gender, cultural difference, map type	Males performed significantly better than females in reference and topographic map use, but not in street map use. Significant differences were found in tasks involving representations of three-dimensional data, contour reading, directions and orientation. Gender difference existed in both cultural groups. Taiwanese participants outperformed US participants in general and specifically in topographic map reading.
Clark et al. (2008)	USA	118	U	EI	Achievement test	Reading, interpretation	C: systematic development of skills tested	Students made significant progress during the one semester of introductory physical geology laboratory – their strategies, schemas and assumptions improved and their confidence in their map reading abilities increased.

Eve, Price, & Counts (1994)	USA	313	U	CO	Achievement test	Reading	C: university grade, academic major, race, age, gender, book reading; NC: reading of geographical magazines, previous geography course, parents' education, parents travelling abroad, size of respondents´ community, travelling abroad	Senior students scored significantly better than freshmen in object localisation. Student performance was positively correlated with their grade point average and book reading. Engineering and natural science majors had higher overall geographic literacy than social science, business and nursing majors. Strongest correlates besides students' age was race (white students scored better than black or Asian students) and gender (males scored better than females).
Gerber (1984)	Australia	640	8–14	CO	Test W-1 of the Iowa test of basic skills; free-recall sketch map drawing; Solomon-Feldman map-reasoning test	Reading, drawing	C: map generalisation, lettering, map-reading ability, nonverbal and verbal intelligence; C&NC: colour in map signs, age, home environment, previous experience with maps, understanding map concept, drawing ability, spatial ability; NC: interest in maps	A strong link was found between children's map-reasoning and their competence and performance in map language. Of the three map design factors, map generalisation and map lettering influenced map-reasoning level, competence in map language, and performance in map language. Colour used in cartographic signs influenced competence and performance in map language. Map reading ability, nonverbal and verbal intelligence influenced all three tested map skills. Age, home environment, and drawing ability influenced the map-reasoning level and competence in map language. Previous experience with maps, understanding the concept of a map and spatial ability influenced children's competence and performance in map language.
Gilmartin & Shelton (1989)	USA	40	U	E	Achievement test	Reading	C: number of classes included in choropleth map	Accuracy rates decreased and reaction times increased as number of classes on map increased.
Griffin (1995)	USA	49	9–10	EI	Achievement test	Reading, analysis	C&NC: approach to map skills instruction, pre-test result, reading skills, maths skills	Effect of instructional method was significant in performance assessment of navigation and route planning skills. Situated cognition group, which developed their map skills in an environment similar to the one where performance assessment was measured, performed better. Students who performed better in pre-test and reading and maths skills tests also performed better in written post-test.

Griffin & Griffin (1996)	USA	45	9–10	EI	Achievement test	Reading, analysis	C&NC: approach to map skills instruction, pre-test result, field-dependence/independence	Effect of instructional method (conventional approach to map skill learning vs. situated cognition approach) was significant in immediate written test. Conventional group performed significantly better. Students who performed better on pre-test also performed better on immediate performance assessment and on immediate and delayed written assessments. Students who performed poorly on pre-test did not benefit as much from situated-cognition instruction as from conventional instruction. More field independent students had higher scores on immediate written and performance assessments.
Grofelnik & Pap (2013)	Croatia	241	15–16	CO	Achievement test	Reading, analysis	C: type of school, map skill tested	Differences in scores were noted between secondary level types of school programmes – pupils from science and mathematics programmes had highest scores, while pupils studying sports programmes had lowest. It was easier for pupils to calculate distance than to determine surface area on map. A difference in difficulty was also found within the group of map reading tasks – reading geographic coordinates was easier than reading contours.
Hanus & Marada (2016)	Czechia	1323	11, 15, 18	CO	Achievement test	Reading, analysis, interpretation	C: age, map skill tested, school type; C&NC: gender, liking for Geography, mark in Geography	Students completed tasks verifying their orientation in map and focusing on object localisation above-average achievement level. Low success was found in map scale use and information transfer between two different depictions of reality. Boys scored better than girls particularly in tasks oriented towards work with map scale. Grammar school students scored better in all tasks.
Harwood & Usher (1999)	UK	---	8–9	EI	Sketch maps drawing	Drawing	C: map skills training, gender; C&NC: familiarity of mapped route	Giving the children more experience of the route increased the "content" on their maps, but did not improve their mapping skills unless accompanied by teaching. Despite performing highly at the beginning, girls did not seem to respond to the teaching as positively as boys.
Hemmer et al. (2013)	Germany	328	8–12	CO	Standardized 15-page sheet for recording of spatial orientation in real space	Reading, analysis	C: Age, gender, spatial intelligence, previous knowledge of maps, previous experience in map use, self-concept; NC: interest in maps	Orientation competence of children in strange spaces grows with age. Boys scored higher than girls. Results showed that spatial intelligence (mental rotation) and previous experience in reading maps influenced map-based orientation competence. Children with positive self-concept concerning their ability to orient themselves in macro space achieved better orientation results.

Henrie et al. (1997)	USA	1564	12 to U	CO	Knowledge of Geography Test	Not specified	C: gender, age, hours of reading, ACT score; NC: travelling, watching geography programmes	Best predictors of geographic knowledge were hours of reading, ACT scores and gender (males outperformed females). Gender gap widened with increased education.
Hirsch & Sandberg (2013) – study 1	USA	60	6–7, 8–11	CO	Aerial maps drawing from frontal pictures	Drawing	C: grade; NC: gender	Children's ability to represent spatial relations of eye-level views in aerial maps develops significantly between first and third grades.
Hirsch & Sandberg (2013) – study 2	USA	37	6–7, 8–11	EI	Aerial maps drawing from frontal pictures	Drawing	C: exposure to vantage points, gender, grade	Children acquired and extended map skills during exposure to enhanced vantage points in both pictured views and actual blocks. Girls benefited more than boys from exposure to enhanced vantage points.
Ishikawa (2016)	Japan	41	U	CO	Achievement test	Reading, analysis, interpretation	C: map skill tested; C&NC: visual-spatial ability	Students mastered tasks oriented towards map reading. By comparison, their rate of success was lower and more differentiated when analysing and interpreting thematic maps. Students' spatial visualisation ability was related to frequency of their detecting spatial patterns in mapped phenomena and making statements by cross-referencing multiple maps, but not to any reasoning about the processes behind the observations.
Johnson et al. (1990)	USA	48	18–20	EI	Computer simulation with written materials	Reading, analysis, interpretation	C: cooperative teaching, method of cooperative learning	Students in three cooperative conditions performed better than those in individual condition. Combination of teacher- and student-led processing resulted in greater problem-solving success and achievement in cooperative conditions than did only teacher-led processing or no processing.
Kastens & Liben (2010)	USA	34	9–10	CO	Response sheets – object localization on map via spatial orientation in real space; clue reports	Analysis	C: object localization and spatial relation to other objects	Different object (flag) localisations evoked different strategies; some of them strongly advantaged participants who used multiple elements of spatial information.

Kelly, Kelly, & Miller (1987)	USA	202	10–12	EI	Achievement test	Analysis	C&NC: teaching method, gender, grade	After one school year of Logo software instruction, treatment group outperformed control group in three of the four measures, one of which was statistically significant. Score difference in relative position skills section was significantly higher for girls than for boys. By contrast, boys had significantly higher scores than girls and fifth graders outperformed sixth graders in self-orientation and spatial relationships.
Leinhardt, Stainton, & Bausmith (1998)	USA	46	12–13	E	Map drawing; interview	Drawing	C: collaborative teaching	Students working in small groups had slightly better understanding of map concepts than those working individually.
Liben et al. (2013)	USA	40	9–10	CO	Object localization via orientation in real space; report of strategies; object localization via computer mapping	Analysis	C: Spatial-test scores, map–space coordinating strategies; NC: gender	Spatial-test scores predicted scores on both mapping tasks. Participants who spontaneously acted to establish map–space–self correspondences performed better on mapping task.
Liebenberg (1998)	South Africa	327	U	CO	Achievement test	Reading, analysis, interpretation	C: Cultural affiliation; NC: years of instruction in geography at university	In general, white students outperformed African and Asian students in map skills test.
Lim (2005)	Singapore	106	14–15	EI	Pre- and post-orientation test	Analysis	C: gender, teaching - field trips	Male students scored significantly better in matching panoramic scene with map of the same area.
Livni & Bar (2001)	Israel	76	9–10	EI	Achievement test	Analysis	C: teaching method	Trial group students showed high mastery of decoding topographic heights and interpreting 3D landforms from physical maps.

Logan, Lowrie, & Diezmann (2014)	Australia	43	10–12	CO	Videotaped interview during navigation and map task solution	Reading, analysis	C: use of co-thought gestures	Gesturing was most influential when students encountered unfamiliar tasks or when they found tasks spatially demanding.
Malinowski & Gillespie (2001)	USA	978	U	CO	Object localization on map via spatial orientation in real space	Analysis	C: gender, previous experience with spatial tasks, maths skills, self-confidence on map-use skills, anxiety/emotional disposition; NC: feelings of task importance	Males found, on average, more points during spatial task than females overall. Wayfinding success was positively correlated with experience with spatial tasks, maths skills, self-confidence on map use skills and negatively correlated with anxiety.
Matthews (1986)	UK	59	6–11	CO	Sketch maps drawing	Drawing	C: gender, age	From the age of eight onwards, boys' recall of maps was richer in detail, more integrated in form and more accurate than that of girls of a similar age.
Michaelidou, Nakos, & Filippakopoulou (2004) – study 1	Cyprus	437	8–12	CO	Achievement test	Reading, analysis	C: map background complexity; C&NC: map scale; NC: gender, attended school	Mean score for large-scale map was significantly higher than for small-scale map for Grade 3, but opposite results were identified for Grade 5. Students in each grade performed significantly better when extracting spatial relationships from political map than when extracting such relationships from physical map with its more complex background.
Michaelidou, Nakos, & Filippakopoulou (2004) – study 2	Cyprus	1118	8–12	CO	Achievement test	Reading, analysis	C: number of thematic layers, map scale, map background complexity, map skill tested; NC: gender	Students scored higher when they worked with simplified physical map. Elimination of thematic layers from small-scale maps resulted in simplistic representations which had a negative influence on performance of older students. In the case of city map, higher number of layers was better for entire sample. Students' performance when extracting spatial relationships was higher on small-scale map. Relationships between three attributes at one location and spatial distribution relationships of two attributes were more difficult for children to extract than simpler relationships.

Michaelidou, Nakos, & Filippakopoulou (2004) – study 3	Greece	718	8–12	CO	Achievement test	Analysis	C&NC: method of landform representation; NC: gender, school	Mean score for determining steepest slope and elevation of hills was higher on map with hill shading than maps with contours.
Nelson et al. (1996)	USA	398	12–18	CO	Achievement test	Not specified	C: type of school; NC: gender, parental education, travel experience, education, reading, TV viewing, hobby preferences, possible teaching career	Church school students performed better than their state school counterparts at both school levels.
Ooms et al. (2015)	Belgium	528	11–18, > 18	CO	Achievement test	Reading, analysis	C: age, familiarity with area, map skill tested; C&NC: gender, NC: youth club membership, colour blindness, dyslexia	Results showed rising trend in pupils' scores with increasing age. Gender might be considered an influencing factor for pupils (depending on scoring system). Both students and pupils obtained good results in cognitively easier tasks (i.e. symbol recognition) and tasks not requiring advanced cartographical knowledge.
Pedersen, Farrell, & McPhee (2005)	USA	168	U	E	Achievement test	Reading, analysis, interpretation	NC: digital/paper map, learning style	Students' performance did not differ significantly with use of paper or electronic maps. Neither was their performance related to the learning style.
Postigo & Pozo (1998)	Spain	300	13, 15, 17, U	EI	Achievement test; sketch map drawing	Drawing	C: age; C&NC: method of instructions, expertise in geography	Improvements in achievement were detected as students' ages and educational levels increased, however, the significance of these improvements varied according to kind of information (implicit, explicit and conceptual) involved in map-learning task. Expertise in geography only influenced learning of implicit and conceptual information.
Postigo & Pozo (2004)	Spain	100	12, 14, 16, U	E	Achievement test; spatial ability test	Reading, analysis, interpretation	C: age, map skill tested; C&NC: geographical knowledge; NC: spatial skills	Map skill performance depended on students' age and educational level. Groups of adolescents performed better on explicit information tasks (map reading) than on implicit (map analysis) or conceptual (map interpretation) tasks. On the other hand, geography undergraduates obtained their best results on implicit and conceptual information items, while performing poorly on explicit tasks.

Riding & Boardman (1983)	UK	96	14	CO	Achievement test	Reading	C&NC: gender, field-dependence/independence, verbal/imagery learning style	Being field-independent rather than field-dependent resulted in better performance in all aspects of map reading for boys, but made no difference for girls. There was no difference between boys and girls in symbol translation, but extrovert boys (verbalisers) did better than extrovert girls in map-photograph correlation and ambivert girls were superior to ambivert boys in view identification.
Scevak & Moore (1998) – study 1	Australia	86	15–16	EI	Achievement test; map recall	Reading	C&NC: reading ability, type of pre-test instruction	Students with high reading ability scored significantly higher in event recall than low ability students and the Question Map cue group scored significantly higher than the Question Map group (whose text did not contain any cues to look at the map).
Scevak & Moore (1998) – study 2	Australia	94	15–16	EI	Achievement test; map recall	Reading, drawing	C: type of pre-test instruction; C&NC: reading ability	Students cued to mark information from text to map scored significantly higher in place name recall than students in group cued to look at map and group not cued about map. Students with higher reading ability scored higher in event recall test. Subjects in both Map draw and Map cue groups scored significantly higher than control group in same test.
Shin (2007)	USA	15	9–10	EI	Videotaped and audiotaped work with GIS; interview; field notes; sketch map	Drawing	C&NC: effectiveness of using GIS in geography lessons	Results showed overall improvement in students' map skills after three geography lessons with use of GIS: use of aerial views; use of map boundaries; use of colour; use of map keys; accuracy of maps.
Sholl & Egeth (1982)	USA	49	U	CO	Relief Format Assessment Test (RFAT)	Reading	C: mathematical aptitude; NC: visual-spatial ability, hemisphericity	Results suggested that solving map-reading problems is primarily dependent upon verbal-analytic and, to a lesser extent, visual-spatial abilities.
Teck (1989)	Singapore	144	12–13	EI	Pre- and post-achievement test	Reading	C: teaching methods, curriculum structure	Pupils are more likely to achieve better overall performance and retention if they follow a curriculum structure with a hierarchical sequence and practical-learning.
Trifonoff (1995)	USA	74	7–8	CO	Achievement test (timed questions)	Interpretation, drawing	NC: type of symbols, map scale	Results indicated that thematic maps were appropriate for this age level; statistical test did not identify best symbol type or scale appropriate for this age level.

Ugodulunwa & Wakjissa (2015)	Nigeria	101	15–18	EI	Geography achievement test (GAT) – maps drawing, place localization on maps	Drawing	C: approach to map skill teaching; NC: gender	Portfolio assessment helped in improving students' performance in map sketching and localisation more than discussion method.
Umek (2003)	Slovenia	43	7–8	EI	Pre- and post-test including map drawing	Reading, drawing	C: teaching method, gender, map skill tested	Group using drawing method achieved better overall results in final test and drawing tasks than group using reading method. Boys were better in initial test and all its parts; girls were much better in post-test. Reading maps is easier than drawing them.
Ungar, Blades, & Spencer (1997) – study 1	UK	41	7–13	E	Video- and audio-taped pre- and post-test map reconstruction with think-aloud method	Reading	C: visual impairment; C&NC: age	Children with visual impairment and sighted children used different strategies when working with maps and these strategies also differed according to the children's age.
Ungar, Blades, & Spencer (1997) – study 2	UK	24	U	E	Video- and audio-taped pre- and post-test map reconstruction with think-aloud method	Reading, drawing	C: visual impairment, map type	Tactile map readers produced poorer reconstructions of both maps used. Readers with visual impairment used different strategies than sighted readers when working with maps. Blind readers used a more fragmentary approach – focusing on individual elements. Types of information recalled from town map and school map differed.
van der Schee & van Dijk (1999)	Netherlands	334	12–13	EI	Pre- and post-achievement test	Reading, analysis	C: map skills training, amount of freedom of choice during map skill training, motivation with regard to subject matter	More motivated students performed better in map skills test. Students in free choice training module performed better in map skills post-test than students in fixed choice order module group. However, the latter group still performed better than control group which had no map skill training.

van Dijk et al. (1994) – study 1	Netherlands	321	12–13	CO	Achievement test	Reading, analysis	C: map skill tested, map complexity, type of relations in map, type of school; NC: gender	Higher percentage of students were able to classify phenomena on a map than to relate phenomena. Easiest thing was to identify phenomena. Students' scores decreased when number of geographical spatial distributions or areal differentiations was increased. Students had significantly higher scores in tasks dealing with vertical relationships on map. Students from schools for general senior secondary education and pre-university education scored significantly better than students at schools for pre-vocational education and general junior secondary education.
van Dijk et al. (1994) – study 2	Netherlands	51	12–13	CO	Achievement test	Analysis	C: general verbal/spatial reasoning; NC: score in language test	Strong correlations between the two parts of the map skills test (spatial interactions, spatial distributions and areal differentiation) and between the two parts of the general reasoning test (verbal, spatial) were found.
van Dijk et al. (1994) – study 3	Netherlands	51	12–13	EI	Pre- and post-achievement test	Reading, analysis	C: method of map skills teaching, report-mark for Dutch/Geography/Mathematics	Progress of students attributable to computer programme was apparent. Experimental group in particular made significant improvement in the most difficult tasks. High correlation between map skills scores and report-marks for Dutch, Geography and Mathematics was found. Most significant correlation was with Mathematics report-mark.
Wiegand & Stiell (1997)	UK	111	5–11	E	Map drawing	Drawing	C: age	Children up to age of 8 drew what they knew rather than what they saw. Youngest children drew hills in elevation, whilst those in middle primary years drew simple plans or plans embellished with form lines in an attempt to provide more information about slope. Older children attempted contours with varying degrees of success.
Winn & Sutherland (1989)	USA	178	14–17	E	Pre- and post-test (map recall and map drawing)	Reading	C: quantity of elements on maps C&NC: form of element depiction; NC: familiarity of materials	Less able subjects remember lists and locations of elements better, select more useful strategies and use those strategies to better advantage when elements are shown as drawings rather than as squares. More able subjects are not affected in these ways by variations in form of elements.