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*Review Article*

# Learning and teaching through inquiry with geospatial technologies: A systematic review

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**Abstract:** The development of digital skills among pupils at the lowest levels is already an important part of education. The implementation of geospatial technologies (GST) is one of the ways to build and deepen these skills in primary and secondary schools. The use of these technologies is possible through an inquiry approach. This paper aims to identify the knowledge gaps on the issue of linking GST and inquiry in primary and secondary school learning and teaching. This article presents findings from 36 English-language empirical research studies published up to 2020 in the Web of Science and Scopus databases. The systematic review focuses mainly on the methods used and the results of the studies. The analysis of the studies shows that the methods used are strongly heterogeneous, and qualitative and quantitative methods are similarly represented. The results of the studies indicate that prior teacher preparation is necessary for this type of learning and teaching, and that students develop digital competencies and knowledge related to GST and the topic of the learning task that is addressed using these technologies. This systematic review presents recommendations and pitfalls for learning and teaching through inquiry with GST, but also recommendations for future research.

**Keywords:** geospatial technologies, inquiry, systematic review, primary education, secondary education.

**Highlights:**

- Prior teacher preparation is necessary for teaching through inquiry with GST.
- Students develop digital literacy and knowledge related to GST and topic of learning.
- GST and inquiry can be incorporated into geography, but also science or social science.
- Researchers focus on GST rather than inquiry

## 1. Introduction

The pressure in education to develop digital competencies is considerable, and the era of distance learning has shown that digital competencies are essential (Schultz & DeMers, 2020) and can be developed through geospatial technologies (GST) (Geraghty & Kerski, 2020).

GSTs enable the display, analysis, or measurement of spatial data (Fargher, 2017). They, therefore, play an important role in people's daily lives and can solve problems in various sectors of human activity, such as emergency services, transportation, agriculture, commerce, and urban planning (Kerski, 2008). These technologies can also be used at various levels of education (Schulze, 2021; Bednarz & Ludwig, 2007). Several studies have focused on evaluating the implementation of GST in education (e.g., Kerski, 2008; Jo, 2016). These studies show the benefits of GSTs in teaching, but also the barriers.

An effective way to incorporate GST into learning is through students' activities (Whyatt et al., 2022). This can be done by students as they solve problem-oriented tasks related to situations that may occur in real life. GST develops students' digital competencies and skills as well as their knowledge. Teaching that draws on these technologies, but that also invites independent problem-solving or self-inquiry, is regarded as a challenge in geography education (Piotrowska et al., 2019). It is also seen as a need and opportunity (Van der Schee et al., 2015), as it develops key competencies and skills that are necessary in this century (Hooft Graafland, 2018).

This systematic literature review extends the current state of knowledge in the area of GIS-based (geographic information system) learning (Mzuza & van der Westhuizen, 2019; Schulze, 2021) to include additional GSTs, and focuses on education in which the inquiry activity is included. It builds on Schulze's (2021) earlier systematic review, which gave an overview of studies between 2005 and 2014. This review pointed out that the methodological approaches in GIS education research, the factors and variables influencing this teaching, and the facets of competence are diverse. A review article by Mzuza and van der Westhuizen (2019) analysed skills gained and developed in teaching and learning with or through GIS such as problem-solving, spatial thinking, and self-directed skills.

The main aim of this paper is to review the research findings on learning and teaching in primary and secondary education with GST through inquiry and to identify knowledge gaps in this field.

## 2. Literature Review

### 2.1. Geospatial technologies in education

GSTs include geographic information systems (GIS), remote sensing (RS), and global navigation satellite systems (GNSS). Some authors use a sub-term – global positioning systems (GPS) – instead of the general term GNSS (e.g., Fargher, 2017). We classify GSTs as information technologies that generally work with geospatial data (Mísařová et al., 2021). The relationship between the basic concepts related to GST is depicted in Figure 1.

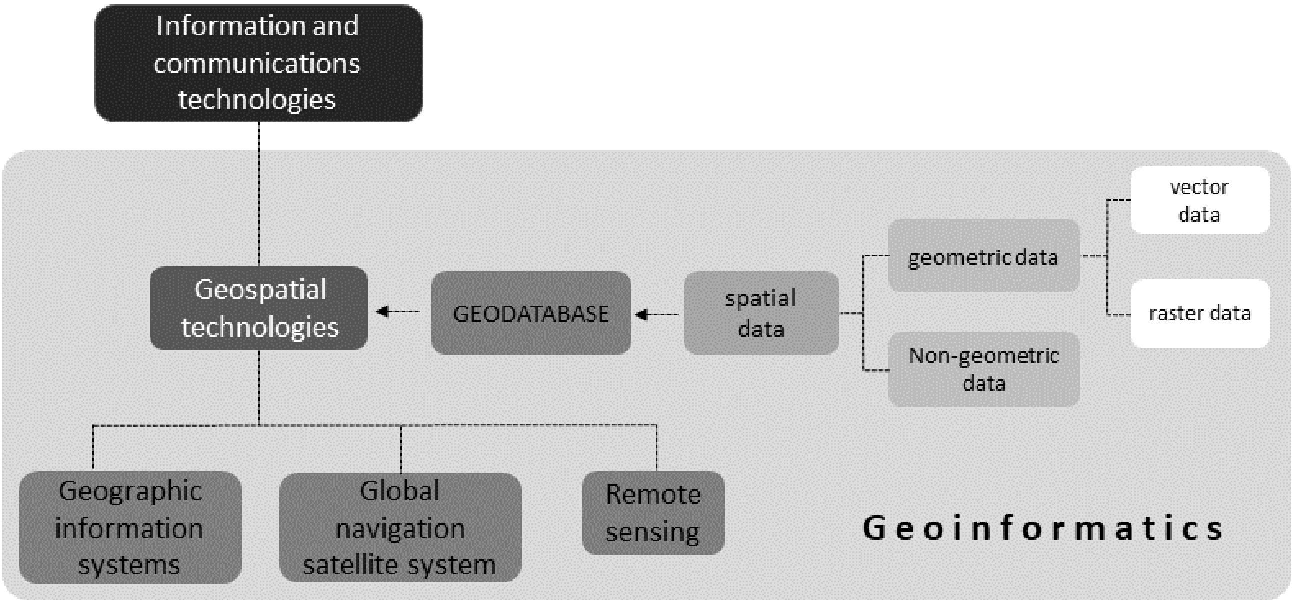


**Figure 1.** Relationship between basic concepts related to GST (Mísařová et al., 2021).

Working with spatial data and GSTs, in general, allows students to develop geospatial thinking. Therefore, these technologies should become part of the curriculum (Fargher, 2017). GSTs are particularly beneficial for geography education, but they also play an important role in other subjects. Piotrowska et al. (2019) identify GIS and GSTs in general as a challenge for geography education because technology brings new ways of seeing the world. Students using GIS to create maps claim that their mapping skills are expanding (Bednarz, 2004). Students can use digital devices to deepen their geographical knowledge and interest. Students' use of GIS develops problem-solving competencies (Bednarz, 2004), and promotes independence in their work (Whyatt et al., 2022). GIS can be used in cross-curricular learning and to develop field orientation, spatial perception, and digital literacy (Barnikel, 2015). GST develops the student's ability to work with a map and digital geospatial data (Mísařová et al., 2021). GIS has the greatest potential of all GSTs in teaching (Mísařová et al., 2021).

Two of the potential pitfalls of using GST in teaching are licensing issues and the lack of methodological materials, but online GST makes it easier to use and license (Hong, 2014). The covid-19 pandemic has resulted in a lot of materials and licenses that can be used in teaching with GST becoming available for free (Geraghty & Kerski, 2020). Another reason for hesitation may be the absence of GST in the national curriculum (Kerski et al., 2013). Teachers consider time as a constraint, both in terms of preparation and in terms of the use of technology in teaching (Hong, 2014). The knowledge of GSTs and the ability to work with them are also essential for teachers (Collins & Mitchell, 2018). However, it is also necessary for the teachers to have knowledge and skills in pedagogy and the subject, the so-called TPCK framework (Mishra & Koehler, 2006). This framework includes three knowledge domains: Technology (T), Pedagogy (P), and Content (C). This knowledge and these skills are acquired through various forms of education, such as workshops and summer schools (Höhnle et al., 2016). After completing the workshop, educators need to ensure long-term classroom implementation of GST by: including GST in the national curriculum (or some other curriculum documents such as Geography for Life); pre-service teacher geography and GIS intervention; and continuous follow-up and coaching (Collins & Mitchell, 2018).

### *2.2. Inquiry in education*

Contemporary teaching aims to produce individuals who will be able to solve unique problems that will move society forward (Hooft Graafland, 2018). Roberts (2013) adds that there is a need for students to learn independently and, in the process, discover new and unfamiliar knowledge. Inquiry is seen as an activity involving active learning about the world (Barnes & Todd, 1995). At the same time, knowledge is constructed about what we already know (Roberts, 2013). Knowledge cannot be taken as ready-made but must be actively developed (Barnes & Todd, 1995). These ideas correspond with constructivist theories of learning, which build on pragmatic pedagogy by Dewey (1929) and his theory of active learning, the social dimension of learning by Vygotskij (1978), and the social construction of reality by Piaget (1954). Dewey (1929) draws attention to the predominant emphasis on facts rather than thinking in education, and points out that it is necessary to learn with curiosity, and that learning is rooted in experience and reflection.

Constructivism underlies approaches to teaching in which the activity of inquiry is involved, such as inquiry-based learning, problem-based learning (PBL) (Oğuz-Ünver & Arabacıoğlu, 2011), and project-based learning. Rezba et al. (1999) propose four levels of inquiry based on how much information is provided to students and how much guidance is provided by teachers. The first level is a confirmation inquiry during which students know a question, procedure and solution of an inquiry. The second level is a structured inquiry a question and procedure are provided by the teacher, but the solution of the inquiry is not identified. At the next level – a guided inquiry students solve a research question given by the teacher. During the fourth and highest level of inquiry, – an open inquiry students formulate their own research question and investigate it through designed procedures.

Constructivist approaches are popular in teaching but it is necessary to ensure that lessons are not only focused on the process of learning, but also the content of learning (Kirscher et al., 2006). Teacher training and support from school leadership are necessary for the successful implementation of constructivist approaches to learning and teaching (Yeung, 2010)

Albion (2015) designated inquiry-based learning as a parent of problem-based learning and project-based learning. This means that problem-based and project-based learning are considered to be types of inquiry-based learning (Albion, 2015; Kirschner et al., 2006), in which collaboration between students is involved (Sproken-Smith, 2005). All these learning approaches involve self-directed learning, in which the student learns through a process of inquiry, often in collaboration with other students (Hmelo-Silver et al., 2007). The student should be able to apply the knowledge and skills learned. The teacher takes a back seat in the solution process and guides the student through the solution so that the main activity is up to the students. The teacher asks the student guiding questions that stimulate their thinking but do not lead directly to an answer (Roberts, 2013). Inquiry can be part of almost any school subject and can be also interdisciplinary, as it typically requires students' interactions with knowledge and methods (Oğuz-Ünver & Arabacıoğlu, 2011; Roberts, 2013). The 5E model of inquiry in science education can be useful for students to formulate a better understanding of scientific and technological attitudes, knowledge, and skills, and the teacher's coherent instruction. This model consists of the following phases: engage, explore, explain, elaborate, and evaluate (Bybee et al., 2006). In social studies, a model called Inquiry Arc is used, which is part of the C3 (College, Career, and Civic Life) Framework for Social Studies State Standards (NCSS, 2013). The aim of the C3 Framework is 'the call for students to become more prepared for the challenges of college and career is united with a third critical element: preparation for civic life…' (NCSS, 2013, p. 5). The Inquiry Arc has four dimensions: 1) developing questions and planning inquiries; 2) applying disciplinary concepts and tools; 3) evaluating sources and using evidence; and 4) communicating conclusions and taking informed action (NCSS, 2013, p. 17).

Problem-based learning is most often defined as a guided inquiry, which is one type of inquiry-based learning, but there are also claims that problem-based learning is nearly equivalent to inquiry-based learning (Kirschner et al., 2006; Roberts, 2013). The biggest difference between problem-based learning and inquiry-based learning lies in problem-solving, which is the core goal of the former method (Hmelo-Silver et al., 2007). Constructivist approaches are more effective for learning at higher cognitive levels (Yeung, 2010). One of the goals of science education is to develop and shape problem-solving skills. A problem task should represent a situation that students may encounter in life, and should easily capture their attention (OECD, 2004).

### *2.2. GST and inquiry in education*

It is possible to use technology in inquiry-based learning, but also in problem-based learning or other methods incorporating constructivist ideas (Albion, 2015). Digital technologies can be incorporated into the solution of learning tasks at a certain stage in the learning process to make the work easier or more efficient (Liu et al., 2021). One of these technologies can be GIS, which is a tool that allows for visualising, reading, creating, querying, summarising, manipulating, analysing, and presenting digital geodata quickly and flexibly (Favier, 2011). There are generally two approaches to implementing GIS in education. The first option is to acquire knowledge about GIS (learning about GIS), while the second option is to use GIS as a tool for solving geographic tasks (learning with GIS) (Rød et al., 2010). This applies to GST as well.

The relationship between inquiry and the use of GIS was described by Favier (2013), but teaching with GSTs is understood to be similar (Mísařová et al., 2021). In GST teaching, the role of teachers and pupils may change, but the focus on technology or geography may also change. The teacher can pass on theoretical knowledge about GST to pupils (for example define GST, describe how GSTs work and their use in practice) in which case the student would be a passive recipient of information about GST. The teacher can use GST to solve geographical topics, for example in the form of displaying maps on a data projector. If teaching is designed to be learner-centred and focused on both technology and geography, then an inquiry-based learning task can be solved through GST (Favier, 2013; Mísařová et al., 2021). GST can thus be used for data collection in the field, for organising, analysing or visualising geodata, e.g., creating a map (Mísařová et al., 2021).

## 3. Methodology

This review study aims to analyse empirical studies that have examined the inclusion of different GSTs in classrooms in which different constructivist approaches have been used. I was primarily interested in peer-reviewed papers that focus on the teaching of students aged between 10 and 19 years, in other words – according to the International Standard Classification of Education – levels ISCED 2 (lower secondary education), ISCED 3 (upper secondary education), and also ISCED 1 (primary education). However, the review also included papers that examined the teaching of prospective or current teachers at these school levels.

The review was conducted systematically (Booth et al., 2016). I primarily searched the Scopus and Web of Science databases for studies to be analysed. The query was based on the following Boolean logic: (Geotechnology OR Geospatial technology OR GIS OR Geographic information system OR Geoinformatics OR GNSS OR GPS OR Remote Sensing) AND (Constructivism OR Inquiry OR Enquiry OR PBL OR Problem-based OR Problem-solving OR Problem-oriented OR Self-directed OR Project-based) AND (Education OR Learning OR Teaching OR School OR Instruction).

Texts were limited to English-language articles and book chapters. I did not initially set any time criterion for the search for publications. The oldest publication traced by this command dated from 1970. The most recent publication was from August 2021, which was subsequently set as the upper time limit. Articles from 1999 to 2020 were included in the analysis after eliminating articles based on selected criteria.

Papers were initially eliminated based on titles. If a study did not fit my topic, it was eliminated. A shortcoming of the search terms was the presence of abbreviations (GIS, GPS, or PBL), which often led to confusion with abbreviations typical of other disciplines. I subsequently analysed the abstracts and selected papers relevant to the topic. In this step, I excluded papers from the review mainly because they were not related to primary and secondary education. In the full-text review, I excluded studies in which GSTs, although mentioned in the abstract, played no role in the research and did not influence the results of the studies. I also excluded studies in which the methodology was not adequately described and those that were not empirical. The process of elimination is shown in the flow diagram (Figure 2).

For each paper, I researched:

- the level of education;
- the teaching topics and learning tasks that were part of the teaching outlined in the study;
- technologies and software used;
- methodology used;

- research objectives or research questions; and
- research results.

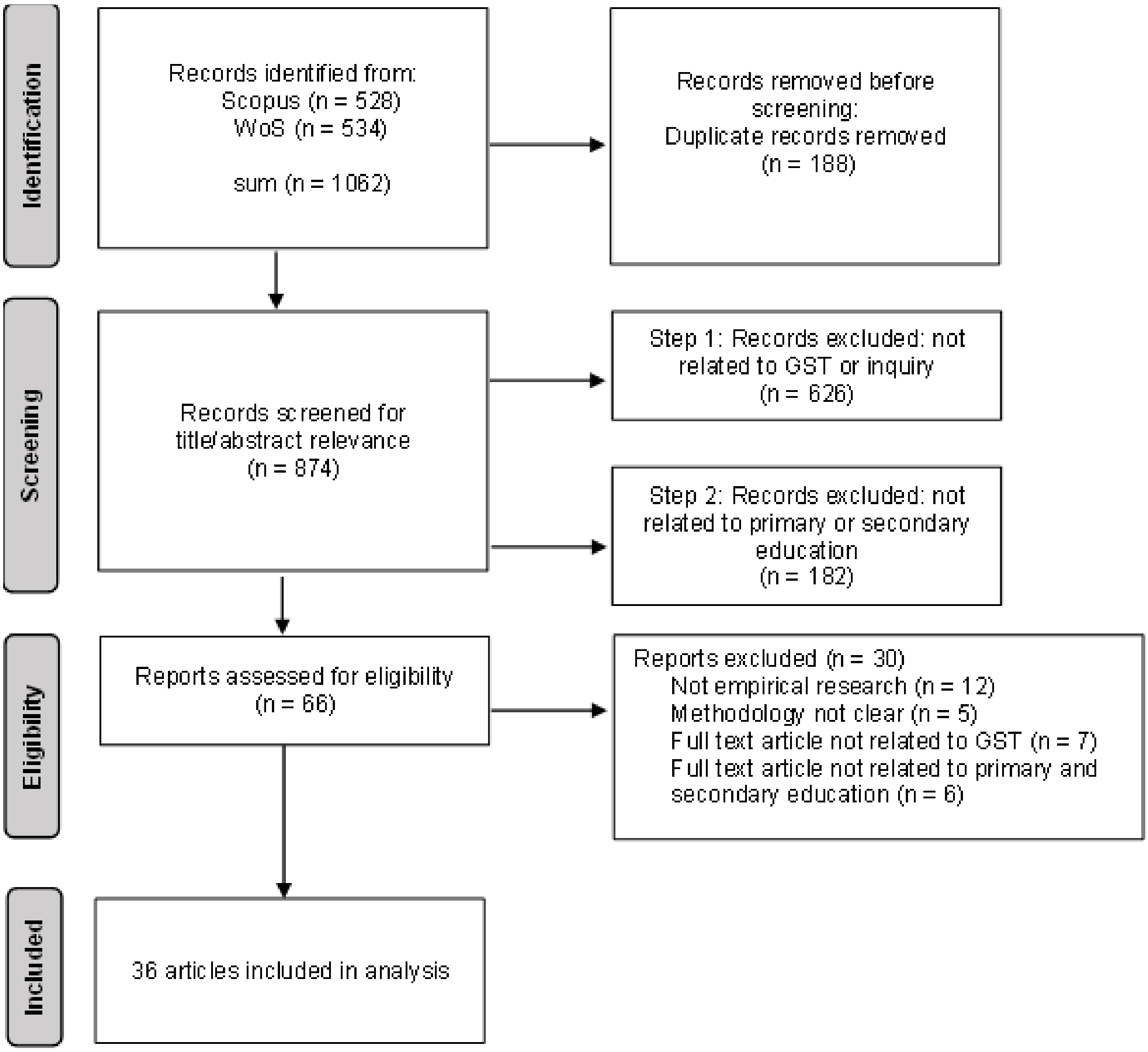


**Figure 2.** PRISMA flow diagram for the conducted systematic review.

## 4. Findings and results

### *4.1. Background*

I included 36 empirical studies (see Table 1) in the analysis. These were mainly from the USA (27), but also from Finland (3), and one each from Turkey, Serbia, Hungary, the UK, Singapore, and the Netherlands. The analysed studies were written between 1999 and 2020. I divided this timespan into five-year periods for a more detailed analysis. The five-year period in which most studies were published was 2011–2015. There were 16 studies published in that period. Eleven studies were written between 2016 and 2020. Only a handful of studies were written in the other five-year periods: two before 2000, five from 2001 to 2005, and three from 2006 to 2010.

Most of the studies dealt with the teaching of geography (11 studies), science (11 studies), and social science (four studies). The topics that were taught, such as hydrology (Czigány et al., 2017), atmosphere and climate (Dupigny-Giroux et al., 2012; Hedley et al., 2013); and natural disaster (Guiterrez et al, 2002; Perugini & Bodzin, 2020), were most often related to physical geography. Social geography was also represented in teaching with GST, for example, industry (Bodzin et al., 2013), services and trade (Favier & van der Schee, 2012), migration (Radinsky et al., 2014) and local problem-solving (Demirci et al., 2013; Schlemper et al., 2019). Regional geography was covered in a study by Wiegand (2003).

In these studies, the teachers or students worked mostly with GIS or with GIS in combination with other GSTs. Only the study by Avard and Clark (2001) mentioned working with RS and GPS, and Liljeström et al. (2013) mentioned working with GPS only. Older studies (up to 2010) tended to use the desktop software Arcview. After that, web services (e.g., Google Maps, Google Earth, ArcGIS Online) were also used. Overall, the use of products from Esri (Arcview, ArcGIS Online, Story Maps, mobile apps) and Google (Google Maps, Google Earth) predominated.

**Table 1.** Summary of Results.

| Author(s) and year | Country | The main object of research | Sample groups (ISCED)* | Methodology** | School subject | Topic | Used Geospatial technology |
|---|---|---|---|---|---|---|---|
| Keiper (1999) | USA | teachers and students | 1 | qual | geography | mixed | GIS (Arcview) |
| Avard & Clark (2001) | USA | teachers | 1+2+3 | mixed | not specified | physical geography | RS + GPS |
| Guiterrez et al. (2002) | USA | teachers | 2 | qnt | not specified | natural disasters | GIS (Arcview) |
| Baker & White (2003) | USA | students | 2 | qnt | science | bioindicators | GIS (ArcExplorer) |
| Wiegand (2003) | UK | students | 3 | qual | geography | quality of life in Brazil | GIS (Arcview) |
| Wilder et al. (2003) | USA | teachers | 2+3 | qnt | science | mixed | GIS + GPS |
| Wigglesworth (2003) | USA | students | 2 | qual | science | planning of way | GIS (Arcview) |
| Brindisi et al. (2006) | USA | lessons | 2+6 | mixed | science | natural disasters | GIS (Arcview, QUEST) |
| Dunleavy et al. (2009) | USA | lessons | 2+3 | qual | mixed | mixed | GPS (Alien Contact!) |
| Liu et al. (2010) | Singapore | students | 3 | mixed | geography | mixed | GIS (ArcGIS) |
| Ebenezer et al. (2011) | USA | students | 3 | mixed | not specified | not specified | GIS + GPS |
| Benimmas et al. (2011) | USA | teachers | 1+2+3 | mixed | mixed | mixed | GIS + GPS |
| Nielsen et al. (2011) | USA | students | 3 | mixed | mixed | mixed | GIS (ArcGIS, Google Maps) + GPS |
| Ratinen & Keinonen (2011) | Finland | teachers | 3 | qual | mixed | geology | GIS (Google Earth) |
| Kulo & Bodzin (2011) | USA | lessons | 2 | mixed | science | energy | GIS (Google Earth, My World GIS) |
| Favier & van der Schee (2012) | Netherlands | lessons | 3 | mixed | geography | services and customers | GIS |
| Dupigny-Giroux et al. (2012) | USA | teachers | 2+3 | mixed | geography | climate | GIS (Google Earth) + RS |
| Hedley et al. (2013) | USA | teachers and students | 2+3 | qnt | science | atmosphere | GIS + GPS + RS |
| Liljeström et al. (2013) | Finland | students | 1 | mixed | science | Ice Age - Lake District | GPS (MapHit Track) |

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| Author(s) and year | Country | The main object of research | Sample groups (ISCED)* | Methodology** | School subject | Topic | Used Geospatial technology |
|---|---|---|---|---|---|---|---|
| Komlenović et al. (2013) | Serbia | students | 3 | mixed | geography | not specified | GIS |
| Demirci et al. (2013) | Turkey | students | 3 | qnt | geography | local problems | GIS (ArcGIS) |
| Bodzin et al. (2013) | USA | students | 2 | qnt | science | energy | GIS (My World GIS) |
| Radinsky et al. (2014) | USA | students | 2+6 | qual | social studies | American Migration | GIS (SocialExplorer) |
| Hagevik et al. (2014) | USA | teachers | 3 | mixed | science | not specified | GIS (ArcGIS + Google Earth) |
| Hong & Stonier (2015) | USA | teachers | 2+3 | qual | social studies | mixed | GIS (ArcGIS + other) |
| Czigány et al. (2017) | Hungary | students | 2+3 | qnt | geography | hydrology | GIS (ArcGIS)+RS |
| Hammond et al. (2018) | USA | teachers | 3 | mixed | not specified | mixed | GIS (ArcGIS) + GPS (Collector) |
| Hong & Melville (2018) | USA | teachers | 1+2+3 | Mixed | social studies | not specified | GIS (ArcGIS Online + mobile apps) |
| Mitchell et al. (2018) | USA | teachers | 1+2+3 | mixed | mixed | not specified | GIS (ArcGIS Online) |
| Egiebor & Foster (2019) | USA | students | 2 | qual | social studies | not specified | GIS (Story Maps) |
| Schlemper et al. (2019) | USA | students | 2+3 | qual | geography | local problems | GIS (ArcGIS Online)+GPS (geocaching) |
| Jadallah et al. (2020) | USA | teachers and students | 1 | qnt | science + social studies | mixed | GIS (QGIS) |
| Jant et al. (2020) | USA | students | 3 | mixed | STEM | mixed | GIS |
| Perugini & Bodzin (2020) | USA | students | 3 | mixed | science | natural disasters (hurricane Irma) | GIS |
| Anunti et al. (2020) | Finland | lessons | 3 | mixed | geography | mixed | GIS (Story Maps) + GPS (Collector) |
| Osborne et al. (2020) | USA | teachers | 1+2+3 | qnt | geography | not specified | GIS+RS+digital mapping |

** ISCED (International Standard Classification of Education) – 1 – primary education, 2 – lower secondary education, 3 – upper secondary education, 6 – bachelor's or equivalent education*
***qnt – quantitative methodology, qual – qualitative methodology*

### *4.2. Level of education and the main focus of research*

As shown in Figure 3, this review is divided into three sections according to the main objects of research: students, teachers (and pedagogy students), and lessons (teaching materials, courses, etc.). The focus of the studies was on education at all levels of primary and secondary education. Most of the reviewed research focused on the International Standard Classification of Education (ISCED) level 3 (12 studies). ISCED level 2 was addressed by seven studies, but this review also includes studies that focused on teachers at all levels of primary and secondary education

(Benimmas et al., 2011), and research combining ISCED 2 and ISCED 3 (nine studies). Radinsky et al. (2014) and Brindisi et al. (2006) compared two groups in their studies – secondary school students and university students. GST can be included from primary school onwards, and teachers at this level show an interest in learning in this area (Benimmas et al., 2011; Hong and Melville, 2018; Jadallah et al., 2020; Keiper, 1999; Liljeström et al., 2013; Mitchell et al.; 2018; Osborne et al., 2020). Studies by Hedley et al. (2013) and Jadallah et al. (2020) paid similar attention to both students and teachers. Two studies (Brindisi et al., 2006; Radinsky et al., 2014) compared secondary education and university education. For simplicity, and in accordance with the objective of this review study, these studies are classified in Figure 3 as secondary education.

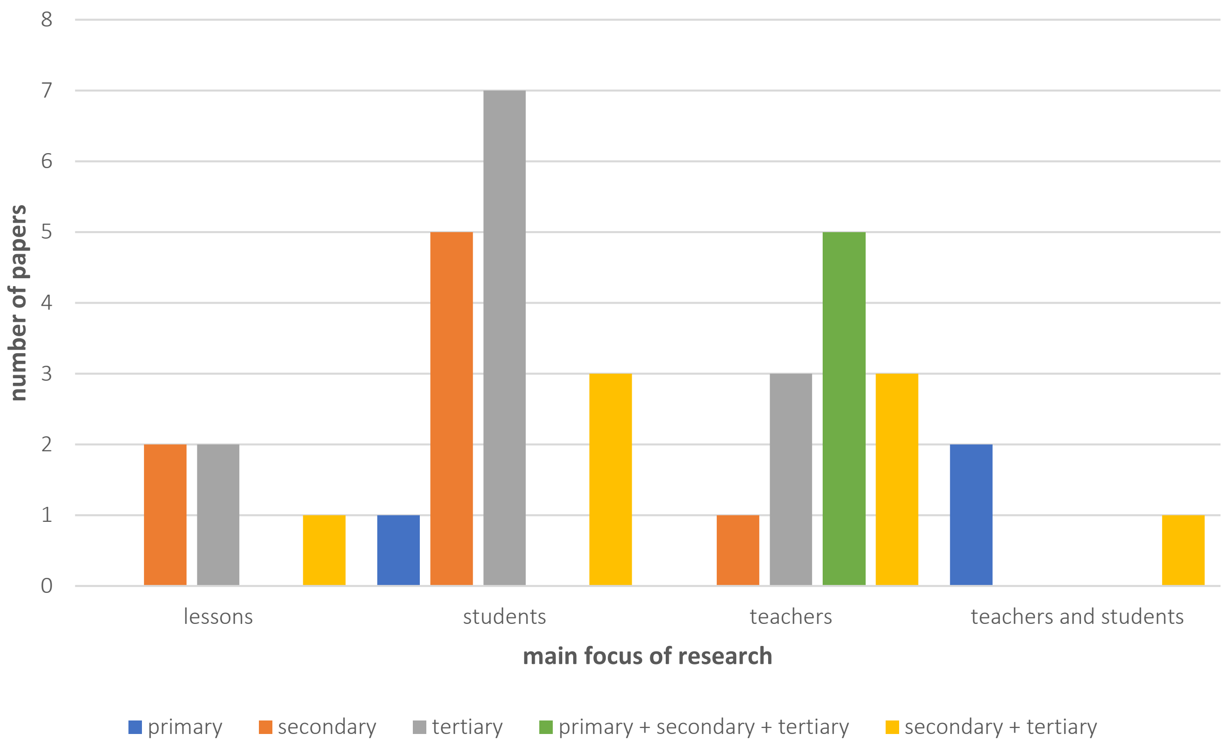


**Figure 3.** Number of papers by the main focus of research and level of education

### *4.3. Findings about methodological approaches and research objectives*

The research methods of the empirical studies that investigated teaching with GST using an exploratory approach were heterogeneous. Nine studies used only qualitative methods, another nine used only quantitative research designs, and mixed research methods was used in 18 studies (see Table 1).

Many of the research questions for studies in which the learner was the main object of research focused on the change in knowledge and skills after learning with GST. Therefore, a quasi-experimental or experimental design was used. Students who did not learn with GST were used as control groups (Baker & White, 2003; Bodzin et al., 2013; Jant et al., 2020; Liu et al., 2010). Some studies used pre-tests and post-tests to determine changes in knowledge (Czigány et al., 2017; Ebenezer et al. 2011, Perugini and Bodzin; 2020; Liljeström et al., 2013).

Guiterrez et al. (2002) and Wilder et al. (2003) studied teachers' acquisition of basic terminology and knowledge of GST use as a function of their completing ongoing professional development. The collaboration between teachers, students, and scientists was described by Hedley et al. (2013), in their study of how students' geoinformation skills and knowledge improved.

Research focusing on lessons, instructional materials, or entire courses used a mixed research design, specifically a design-based research (educational design research) approach (Anunti et al., 2020; Dunleavy et al., 2009; Favier & van der Schee, 2012; Kulo & Bodzin, 2011). These studies aimed to validate and optimise instructional material (Dunleavy et al., 2009; Favier & van der Schee, 2012; Kulo & Bodzin, 2011) or whole year-long courses (Anunti et al., 2020). Observations, teacher interviews, and focus groups were conducted as part of these studies. The evaluation of GIS-based projects was also addressed by Demirci et al. (2013) and Nielsen et al. (2011). The Discover Our Earth programme was evaluated in a study by Brindisi et al. (2006) using qualitative methods (observations) and quantitative methods (pre-test and post-test assessments and questionnaires).

Mixed research designs were used in the evaluation of the teacher training courses. Questionnaires designed for both qualitative and quantitative data analysis (Avard & Clark, 2001; Hong & Melville, 2018; Hong & Stonier, 2015) were combined with other methods, such as interviews asking questions about the inclusion of GIS in the curriculum (Benimmas et al., 2011).

A questionnaire (Osborne et al., 2020) was used to explore the differences in the inclusion of GST in the curriculum between rural and urban schools, as well as between government and non-state-sponsored schools. Course evaluations were conducted by Dupigny-Giroux et al. (2012), Hammond et al. (2018), and Mitchell et al. (2018), but these evaluations were based on knowledge and skills attainment.

A case study approach was used in a comprehensive examination of the teaching. The studies using this approach described the course of instruction from the perspective of the students and the teacher (Keiper, 1999), a workshop for students (Schlemper et al., 2019), and a course for prospective teachers (Ratinen & Keinonen, 2011). In these studies, data were collected by field notes on observations and recording instructions, and everything was subsequently coded. Hagevik et al. (2014) examined multiple teaching events and conducted interviews with teachers. Lesson plans, student artefacts, and GST projects were analysed and compared with emails, observations, and field notes. Radinsky et al. (2014) used a qualitative approach, but they also used a grounded theory approach. Egiebor and Foster (2019) used the phenomenography approach to try to find out how students described different learning experiences.

Komlenović et al. (2013) used a questionnaire to investigate students' perceptions of the practical use of GIS in everyday life. The practical use of GIS was also of interest to Wigglesworth (2011), who used the Group Assessment of Logical Thinking test to divide students into three groups according to their way of thinking about pathfinding.

The research by Jadallah et al. (2020) stood out from all other research. Using sequential analysis, the study examined the frequency of indexical expressions (verbal expressions to convey the degree of tentativeness or certainty).

### *4.4. What learning though inquiry with GST brings to the students?*

This review shows that learning with GST has several benefits. Using GIS, students practise geographic knowledge and are taught to ask geographic questions, organise geographic information, and analyse it (Keiper, 1999). This type of learning helps students understand what GIS is and what it is used for, improves communication skills, and helps them personally and professionally (Demirci et al., 2013). It also produces a change for the better in attitudes to these technologies (Bodzin et al., 2013). It is an interactive tool that develops students' cartographic skills (Komlenović et al., 2013). GIS makes students more capable of analysis and evaluation (Liu et al. 2010). It also offers the potential for mapping (Baker & White, 2003).

Teaching with GIS improves geospatial thinking (Perugini & Bodzin, 2020). Knowledge of geography and history is improved (Bodzin et al., 2013; Czigány et al., 2017; Egiebor & Foster, 2019) and through GIS, knowledge of science, specifically atmospheric science, can also be developed (Hedley et al., 2013; Perugini & Bodzin, 2020). Experience with both GIS and ICT will improve perceptions of technology as a tool for gaining experience and knowledge (Ebenezer et al., 2011). GIS offers a more diverse view of geospatial data and improves the ability to analyse that data (Baker & White, 2003).

GIS and RS are tools that make it convenient to solve local problems (Nielsen et al., 2011). There is an improvement in geoinformation skills and knowledge about the place of residence (Radinsky et al., 2014; Schlemper et al., 2019). Personal experience plays an important role for younger students, but university students can make logical inferences and connect history to space (Radinsky et al., 2014).

The analysis of the studies included in this review shows that the skills and knowledge acquired are not dependent on gender (Jant et al., 2020; Bodzin et al. 2013), a point that is also confirmed by Hedley et al. (2013). They do not depend on socioeconomic status, either.

Students rate GIS instruction positively due to the use of technology and the opportunity to collaborate. However, some find it difficult and frustrating (Perugini & Bodzin, 2020). Through the use of GIS (specifically Story Maps), students feel more engaged and can explore their homes, cultures, and neighbourhoods (Egiebor & Foster, 2019). Students also positively evaluate fieldwork (Schlemper et al., 2019). One example of this is when they were exploring glacial processes using GPS tools for saving their route and collecting their field notes (Liljeström et al., 2013).

Using GPS and augmented reality makes students feel engaged, but field data collection and group work also contribute to student involvement (Dunleavy et al., 2009). This finding was supported by Wigglesworth (2011), who argued that GIS engages students in problem-based learning. Technology 'was not as important and interesting as the emerging mediated tool-integrated learning practices that resulted from its use' (Liljeström et al., 2013, p. 79), and mobile phones made students feel like professionals.

In this type of teaching, some students experienced cognitive overload, but some also had difficulty with hardware and software (Dunleavy et al., 2009). Older students (16–17 years old) are more likely to ask questions and discuss concepts, while younger students (14–15 years old) are slower to reach conclusions and more concerned with appearances when creating maps (Wiegand, 2003).

Students' geoinformation skills can also develop at home (Komlenović et al., 2013). Active student participation is important because students play the role of geographers (Keiper, 1999). The role of the instructor (teacher) is important for students because the instructor boosts students' confidence in their abilities (Baker & White, 2003).

### *4.5. What do teachers need to teach through inquiry with GST*

Most of these studies had a common interest in teacher education, so they focused on the description of the educational activity (summer school, workshops, etc.). Questionnaires on opinions about GST workshops were often chosen as a tool for data collection. An example is the study by Hong and Melville (2018), in which teachers used ArcGIS Online, which they rated as suitable for teaching. Story Maps was rated the best, and analytical tools the worst. Based on the professional development they were offered, teachers questioned how to use GIS effectively and frequently in the classroom. A different goal was set in Mitchell et al.'s (2018) study, which measured the changes teachers experienced in skills and knowledge after a one-week development activity. The biggest change took place in the greater level of student engagement. The positive impact of the training workshop was felt by teachers from the Middle East and North Africa, who reported that the training workshop met their expectations (Benimmas et al., 2011).

Through a long-term model of scientific professional development, teachers' acquisition of the basic terminology and knowledge associated with the use of GST (Guiterrez et al., 2002) changed significantly, but their self-assessed confidence in using GST skills also increased the use of GST in participating teachers' classrooms (Wilder et al., 2003).

As geospatial pedagogical content knowledge grows, teachers become more autonomous and able to use and incorporate technology in their teaching (Hammond et al., 2018; Hong & Stonier, 2015). Osborne et al. (2020) explored teachers' professional development as well as factors influencing the implementation of GIS in classrooms. Teachers identified long-term support as essential because incorporating GIS into the classroom was not easy. This study also found that teachers in the city were more open to geo-technology. Government-sponsored schools needed more attention.

Teaching is improved by professional development, and teachers work better with technology and feel less frustrated (Hagevik et al., 2014); and knowledge of atmosphere, hydrology, land cover, soils, and GPS is improved (Avard & Clark, 2001). Prospective teachers achieve an improvement in their geographical thinking after gaining experience with Google Earth, but geological knowledge is not enhanced as a result (Ratinen & Keinonen, 2011). Teachers' participation in development programmes changes pedagogical approaches and classroom effectiveness while significantly improving their students' observational skills, critical thinking skills, and understanding of GST (Dupigny-Giroux et al., 2012).

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According to teachers, good practices for first GIS implementation are (1) making the first activity relevant for the students, (2) exposing the GIS slowly, a small amount at a time, (3) using peer leaders, and (4) providing tutorials videos (Hong & Stonier, 2015, p. 113).

### *4.6. How do you plan an inquiry class that uses GST?*

Some of the research has focused on the development and evaluation of teaching material, subject matter, or instruction, but also on how communication between teachers and students takes place in the classroom.

Favier and van der Schee (2012) proposed an optimal design of teaching material for a GIS research project that teachers should be able to use to construct a research project in which GIS is used. Teaching with GIS should be a combination of computer tasks, geographic discussions and strategies of geographic inquiry. The project was positively evaluated because it was something new and different for the students. They could create maps and research on their own, but they had to plan their work, and the workload was high.

A model portfolio for a geomedia course has been validated as appropriate (Anunti et al., 2020). The portfolio was used to meet the course objectives, but students identified working with GIS as challenging, so they required teacher assistance. The time-consuming nature of such assignments was also confirmed in Integrate GST in an energy unit (Kulo & Bodzin, 2011). However, in this case, some tasks were simplified and omitted. The authors tried to improve the students' learning process by revising the tasks (changing words, and adding screenshots).

The study by Jadallah et al. (2020) was distinct from all the other research, not only methodologically. It investigated the effect of technology (specifically GIS) on the frequency of indexical expressions, i.e., verbal expressions that convey a degree of certainty. These may be boosting (definitely, in fact, etc.) or hedging (perhaps, maybe, etc.). In this study, they were used by teachers and students in classroom interactions during social studies classes. It appeared that boosting was more common in GIS classes for both teachers and students. The uncertainty of the teacher's speech (use of hedging) led students to also express uncertainty by hedging.

## 5. Discussion & Conclusion

This study aimed to review the research findings on learning and teaching in primary and secondary education with GST through inquiry and to identify knowledge gaps in this field. The review study also investigated methodological approaches to these questions. WoS and Scopus databases were used for the review. The review included papers that were written up to 2020, and it presents a sufficient sample of studies to allow for a detailed analysis and to identify future research direction. The study produced a wide range of results. A summary is given in Table 1. It was possible to determine at what level of education GST and inquiry could be included, which software and applications were used, and what topics and learning tasks were covered in the classroom. It was also established what research methodology was chosen and what the research objectives or research questions were.

Most of the articles (27 out of 36) in this review study were from the USA, which may reflect the fact that GST is found in the Geography for Life national standards, but teachers are not required to use them (Heffron & Downs, 2012). It may also be related to the long tradition of using GST in education. GST has been used in teaching in the USA since the 1990s (Bednarz, 2004). GST is also in the curriculum in Finland, which is also represented more than once in the review study (Kerski et al., 2013). Research shows that GST can be used at all levels of primary and secondary education, but it is more common in upper secondary schools (ISCED 3), which corresponds with the results from Schulz (2021), who included higher education in his review.

Teaching and learning through inquiry with GST has several advantages, such as improved problem-solving skills – both independently and in groups (Bednarz, 2004; Hmelo-Silver et al., 2007; Sproken-Smith, 2005), a positive attitude toward learning (Bednarz, 2004; Robert, 2013) and digital competencies (Albion, 2015; Hammond et al., 2018). The development of mapping skills, such as map creation, is another positive aspect of working with GST (Mísařová et al., 2021; Wiegand, 2003).

When solving problems, pupils can draw on their own experiences and solve problems around the school and their homes. This stimulates their interest and motivation, and they learn from their own experiences (Dewey, 1929). If the pupils themselves choose a problem they want to solve, and choose a solution themselves, an open inquiry is achieved. However, when teaching with GST, students need either some prior knowledge or instructions (e.g., screenshots) on how to work with the technology (Kulo & Bodzin, 2011). This is at a lower level than an open inquiry (a structured inquiry or a guided inquiry). At primary school, one can use the lowest level (confirmation inquiry) (Keiper, 1999; Rezba et al., 1999). GST can prepare students for the challenges of college, career, and civic life (Hong & Melville, 2018; NCSS, 2013).

Despite the advantages of this type of teaching and learning, there are some barriers, especially the time required for preparation and implementation (Hong, 2014). These benefits and barriers also apply to learning through inquiry with GST, as the results of the studies in this systematic review have shown.

GIS is most commonly used in GST teaching through inquiry. If GNSS or RS is used in teaching, it is most often together with GIS (Mísařová et al., 2021). Only one study uses GPS technology only when playing geolocation games (Dunleavy et al., 2009). It is possible to use a wide range of GST tools. Older research worked with desktop software (e.g., Arcview), but since the 2010s WebGIS (e. g. ArcGIS Online, Story Maps or Google Maps) or mobile applications (e.g., Collector by Esri) have been used in research. The software applications that are used in research are free or available with special licenses for schools (e.g., license ArcGIS for School Bundle by Esri).

The development of teachers' skills should be carried out at workshops or summer schools, which can be governed by the TPCK framework to ensure that they develop technological knowledge and skills (in these cases GST), pedagogical (inquiry in education), and professional knowledge (most commonly geography content) (Collins & Mitchell, 2018; Koehler & Mishra, 2009; Yeung, 2010).

GSTs can be incorporated into geography, but also other fields of science or social science. They can be used for topics in physical geography, natural disasters, or local problem-solving, which are popular topics for teaching geography (Korvasová, 2022). Regional geography was used in only one of the studies (Wiegand, 2003). In constructivist approaches to teaching, it is necessary to ensure that the lessons are not only focused on the learning process but also the content of learning (Kirscher et al., 2006). Some papers that were included in this systematic review (e.g. Bodzin et al., 2013; Czigány et al., 2017; Egiebor & Foster, 2019) confirmed that the emphasis was not only on developing GST skills but also on deepening knowledge of the industry. That finding may be due to the focus of this review study, which links GST with inquiry.

Based on the analysis of the papers, it can be said that more attention is being paid to GST than inquiry (in terms of research questions, conclusions and theoretical frameworks). In most of the studies (19), it was assumed that inquiry is already successfully implemented in teaching, and attention should be paid to the effect of GST on the learning process, acquired skills, and attitudes. The implemented teaching methods (inquiry-based learning, problem-based learning, etc.) were more widely represented only in the studies by Czigány et al. (2017), Hong and Stonier

(2015) and Liljeström et al. (2013), but remained at the same level in other studies (e. g. Hong & Melville, 2018; Perugini & Bodzin, 2020; Schempler et al., 2019). In general, inquiry-based learning has been used more for physical geography topics, and problem-based learning more for socio-economic topics.

The research designs and research approaches are heterogeneous due to the heterogeneous research objectives and research questions, which correspond with the findings of Schulz (2021), who has pointed out that GIS education needs a systematic research framework for future efforts.

The results of the studies were divided into three sections according to the main focus of the research: students, teachers, and lessons (and learning materials). The results of the studies are more uniform and mostly share the view that the positives of GST and inquiry outweigh the barriers involved in implementing this learning. Students can use GSTs to develop the competencies and skills needed for this century.

The following recommendations and pitfalls for learning and teaching through inquiry with GST have emerged from this review study. The uses of GST in this context should:

- deal with local problems related to the area around the school and home as a start that can lead to observing other areas later;
- involve fieldwork (e.g., with GNSS data collection);
- deal with problems relevant to the learner;
- involve group learning;
- involve prior teacher training (e.g., through workshops), which is essential;
- acknowledge this teaching is time-consuming;
- involve long-term and frequent inclusion of GSTs in teaching, which has benefits; and
- involve a choice of web-based tools, as these are advisable.

### *5.1. Limits of the review study*

Although some papers identified the pitfalls of teaching with GST (e.g., Anunti et al., 2020; Kulo & Bodzin, 2011), they presented mostly positive results of GST implementation in teaching. Another limitation of this review may be the restriction of the search to English-language studies. The databases identified studies in other languages (Chinese, German, Spanish, Portuguese, Finnish, and Turkish). Five other studies could have been included in this review but it was not possible to know from the abstracts whether they would have met all of the criteria for inclusion. Further pitfalls may have arisen from the choice of keywords. Not all GSTs were mentioned in the search terms (e.g., geodatabase) and the terms were limited to only some teaching methods associated with inquiry.

### *5.2. Future directions and a research gap*

Previous research has addressed several aspects: 1) teacher training (Benimmas et al., 2011; Hagevik et al., 2014; Hong & Melville, 2018), 2) benefits of GST and inquiry (Bodzin et al., 2013; Czigány et al., 2017; Egiebor & Foster, 2019), and inquiry classes and how to plan them (Anunti et al., 2020; Favier & van der Schee, 2012).

This review study revealed several research gaps. Some of these unexplored findings appear to be important and worthy of investigation in the context of the benefits and pitfalls of learning and teaching through inquiry with GST. Furthermore, the previous investigation, in which the main object of research was teachers, had focused primarily on short-term research (evaluation of workshop or summer school) and there is a lack of a long-term perspective, e.g., monitoring the teacher's work throughout the school year or a longer period. No study to date has directly attempted to empirically evaluate a holistic view of teaching with GST in which an inquiry approach is involved. Where multiple perspectives were present in studies (e.g., teacher and student perspectives), there was no cross-analysis, e.g., a study by Hammond et al. (2018). The papers that aimed to validate the learning material were closest to a holistic view, as the authors examined the perspectives of the learner, the teacher, and the learning task itself. Little attention was paid to the process of learning, e.g., in the view of the 5E model, and the phase of inquiry by Bybee et al. (2006) or dimensions in Inquiry Arc (NCSS, 2013). Studies in this systematic review offered only descriptions of lessons.

There were no studies that revealed what is behind teachers' beliefs and motivations for implementing GST into their teaching, or what situations occur in learning and teaching through inquiry with GST. Most of these studies dealt with teacher training but did not explore how the perception of GST varies according to the different education of teachers. In most of the research, the influence of GST prevailed over inquiry, so it is necessary to include this aspect more in future research. Very little empirical research has been done on levels of inquiry (Rezba et al., 1999) or the type of constructivist approach. In future research, attention can be paid to topics in regional geography.

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