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Pedagogical integration of digital GIS tools in secondary education:
Teachers' uses, classroom organisation, and constraints

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Pedagogical integration of digital GIS tools in secondary education: Teachers' uses, classroom organisation, and constraints

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Abstract

This study examines how geography teachers implement GIS-related digital work in secondary education and what this reveals about the pedagogical integration of specialised digital tools. Drawing on semi-structured interviews with 20 Finnish lower and upper secondary geography teachers, the study analyses the tools teachers use, the pedagogical organisation of GIS-related work, and the factors shaping its scope, depth, and continuity. The findings show that GIS-related teaching was established in principle but selective in practice. Teachers regularly used digital spatial tools, mainly lightweight browser-based services such as Google Earth, Google Maps, and, in upper secondary settings, Geodata portal "Paikkatietoikkuna". More demanding GIS applications were rare and usually reserved for later upper secondary study. GIS-related work was organised mainly through teacher-led forms such as demonstration, tightly guided progression, and whole-class work, especially in lower secondary contexts. Student-led forms, including independent work supported by written instructions and inquiry-oriented tasks, appeared more selectively and were linked mainly to upper secondary teaching and later learning stages. Interpreted through the revised Bloom's taxonomy, lower secondary work was more often associated with remembering, understanding, and applying, whereas upper secondary work more often moved towards analysing, evaluating, and creating. Key constraints included lack of time, uneven teacher expertise, weak device routines, and the influence of curriculum and the digital matriculation examination on software choice. The study shows that the educational value of specialised digital tools depends not only on access, but also on pedagogical usability, curricular timing, and institutional routines.

Keywords: geography education; GIS; digital education; geomedia; pedagogical organisation; secondary education

1. Introduction

Digital technologies are now embedded in many educational systems, yet the practical enactment of digitally supported teaching varies considerably across subjects and school contexts [1,2]. For digital education research, this raises a central question: how do specialised digital tools become usable, meaningful, and sustainable in everyday teaching rather than remaining peripheral or aspirational? In geography education, this issue is especially significant because geographic information systems (GIS) and, more broadly, geographic information science (GIScience) are not merely optional classroom tools or topics. They refer to the use and study of computer-based software, digital spatial datasets, and related methods for representing, analysing, and communicating geographically referenced information [3–5]. Geography therefore provides an informative case for examining how subject-specific digital practices are shaped by the interaction of pedagogy, tool design, and institutional conditions.

Within geography education, GIS has long been associated with ambitions to strengthen inquiry, spatial thinking, visual reasoning, and engagement with real-world data [6,7]. At the same time, earlier research has shown that the adoption of GIS in schools depends not only on curricular goals but also on teachers' expertise, access to suitable software, the usability of digital tools, and broader school-level conditions [2,8,9]. International review research further suggests that GIS integration in education remains uneven despite its recognised pedagogical potential, largely because of persistent issues related to teacher preparation, technical support, and curricular positioning [10,11]. In this sense, GIS is not only a topic within geography; it is also an example of a broader digital education challenge: how specialised technologies with strong educational potential are adapted, simplified, or constrained as they enter ordinary classroom practice.

In Finland, national curricula for lower and upper secondary geography emphasise digitalisation, geomedia, and the interpretation and production of spatial information [12,13]. However, curriculum texts leave considerable room for local interpretation regarding what GIS-related teaching should include, how demanding the required digital practices are, and at which stage they should be introduced [14,5]. Previous work based on the same interview dataset has already examined classrooms as visual teaching spaces and the broader use of digital tools in geography teaching. The present article focuses more specifically on GIS-related digital tools, how they are pedagogically used in school geography, and the conditions that shape the scope and depth of that use in Finnish secondary schools.

On the Finnish school system, compulsory basic education covers Grades 1 to 9 (typically ages 7 to 16). Geography is integrated into Environmental Studies in Grades 1 to 6 and taught as a distinct subject from Grade 7 onwards, where it emphasises spatial thinking and human–environment relations [12]. After basic education, students continue to upper secondary education in either the general or vocational track. In general upper secondary education, geography includes one compulsory module and three elective modules in the National Core Curriculum [13]. Across these stages, geography occupies a distinctive position between the natural and social sciences and supports students' multiliteracy, critical thinking, and use of geomedia and geospatial technologies for interpreting and communicating geographic information [5,13].

The aim of this article is to examine how geography teachers implement GIS-related digital work in secondary education and what this reveals about the pedagogical integration of specialised digital tools in ordinary classroom practice. More specifically, the article asks three questions: (1) What kinds of GIS-related digital tools do teachers report using, and how do these differ in practical and pedagogical demand? (2) How is GIS-related digital work organised pedagogically, particularly in relation to teacher guidance, student independence, and differences between lower and upper secondary contexts? and (3) Which organisational, curricular, and professional factors shape the scope, depth, and continuity of GIS-related teaching? These questions focus not only on whether digital tools are present, but on how different forms of GIS-related work become possible, limited, or postponed in school practice.

The article contributes to digital education research in three ways. Empirically, it shows how specialised digital tools are used unevenly within one subject area, with everyday teaching relying mainly on lightweight browser-based tools and more demanding GIS applications appearing only selectively. Conceptually, it frames GIS teaching as a case of subject-specific digital pedagogy in which the educational value of technology depends on pedagogical usability, classroom organisation, and curricular timing rather than on technical capability alone. Practically, it identifies conditions that shape whether GIS-related teaching remains limited to guided exploration or extends towards more sustained production and analysis.

2. Background

2.1 Digital tool integration in classroom practice

Research on educational technology has consistently shown that digital tools do not automatically transform teaching. Their classroom use depends on external conditions such as access, time, and technical reliability, as well as internal factors such as teachers' beliefs, confidence, and pedagogical judgement [1,2,15]. For digital education research, this means that technology integration is best understood not simply as a question of availability, but as a process of pedagogical adaptation in which tools must become usable within the temporal, organisational, and curricular realities of everyday classrooms.

A recurring issue in digital education is that specialised digital tools often enter classrooms with strong pedagogical promise but uneven practical uptake. Earlier studies of GIS teaching have linked such tools with inquiry, spatial reasoning, data visualisation, and higher-order thinking, but they have also documented persistent barriers. These include limited teacher training, insufficient time for preparation and classroom implementation, the complexity of specialist software, and the difficulty of integrating GIS meaningfully into already crowded curricula [7,8,16,17]. Teachers often adopt tools that are easy to access and quick to use, even when such tools support only a restricted range of functions [9,18]. Recent systematic reviews confirm that these barriers continue to characterise GIS implementation internationally, even as web-based and open tools have broadened access and inquiry-based applications [10,19,20]. The findings of this article suggest that this tension is visible not only between adoption and non-adoption, but also between lighter and more demanding forms of use within school practice.

2.2 Revised Bloom's taxonomy and levels of cognitive demand

To interpret the level of cognitive demand in GIS-related tasks, this article draws on the revised Bloom's taxonomy. In the revision by Anderson and Krathwohl [17], the taxonomy distinguishes between types of knowledge and levels of cognitive process, allowing teaching tasks to be examined not only in terms of what students are expected to know, but also in terms of how they are expected to work with that knowledge. The revised taxonomy identifies six levels of cognitive process: remembering, understanding, applying, analysing, evaluating, and creating. Alongside this process dimension, the knowledge dimension ranges from factual and conceptual knowledge to procedural and metacognitive knowledge. In educational research, the revised taxonomy is often used to distinguish lower-order from higher-order thinking and to examine how task demands develop from simpler forms of recall and recognition towards more complex interpretation, comparison, judgement, and production [17].

2.3 GIS as a case of subject-specific digital pedagogy

In geography, these broader questions are especially visible because GIS is both a disciplinary content area and a digital medium for learning. Computer-based GIS teaching can therefore be understood as a case of subject-specific digital pedagogy, where the educational value of technology depends on how digital tools support students in viewing, interpreting, producing, or analysing geographically referenced information. This includes both lightweight browser-based map services and more demanding GIS applications. However, the educational significance of these tools differs. Some primarily support browsing and visual inspection, whereas others enable students to compare layers, create simple maps, or conduct more explicit spatial analysis [21,22]. The distinction matters because the pedagogical demands placed on teachers and students increase as tasks move from viewing towards production and analysis. A useful way to clarify this is to see GIS work as part of a wider geomedia cycle. Hynynen et al. describe geomedia work as proceeding through recurring phases of data acquisition, modification or combination, analysis and interpretation, visualisation and presentation, and eventual use in decision-making or planning, after which a new cycle may begin [23]. This framing is particularly relevant for GIS because it emphasises that work with spatial information is not limited to viewing maps on screen, but may also involve collecting digital data, processing or combining datasets, analysing patterns, visualising results, and using those outputs in further reasoning or decision-making. In this sense, GIS teaching can connect classroom tasks with the broader digital workflows through which spatial knowledge is produced and used. A second useful framework is the GeoTAITO model developed by Lammi et al., which synthesises geomedia and GIS-related skills across educational levels [24]. In that model, skills range from recognising and using geomedia in everyday contexts to reading, interpreting, evaluating, and producing geomedia, making conclusions from analysis, and eventually acting or influencing through geomedia. The model also underlines that these skills develop gradually, and that the higher levels depend not only on technical competence with software and datasets but also on growing geographical understanding and critical literacy. For the present article, these two frameworks help clarify why the difference between lightweight browser-based tools and more demanding GIS applications is pedagogically important: different tools support different phases of geomedia work and make different levels of cognitive demand and student autonomy possible in school practice.

3. Materials and methods

The study is based on a qualitative design using semi-structured thematic interviews. The target group comprised Finnish subject teachers teaching geography in lower secondary school (Grades 7–9) and upper secondary school. Participants were identified manually through publicly available school websites and contacted by email. More than 120 teachers were invited, and 20 ultimately participated. The sample included teachers working in lower secondary education, upper secondary education, or both, with variation in teaching experience and subject background. Most participants worked in the Helsinki metropolitan area, and upper secondary teachers were more strongly represented in the final sample. For more details about the material, see [25].

Interviews were conducted either onsite at participants' schools (n = 8) or remotely via Microsoft Teams (n = 12). All interviews were audio-recorded using a mobile recording application and transcribed primarily manually. During transcription, fillers and non-lexical utterances were removed when they did not affect meaning. For the present article, we used data-driven content analysis. We first read the interview transcripts repeatedly to identify references to GIS tools, GIS teaching situations, levels of student activity, and perceived obstacles or enabling conditions. We then organised these references into analytic categories through constant comparison across cases. Four themes were central to the analysis: the digital tools used for GIS teaching, the character and level of GIS-related tasks, the pedagogical organisation of teaching, and the constraints that limited analytically richer uses of GIS. Direct quotations are translated into English and presented with anonymised teacher identifiers in the form Teacher 17.

4. Findings

4.1 GIS-related digital tools in school geography

Teachers reported a broad repertoire of digital tools in geography teaching, but a much narrower range of tools for GIS-related work. In the wider set of digital tools, teachers mentioned learning platforms, drawing software, spreadsheet and word-processing programs, presentation tools, games, and map-based applications. For GIS-related teaching specifically, however, the toolset was dominated by browser-based map services. As shown in Figure 1, the most frequently mentioned tools across both lower and upper secondary education were

Google Earth and Google Maps. In upper secondary settings, teachers also referred relatively often to Geodata portal “Paikkatietoikkuna”, whereas other web-based map services or GIS programs received only occasional mentions. More specialised GIS applications such as ArcGIS were mentioned by only a small minority of teachers, usually those with stronger geoinformatics backgrounds or other prior experience of GIS software. This indicates that the present article addresses a more specific subset of the wider interview material: not digital classroom tools in general, but the digital tools teachers associated with GIS-related teaching. This connection between software choice, students’ readiness, and curricular sequencing is captured in one teacher’s explanation:

> “*It does take time to get to grips with ArcGIS, so I do not introduce it in the first module. Instead, the emphasis is on, for example, Google Earth, which for many students is already something like, ‘How does this work?’ In the later modules, students also tend to have a bit more motivation.*” (Teacher 2)

This account illustrates how teachers linked software choice to both students’ readiness and the practical sequencing of the curriculum, rather than to technical capability alone.

The interview data also suggest a clear differentiation between GIS-related tools according to the level of knowledge they require and the level of software-use demand they place on teachers and students, as illustrated in Figure 2. Google Earth and Google Maps functioned mainly as general-use tools for browsing, locating places, and visually inspecting spatial patterns. Teachers commonly used them to show locations, open a landscape or area for inspection, or support discussion of geographical phenomena. Geodata portal “Paikkatietoikkuna” and similar services represented an intermediate level because they enabled students not only to inspect maps but also to combine layers, view thematic information, and in some cases produce simple maps or perform limited analysis. More demanding applications such as ArcGIS represented a qualitatively different level of work because they made more explicit spatial analysis and stronger student production possible. In practice, however, this highest level appeared only rarely in the interviews. Teachers usually located such work in later upper secondary study, especially in the optional geomedia module, if they used it at all.

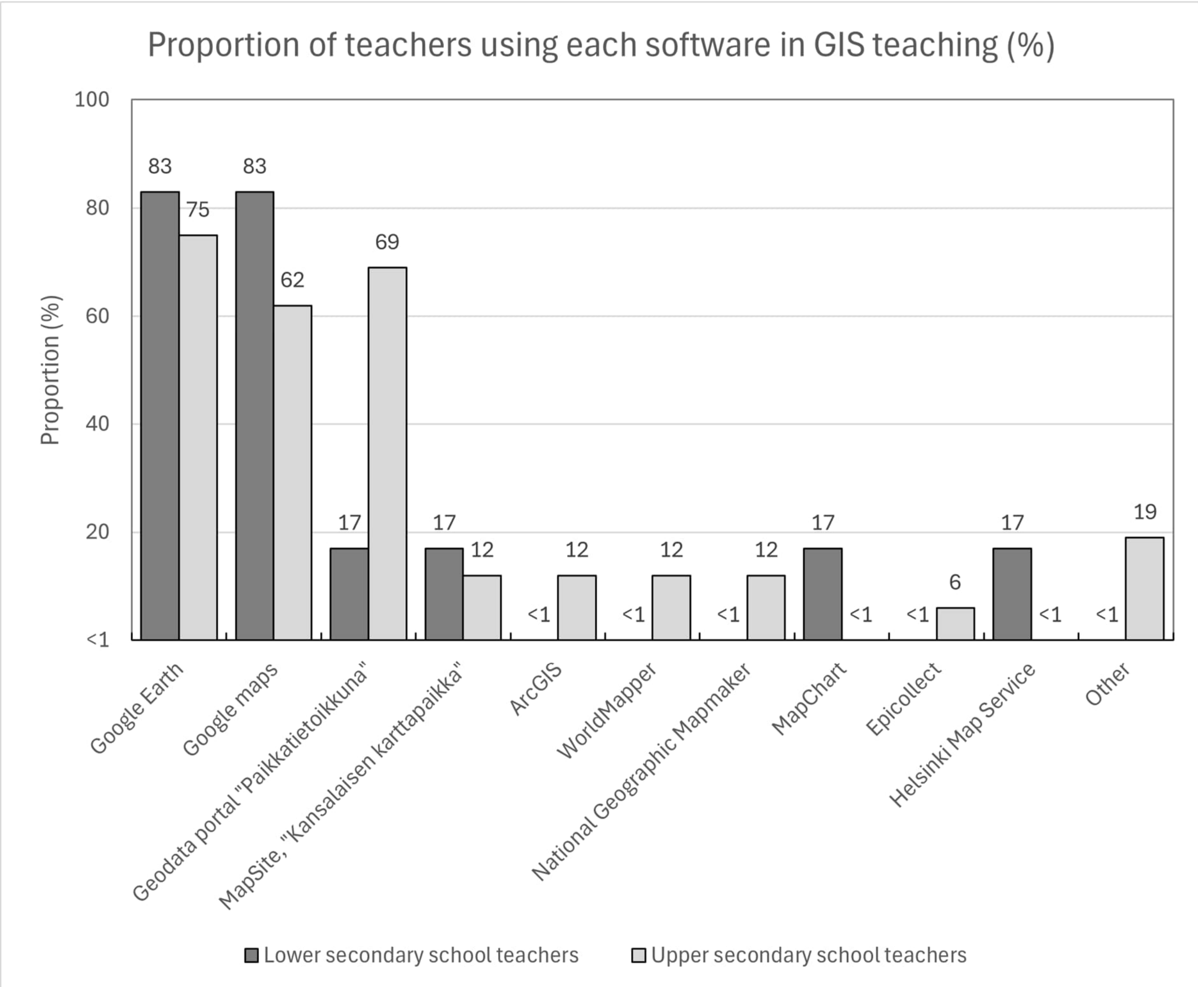

Figure 1. Percentage of teachers using different software in GIS teaching in lower and upper secondary schools.

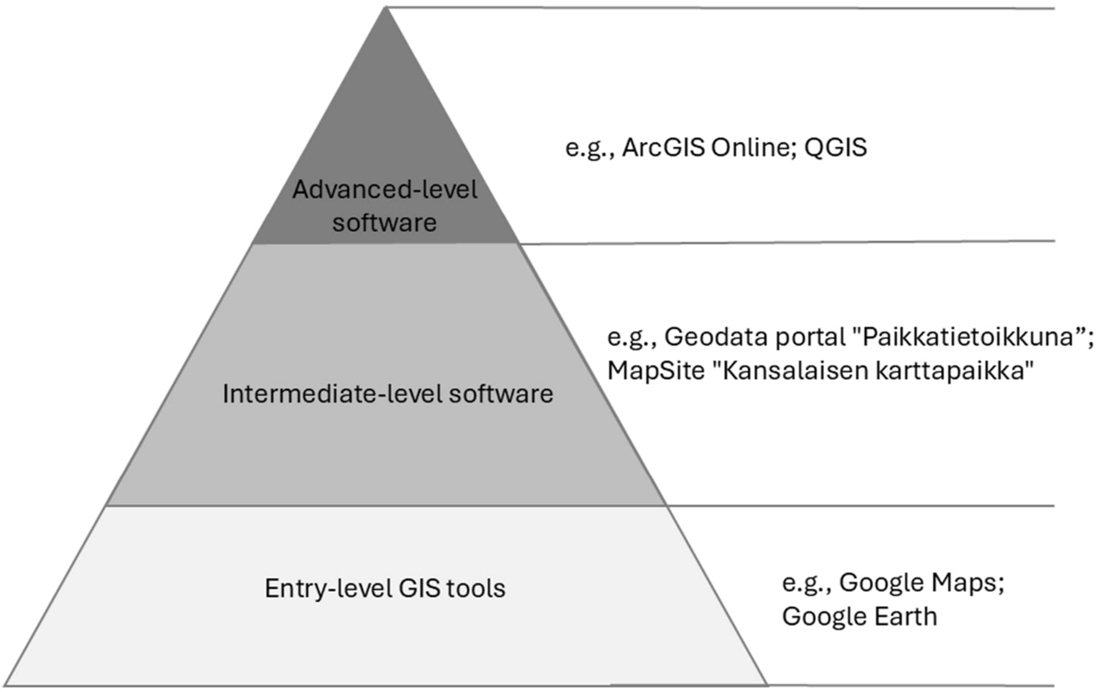

Figure 2. Categorisation of GIS-related software according to the level of knowledge and the level of software-use demand.

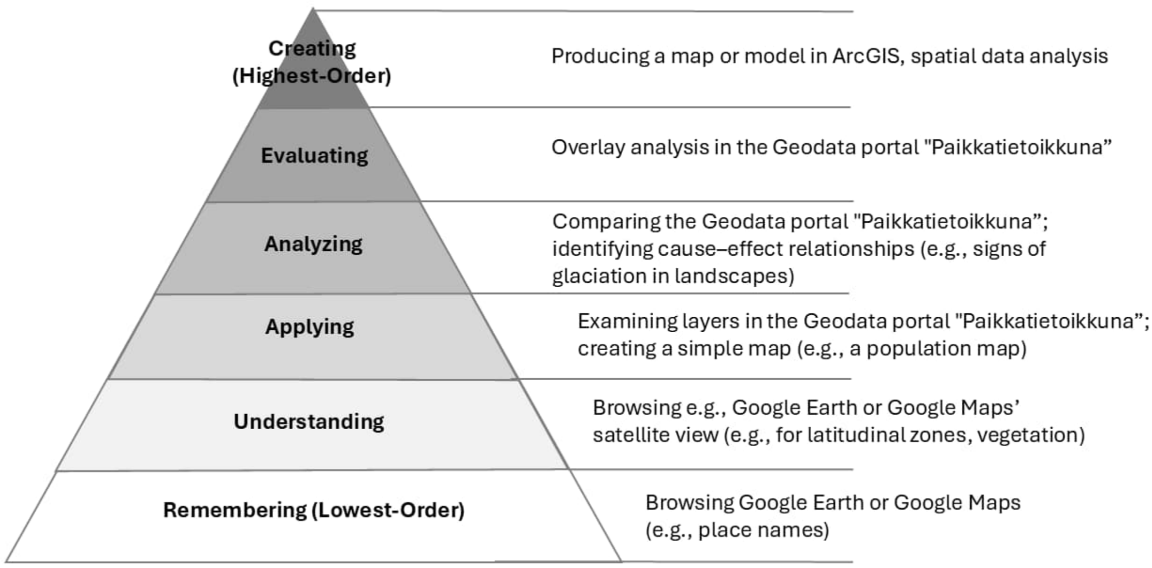

Figure 3. GIS teaching in relation to revised Bloom's taxonomy [17] and the geographical teaching examples provided by teachers.

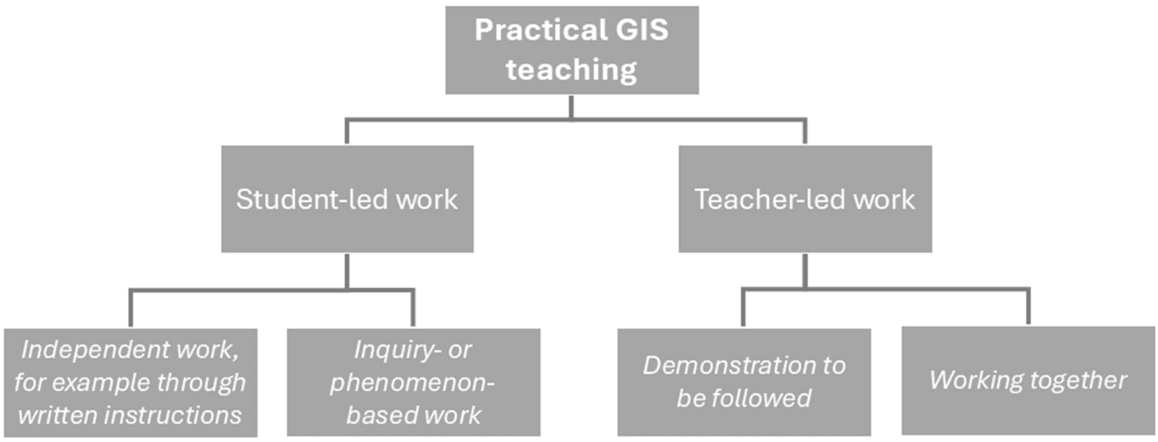

Figure 4. Pedagogical approaches to practical GIS teaching, showing the distinction between student-led and teacher-led work and their main subtypes.

4.2 Pedagogical organisation

Teachers commonly described GIS teaching as heavily structured and often teacher-led, especially when students were first introduced to a new digital tool or task. This pattern distinguished between student-led and teacher-led pedagogical approaches and showed that most practical GIS teaching was organised through demonstration, tightly sequenced guidance, and carefully controlled progression. Figure 4 summarises this distinction by showing two broad pedagogical orientations in the data: student-led work and teacher-led work. Within student-led work, teachers described independent work supported by written instructions and, more occasionally, inquiry- or phenomenon-based work. Within teacher-led work, the data pointed especially to two practical forms: follow-along demonstration and whole-class work. In many accounts, the teacher first demonstrated the procedure step by step, after which students either repeated the same actions simultaneously or carried them out afterwards with written instructions. Teachers emphasised that GIS-related production tasks required highly explicit guidance because students could otherwise become lost in the sequence of actions rather than focusing on the geographical meaning of the task. This pattern was particularly visible in tasks such as making diagrams, producing basic maps, or learning how a map service worked for the first time, like a Teacher 9 said:

> *"In class, I show them that we go to this site and click here, and then we do it like this. There are also instructions on the handout. Some students get through it very easily, while others immediately start asking what they are supposed to do and what the website was. So the instructions are really a very explicit step-by-step version: click here, and then here."* (Teacher 9)

Teachers also described how procedural control was necessary to maintain coherence in digital production tasks:

> *"I usually explain first and want them to look at the whole thing at that moment. Especially because I have required them to produce those schematic figures using digital software. In that situation, you cannot really draw with the software at the same time and follow what is happening on the board, because then it always becomes, 'Wait, which tool was this again?' So I have done it in such a way that the laptop is opened only after the whole thing has been put together. Otherwise, they end up with outputs that no one knows how they relate to anything."* (Teacher 12)

Together, these quotations show that teacher-led pacing was used to reduce fragmentation and ensure that students remained focused on the intended learning task rather than on procedural uncertainty.

More independent student work appeared mainly in upper secondary contexts and usually only after students had already developed some familiarity with digital tasks. Even then, independence was conditional rather than complete. Teachers often provided detailed written instructions and remained continuously available to solve technical or conceptual problems. In lower secondary teaching, by contrast, teachers more often preferred whole-class progression and tightly teacher-directed work because lesson time was short, digital routines were weaker, and students were seen as needing more support. Figure 4 thus not only categorises pedagogical approaches but also helps make visible how they were distributed across the data: teacher-led forms were more common overall, whereas student-led approaches appeared more selectively and were linked especially to upper secondary contexts and later stages of learning. Figure 3 complements this pedagogical distinction by relating teachers' examples to the revised Bloom's taxonomy. In lower secondary teaching, GIS-related work was more often described at the levels of remembering, understanding, and applying, for example when students opened a map service, viewed a limited number of layers, or inspected a place. In upper secondary contexts, especially in later modules, teachers more often described tasks that moved towards analysing, evaluating, and creating through comparing layers, producing maps, or carrying out small inquiry tasks more independently. This is broadly consistent with earlier work showing that more inquiry-oriented and student-centred GIS tasks are more likely to emerge when students have already developed sufficient familiarity with the tools and the topic [26,27]. The figure therefore does not suggest a strict hierarchy of fixed lesson types, but rather a shift in the typical cognitive demand of GIS-related work from lower secondary to upper secondary teaching [26,27]. This shift was also explicitly described by teachers, as in the following example from Teacher 17:

> *"For example, in lower secondary school the instructions are even clearer and more detailed. You might just open two or three layers, and that is it. Upper secondary students, by contrast, can do a bit more independently, simply on the basis of an instruction such as 'Make maps on the following topics'. Then they are able to find which layers need to be selected, or compare them with each other." (Teacher 17)*

This comparison highlights that differences between lower and upper secondary GIS teaching concerned not only content level, but also the amount of procedural autonomy teachers considered feasible.

4.3 Constraints on sustained and analytically demanding GIS teaching

Teachers described several recurring constraints that limited the depth and continuity of GIS teaching. First, time was a pervasive issue. In upper secondary education, many teachers felt that the curriculum already contained so much subject content that there was little room for more demanding GIS work before the optional geomedia module. Some explicitly stated that they postponed stronger GIS-related production and analysis until that module because earlier courses were too full. In lower secondary education, time pressure appeared in a somewhat different way. Teachers stressed that ordinary lessons were too short for slow digital routines, especially if pupils had to fetch devices, log in, and troubleshoot basic technical problems before any substantive task could begin. As a result, some teachers preferred paper-based production tasks even when digital alternatives were available.

A second major constraint concerned teacher expertise. Many teachers described advanced GIS applications as too demanding or too difficult to teach, especially if they themselves had only limited experience with such software. This issue was closely linked to differences in teachers' educational backgrounds, since only a small number of participants reported geoinformatics studies beyond the minimum requirement. This is also consistent with earlier work showing that teachers' GIS-related preparation strongly shapes their readiness to use such tools in school settings [30]. Teachers with stronger GIS-related backgrounds were more willing to use demanding applications such as ArcGIS, whereas others relied on lighter tools that felt manageable in classroom conditions. A third constraint concerned curricular interpretation and assessment. Teachers noted that curriculum documents left considerable room for interpretation concerning what GIS teaching should involve at different stages. In upper secondary education, this interacted strongly with the digital matriculation examination. Some teachers prioritised software and procedures that aligned with the examination environment and avoided spending time on tools that were not directly useful for assessment. Taken together, these constraints meant that GIS teaching was often present in principle but selective in practice. Students encountered digital spatial tools regularly, yet opportunities to move towards more sustained production, comparison, and analysis remained uneven. This helps explain why the pedagogical patterns shown in Figures 3 and 4 are weighted towards guided work and lower or intermediate levels of GIS-related cognitive demand rather than towards routine student-led spatial analysis [28,29]. Time constraints and device routines directly limited the use of digital production tasks:

> *"Usually everything is done on paper. It takes a huge amount of time to fetch computers from cupboards and to log in. And then there is always the question of where things should be saved or whether earlier work can still be found. Basic things are not self-evident after all. That is why I am not very enthusiastic about them." (Teacher 3)*

Upper secondary teaching was also shaped by alignment with the matriculation examination:

> *"Mostly those, because students will be dealing with them in the matriculation examination anyway. And then we do not want to mix in too many different ones. There are no major differences between them, but it is well known that some tiny detail can make the whole thing fall apart and collapse. Some students are used to working with their own programs, and of course they may do so, but we always point out that there may be an unpleasant surprise in the matriculation examination and no one will help there." (Teacher 16)*

Taken together, these examples show that constraints on GIS teaching were not abstract background factors, but directly shaped the kinds of digital tasks teachers considered worth assigning and the tools they regarded as pedagogically viable.

5. Discussion

The first main discussion point concerns the kind of GIS-related digital work that was actually visible in school geography. The findings showed that teachers used digital spatial tools regularly, but this use was concentrated mainly on lightweight browser-based services such as Google Earth, Google Maps, and, in upper secondary settings, Geodata portal “Paikkatietoikkuna”. More demanding GIS applications such as ArcGIS appeared only rarely and were usually associated with later upper secondary study, especially the optional geomedia module. This suggests that, in everyday school practice, GIS teaching was not absent but selective: teachers did engage students with digital spatial tools, yet the depth of that engagement depended strongly on whether the tools were seen as manageable in relation to time, student readiness, and the sequence of the curriculum. In this respect, the findings support the interpretation that what counts as GIS teaching in practice is shaped less by the full analytical potential of available technologies than by whether those technologies can be used quickly, coherently, and with sufficient pedagogical control in ordinary lessons.

The second main discussion point concerns pedagogical organisation. The findings showed that GIS-related digital work was commonly organised through teacher-led approaches, especially demonstration, tightly sequenced guidance, and limited procedural autonomy when students were using a tool or completing a task for the first time. Figure 4 makes this pattern more explicit by distinguishing between two broad pedagogical orientations in the data: student-led work and teacher-led work. In practice, teacher-led forms such as follow-along demonstration and whole-class work were more common overall, whereas student-led forms appeared more selectively and were linked especially to upper secondary contexts and later stages of learning. More independent work was described mainly in upper secondary teaching and usually only after students had already developed some familiarity with digital tasks. By contrast, lower secondary teaching was more often characterised by whole-class progression, highly explicit step-by-step instructions, and lower expectations of independent task completion. Read together with Figure 3, these patterns suggest that pedagogical differences between lower and upper secondary GIS teaching concerned not only content level, but also the typical level of cognitive demand teachers considered realistic. In this sense, the revised Bloom's taxonomy is used here as an interpretive lens for teachers' examples rather than as a strict coding framework for every classroom task. This keeps the discussion close to the empirical findings and supports the broader interpretation that technology integration is shaped by classroom organisation and pacing, not by access alone [1,2,16].

The third main discussion point concerns the factors that limited the scope, depth, and continuity of GIS teaching. The findings identified several recurring constraints: lack of time, especially in content-heavy upper secondary modules; weak student device routines and lesson start-up losses in lower secondary classes; uneven teacher expertise with more demanding GIS applications; and the influence of curricular interpretation and the digital matriculation examination on software choice. Taken together, these factors help explain why GIS-related teaching often remained at the level of guided exploration or limited production rather than developing into more sustained student-led comparison, mapping, or analysis. The practical implications drawn from this article remain consistent with these findings: if schools wish to support deeper forms of GIS-related digital work, they need not only access to tools, but also better alignment between curriculum, assessment, teacher competence, classroom routines, and the practical usability of software.

6. Conclusion

This study shows that GIS-related digital work in Finnish secondary geography is established in principle but selective in its pedagogical realisation. Teachers reported regular use of digital spatial tools, yet this use relied mainly on lightweight browser-based services such as Google Earth, Google Maps, and, in upper secondary settings, Geodata portal "Paikkatietoikkuna". More demanding GIS applications remained rare and were typically associated with later upper secondary study or optional coursework. The findings therefore suggest that the presence of digital tools in a subject does not by itself indicate deep pedagogical integration. What matters is whether those tools can be used in ways that are manageable within classroom time, aligned with curricular and assessment priorities, and supported by teacher expertise.

Taken together, the findings point to a broader lesson for digital education research. The educational value of specialised digital tools depends less on technical sophistication than on pedagogical usability under real school conditions. In this study, GIS-related work was typically organised through teacher-led forms such as follow-along demonstration and whole-class work, as summarised in Figure 4. Student-led forms, including independent work supported by instructions and inquiry- or phenomenon-based work, appeared more selectively and were linked mainly to upper secondary contexts and later stages of learning.

Read together with Figure 3, these findings suggest that upper secondary GIS work more often moved towards tasks that teachers associated with higher levels of cognitive demand, while lower secondary work remained more often at the levels of remembering, understanding, and applying. Here, the revised Bloom's taxonomy [17] functions as an interpretive framework for teachers' examples rather than as a strict coding scheme for all classroom activity. At the same time, lack of time, uneven teacher expertise, weak device routines, and the influence of the digital matriculation examination limited the scope, depth, and continuity of GIS-related teaching. For geography education, these findings underline the need to view GIS not as an isolated innovation, but as part of a wider pedagogical ecology shaped by curriculum, assessment, software usability, classroom routines, teacher learning, and the inclusion of GIS in teacher education [31]. Unlike the first article based on the same interview material, which focused on classroom spaces and teaching technologies, the present article specifically contributes an account of how teachers used GIS-related software, how they pedagogically organised GIS work, and why more analytically demanding uses of GIS often remained limited. The study is based on a qualitative sample of 20 teachers and does not aim for statistical generalisability. In addition, the data capture reported practices rather than classroom observation. Even so, the interviews provide a detailed account of how teachers interpret the place of GIS in their subject and how specialised digital tools are adapted to fit everyday pedagogical realities.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the authors used Microsoft Copilot in order to enhance the English, grammar, and idiomatic expressions within the text. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

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CRediT authorship contribution statement

Petteri Muukkonen: Conceptualization, Funding acquisition, Methodology, Project administration, Supervision, Writing – original draft, Writing – review and editing. Ronja Päivärinta: Conceptualization, Formal analysis, Methodology, Writing – original draft.

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