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Title:

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Abstract

This study analyses how upper secondary students demonstrate foundational GIS competence in essay responses to a Finnish geography matriculation examination. A random sample of 100 Finnish-language responses was examined using qualitative deductive content analysis, the revised Bloom's taxonomy, the SOLO taxonomy, and the GeoTAITO model. The task addressed geographic information, spatial datasets, and spatial analyses through an applied esports context. Although the national core curriculum expects students to master foundational GIS- and geomeia-related competencies, many did not define geographic information as the combination of location and attribute information, and most could not name a spatial analysis. Responses were stronger when discussing practical benefits for players, game companies, and broadcasters. The findings identify a foundational bottleneck in GIScience education: contextual familiarity with spatial representations does not necessarily develop into formal understanding of spatial data and GIS analysis.

Keywords: GIScience education; GIS education; GIS competence; assessment; GIS learning; matriculation; Revised Bloom's taxonomy; SOLO taxonomy

1. Introduction

Young people encounter geographic information, GIS, and geomeia increasingly often in school and in everyday digital environments, including social media, mobile applications, digital games, online maps, and location-aware services (Hynynen et al., 2023; Muukkonen et al., 2022). These encounters are part of a broader digital turn in geography and geomeia studies, but the educational question concerns what learners are able to understand and do with such information (Ash et al., 2018; Fast et al., 2017; Lapenta, 2011). Everyday geomeia use can shape how young people appropriate, navigate, and make sense of space, yet exposure to maps, satellite imagery, virtual globes, online GIS, and web-based mapping services does not automatically mean that learners possess the knowledge and skills needed to interpret cartographic and geospatial information accurately or critically (Anunti et al., 2018; Fischer, 2014; Havelková & Hanus, 2019; Moorman & Crichton, 2018; Ooms et al., 2016). In addition, accessible online GIS and digital geomeia can offer powerful learning opportunities when students actively create, manipulate, and interpret spatial representations in pedagogically guided tasks (Barnikel & Ploetz, 2015; Jekel et al., 2014). The GI Learner review similarly argues that spatial literacy, spatial thinking, and GIScience should be integrated into school education through a learning line that supports age-appropriate progression in geospatial thinking (Zwartjes et al., 2017). However, learners may remain familiar with interfaces and examples without developing a formal understanding of how spatial data are structured, analysed, represented, and interpreted. For GIScience education, foundational GIS competence therefore includes conceptual knowledge of geographic information, methodological knowledge of spatial data and analysis, image interpretation skills, technological understanding, spatial thinking, and the capacity to interpret geomeia critically (Anunti et al., 2020; Bearman et al., 2016; Healy & Walshe, 2020; Hickman, 2022;

Lee & Bednarz, 2012; Moorman & Crichton, 2018; Muukkonen, 2026; Pellikka et al., 2024; Schulze et al., 2015; Zwartjes et al., 2017).

This article uses the Finnish geography matriculation examination as an empirical setting for analysing this challenge. Finland provides a relevant case because geography is the principal school subject through which students encounter geographic information, geomedial, spatial data, and GIS-related analytical practices. In Finnish schooling, geography is taught as part of Environmental Studies in Grades 1–6, as a separate subject in Grades 7–9, and in general upper secondary education through one compulsory and three elective national modules (Finnish National Agency for Education, 2014; 2019; 2024b). The Finnish school system is typically described as a continuum from pre-primary education to nine years of compulsory basic education, followed by upper secondary education in either the general or vocational track (Finnish National Agency for Education, 2024a; Ministry of Education and Culture, 2025). Within this system, GIS- and geomedial-related competencies are expected to develop cumulatively from basic awareness of geographic information and everyday geomedial use toward more advanced abilities to collect, analyse, evaluate, and communicate with geomedial (Lammi et al., 2026). However, the extent to which students can demonstrate such competence in high-stakes assessment remains an empirical question.

The Finnish Matriculation Examination is a nationwide digital school-leaving examination completed at the end of general upper secondary education. It also serves as an important qualification for entry to higher education (Finnish Matriculation Examination Board, 2024; Ministry of Education and Culture, 2025). Geography is an elective subject within the humanities and natural sciences group, and its tasks typically require students to interpret multimodal materials, use disciplinary concepts and produce extended essay responses. From a GIScience education perspective, this assessment context is valuable because essay

responses make students' reasoning visible. They can show how students define concepts, connect spatial ideas, justify analytical choices, and reveal misconceptions in ways that selected-response formats cannot easily capture, especially when responses are analysed through frameworks that attend to the structural quality of reasoning (Biggs & Collis, 1982; Chan et al., 2002; Hickman, 2022). The examination therefore provides a rare high-stakes dataset for studying not only whether students know basic GIS terminology, but how they organise and express GIS-related understanding in written form.

The aim of this study is to analyse how upper secondary students demonstrate foundational GIS competence in essay responses to a digital geography matriculation examination task. The study focuses on students' ability to define geographic information, recognise spatial datasets, name and describe basic spatial analyses, and express GIS-related reasoning at different levels of structural maturity. By combining the cognitive demand of the task, the SOLO-level maturity of the responses, and the GIS and geomeia competencies demonstrated in those responses, the study examines the transition from everyday recognition of spatial representations to formal understanding of spatial data and GIS analysis. The study is guided by the following research questions:

1. How do upper secondary students demonstrate foundational GIS competence in essay responses, particularly in relation to geographic information, spatial datasets and basic spatial analyses?
2. What strengths, gaps and misconceptions are visible in these responses, and how does their SOLO-level maturity reflect students' GIS-related reasoning in relation to the cognitive demand of the task?

2. Theoretical background

2.1 Foundational GIS competence and geomeia in school geography

Foundational GIS competence is not a single skill but a layered form of understanding that connects spatial data structures, cartographic and geospatial representations, and critical interpretation (Briwa & Wetherholt, 2020; Goodchild, 1992; Lee & Bednarz, 2012; Muukkonen et al., 2022; Zwartjes et al., 2017). In GIScience, geographic information is commonly understood as spatially referenced data that link geometry, attributes, and context (Goodchild, 1992; Muukkonen et al., 2022). For school-level GIS education, the central issue is therefore not whether students can recognise maps or location-aware applications, but whether they understand how spatial data are structured, represented, queried, analysed, and interpreted.

In Finnish school geography, these GIScience ideas are embedded in the broader curriculum concept of geomediality, which covers multiple forms of spatially referenced media and data (Hynynen et al., 2022; Muukkonen et al., 2022; Pellikka et al., 2024). International geomediality studies similarly frames geomediality as part of the co-production of media, space, place, and mobility in mediatized societies (Fast et al., 2017; Lapenta, 2011), while everyday geomediality use shapes how people appropriate space in daily life (Fischer, 2014). This broad framing is pedagogically useful because it connects school geography with young people's everyday media environments.

Anunti et al. (2018) found that upper secondary students mainly used accessible digital geomediality, such as web materials, digital images and videos, as sources of geographic information, but they did not necessarily know the concept of geomediality well.

Geomediality and GIS work can be understood as a sequence from data acquisition and processing to analysis and visualisation (Hynynen et al., 2023). This sequence is directly relevant to the Matriculation Examination's Geography exam in the spring 2020 and the exam's task 9: students were expected to define geographic information, recognise what

kinds of spatial datasets can be collected, name suitable analyses, and discuss the use of the resulting information. The task therefore tested whether students could connect the main stages of geomeia and GIS work rather than only describe spatial representations at the surface level.

The GeoTAITO model is a developmental model of school pupils' and students' geomeia competence (Lammi et al., 2026). It is used here as a domain-specific framework for locating foundational GIS competence within a progression from basic awareness and interpretation of geographic information toward more advanced analytical and evaluative geomeia competence. This makes the model relevant for analysing whether upper secondary students can define geographic information, recognise spatial datasets, and describe spatial analyses in an assessment context.

2.2 Learning objectives and structural maturity in GIS-related essay responses

To analyse the task side of the assessment, this study uses the revised Bloom's taxonomy (Anderson & Krathwohl, 2001). The taxonomy distinguishes between knowledge dimensions, including factual, conceptual and procedural knowledge, and cognitive processes ranging from remembering and understanding to applying, analysing, evaluating and creating. This distinction is useful in GIScience education because GIS-related assessment tasks may appear similar at the level of topic while requiring different kinds of knowledge. For example, defining geographic information primarily requires conceptual precision, whereas naming and describing spatial analyses requires procedural or methodological knowledge. Comparing virtual and real-world spatial datasets, in turn, requires students to apply and analyse conceptual knowledge about spatial data structures. In map-reading research, Ooms et al. (2016) similarly used Bloom's taxonomy to identify the cognitive level required by cartographic tasks and showed that map reading, map analysis and map interpretation correspond to different forms of cognitive demand. Their findings also indicate

that higher-level tasks may fail not because students cannot reason analytically in general, but because they lack prerequisite lower-level knowledge such as symbol recognition, scale understanding or cartographic terminology. Bloom's taxonomy is therefore used here to classify the intended cognitive demand of the sub-tasks before students' responses are evaluated, while the subsequent SOLO and content analyses examine how far students were able to meet that demand in practice.

Table 1. Application of the SOLO taxonomy to essay responses to Task 9 in the spring 2022 geography matriculation examination. The criteria are based on the SOLO taxonomy (Biggs & Collis, 1982), the official characteristics of a good answer, and observations made during the reading of the essay responses.

SOLO class	Level	Characteristic features of the essay response
0	No response	The candidate has left the response field for the sub-task blank.
1	Prestructural	The response is incorrect or does not answer the task. It addresses irrelevant or wrong perspectives.
1A	Transitional	The response is incorrect as a whole, but a small part of it shows some understanding of a relevant perspective. It is clear that the candidate has not understood the central aspects of the question. Correct and relevant content is treated only narrowly.
2	Unistructural	The response presents one correct perspective in more detail. Essential perspectives are missing or are only mentioned briefly and list-like. Examples may be weak because the student is not able to apply the issue in the new context.
2A	Transitional	The response examines two perspectives related to the task, but only superficially. At least one of the perspectives lacks sufficient justification or examples.
3	Multistructural	The candidate approaches the correct topic from two or more perspectives and supports the response with relevant examples or a clear explanation. Connections and causal relationships between perspectives are missing or remain superficial.

3A	Transitional	The response forms a coherent whole, although the connections between ideas are still partly incomplete. It includes minor observations about how the phenomenon is connected to practical applications.
4	Relational	In a structurally successful response, several relevant perspectives are analysed and links between them are made visible. Geographical terminology is used accurately.
4A	Transitional	The response is logical and multifaceted, and it analyses and evaluates causal relationships related to the phenomenon.
5	Extended abstract	The coherent and excellently structured response demonstrates deep understanding of the phenomena and concepts related to the task and their connections to the real world. The topic is examined at different regional scales. Different perspectives are analysed in detail and evaluated critically.

In this study, Bloom’s taxonomy and SOLO taxonomy serve different purposes. Bloom’s taxonomy is used to characterise the learning objectives and cognitive demand embedded in the examination task, whereas SOLO provides a way to examine how structurally mature students’ written responses are. SOLO is particularly useful here because GIS-related essay responses may contain isolated correct terms without integrating them into a coherent explanation of spatial data or analysis. This distinction links the task side and the response side of the assessment and motivates the analytical design described in the methods section.

3. Materials and methods

3.1 Study context, data and examination task

The study is based on essay responses to Task 9, “Use of geographic information in e-sports”, in the Finnish geography matriculation examination administered in spring 2022 (Finnish Matriculation Examination Board, n.d.). The geography examination consists of nine tasks, of which candidates answer five. The tasks are divided into three parts: Part 1 contains one compulsory 20-point task, Part 2 contains four 20-point tasks from which candidates answer two, and Part 3 contains four 30-point tasks from which candidates answer two (Finnish

Matriculation Examination Board, 2024). The maximum score is 120 points. Task 9 was one of the optional 30-point tasks in Part 3 and consisted of four sub-tasks (9.1–9.4) (Finnish Matriculation Examination Board, n.d.). It was selected for this study because it addressed geographic information conceptually, methodologically, and in an applied context.

Altogether, 2,276 candidates participated in the geography examination, and 618 answered Task 9. Approximately 5% of the candidates took the examination in Swedish. The present analysis is based on a random sample of 100 Finnish-language essay responses drawn from the full set of responses to Task 9.

Task 9 comprised four sub-tasks addressing conceptual knowledge, spatial datasets, spatial analysis, and the use of geographic information from different stakeholder perspectives. It was accompanied by two stimulus materials. Material 9.A presented a map-like screenshot showing the movement routes of two teams in a virtual game world, whereas Material 9.B presented a three-dimensional visualisation of locations where 11 million player characters had died in a game environment. Together, these materials oriented candidates to the applied e-sports context and showed how spatial data may be represented in a virtual environment. The wording of the task and sub-tasks, point allocation, and selected extracts from the official characteristics of a good answer are summarised in Table 2.

The Finnish Matriculation Examination Board granted research permission for the data. The underlying dataset contains authentic student essay responses from the Matriculation Examination and is therefore confidential. For this reason, findings are reported only as aggregated summaries and reconstructed typical essay answers; the data cannot be made publicly available.

Table 2. Task 9 and its sub-tasks in the spring 2022 geography matriculation examination.

The table includes the task wording and selected extracts from the official characteristics of a good answer. The task asked candidates to apply knowledge of geographic information to an e-sports context and to answer each sub-task in essay form (Finnish Matriculation Examination Board, n.d.).

Task and sub-tasks	Geography matriculation examination, spring 2022, wording of Task 9	Expected content according to the characteristics of a good answer	Points
9	Use of geographic information in e-sports		Totally 30 points
9.1	Define the concept of geographic information.	A correct answer defines geographic information using the concepts of location information and attribute information. Additional credit is given for clarifying that location can be expressed, for example, as coordinates and that attribute information refers to properties of the object or place.	3 points
9.2	Discuss what types of spatial datasets can be collected from a virtual game world. Use materials 9.A and 9.B in your answer. In addition, compare spatial datasets from a virtual game world with spatial datasets from the real world.	A strong answer discusses different types of spatial datasets that can be collected in a virtual game world, uses the provided materials, and compares virtual-world and real-world spatial data. Credit is given for accurate spatial vocabulary and for identifying, for example, point data, line data, and raster-like density representations, as well as similarities and differences between virtual and real-world coordinate systems and data collection.	12 points
9.3	Name two spatial analyses that could be used to study the actions of entertainment game characters in a virtual game world. Briefly describe how they could be used for this purpose. You may use materials 9.A and 9.B in your answer.	A strong answer names two relevant spatial analysis methods and explains briefly how they could be used in the given context. Examples in the official guidance include overlay analysis, network/connectivity analysis,	6 points

		buffer/neighbourhood analysis, and density analysis or heat maps.	
9.4	Discuss what benefits an individual player, the company that developed the game, and a television channel broadcasting e-sports may gain from geographic information related to the game.	A strong answer discusses the benefits of geographic information from the perspectives of all three actors named in the task: the individual player, the game company, and the broadcasting channel. Credit is given for justified observations, concrete examples, and use of the provided materials where relevant.	9 points

3.2 Analytical procedure

The essay responses were analysed using qualitative deductive content analysis. The analysis proceeded in six stages. First, each sub-task was interpreted in relation to the knowledge and cognitive process dimensions of the revised Bloom’s taxonomy to identify the expected cognitive demand (Anderson & Krathwohl, 2001). Second, all sampled essay responses were read and provisionally classified by sub-task using the SOLO taxonomy to assess the structural quality of students’ reasoning (Biggs & Collis, 1982; Chan et al., 2002). Third, the coding criteria were refined on the basis of this first reading, and the responses were reclassified without reference to the first-round codes. Fourth, responses that remained uncertain after the second round were read a third time before a final SOLO category was assigned. Fifth, the content of the responses was interpreted in relation to GIS and geomedial competencies, particularly the foundational domains described in the GeoTAITO model (Lammi et al., 2026). Sixth, reconstructed typical responses were created to illustrate recurring patterns of GIS-related understanding, reasoning, and misconceptions at different SOLO levels. These final steps made it possible to identify not only the structural maturity of the responses but also the specific GIS-related concepts, methods, and misconceptions expressed in them.

The task-specific SOLO criteria are summarised in Table 1. After the final classification, reconstructed typical responses were created to illustrate qualitative differences between SOLO levels. These are not verbatim quotations, but synthesis-like examples that represent recurring patterns of GIS-related understanding and misconceptions across the dataset; the full set of reconstructed typical responses by sub-task is provided in Supplementary material S1.

Because authentic examination essay responses could not be quoted verbatim, reconstructed response excerpts were created to represent typical features of different SOLO levels. Each reconstructed excerpt combines recurring features observed across several essay responses rather than reproducing any single candidate answer. These reconstructed typical responses are among the central results of the study: they show how the same GIS-related task can produce qualitatively different forms of reasoning, from fragmented or misplaced associations to more accurate but still structurally limited explanations. In the present article, the analysis focuses on students' understanding of the concept of geographic information, their grasp of core GIS-related basics, and their knowledge of basic spatial analyses. The aspects dealing more extensively with the broader application of geographic information in the e-sports context are not foregrounded here.

4. Results

The essay responses show a clear contrast between students' ability to discuss the practical uses of geographic information and their ability to explain the conceptual and methodological foundations of GIS. The weakest performance appeared in sub-task 9.1, which required candidates to define geographic information, and in sub-task 9.3, which required them to name and describe spatial analyses. Responses were more developed in sub-task 9.4, where candidates could discuss practical benefits for players, game companies, and broadcasters. This pattern suggests that many students could reason about familiar applications of spatial

information but had difficulty articulating the data structures and analytical operations behind them. The cognitive demand of the sub-tasks, classified using the revised Bloom’s taxonomy, is shown in Table 3, and the distribution of essay responses across SOLO classes is summarised in Table 4. Reconstructed typical responses are used throughout the section to show how different levels of GIS-related reasoning appeared in the essay answers; a fuller set of reconstructed typical responses is available in Supplementary material S1.

Table 3. Classification of the sub-tasks according to the knowledge dimension and cognitive process dimension of the revised Bloom’s taxonomy (Anderson & Krathwohl, 2001). Bold entries indicate the primary knowledge dimension and highest cognitive process required by the sub-task; entries in parentheses indicate secondary knowledge or cognitive processes needed for producing a complete essay response.

	Cognitive process dimension in the revised Bloom’s taxonomy					
Knowledge dimension	Remember	Understand	Apply	Analyse	Evaluate	Create
Factual knowledge	9.1 (9.3)					
Conceptual knowledge	(9.1)		9.2, 9.4	9.2, 9.4		
Procedural knowledge		(9.2)	9.3 (9.4)			
Metacognitive knowledge						

Table 4. Distribution of essay responses across SOLO classes by sub-task, based on the SOLO taxonomy (Biggs & Collis, 1982). Values are percentages (%) of the analysed sample (n = 100).

	Proportion of answers in SOLO taxonomy classes (%)										
Sub-task	0	1	1A	2	2A	3	3A	4	4A	5	Row sum

9.1	1	26	45	9	7	10	2	0	0	0	100
9.2	1	10	26	20	31	9	3	0	0	0	100
9.3	17	25	41	14	3	0	0	0	0	0	100
9.4	4	12	3	11	25	29	8	7	1	0	100

4.1 Understanding of the concept of geographic information

Essay responses to sub-task 9.1 showed substantial weaknesses in students' command of the basic concept of geographic information. In the sample, 71% of essay responses fell into SOLO classes 1 or 1A, indicating that most students either defined the concept incorrectly or only demonstrated fragmentary understanding. Only a minority produced a definition that clearly combined location information with attribute information, which was required for a fully correct answer. In practice, this means that the most fundamental conceptual basis for later GIS-related reasoning was missing in a large share of essay responses.

The most typical misconception was that geographic information was understood as general knowledge about a place rather than as data in which location and attributes are linked. In the weakest responses, students interpreted the concept as local familiarity, place knowledge, or the ability to move successfully in an environment. Another recurring error was to equate geographic information with a single application or technology, such as GPS, Google Maps, or location tracking on a phone. Some responses also reduced the concept to one narrow content area, such as population statistics, without articulating the underlying principle of spatially referenced data. A reconstructed prestructural response illustrates this place-knowledge interpretation: *“Geographic information means knowing the details of a place or having an overall picture of an area. It helps people move around, for example in their home town.”*

A transitional prestructural response shows partial but still imprecise recognition of place-related information: *“Geographic information is all the information collected about a place*

and the things connected to it. For example, Google Maps shows geographic information on a map.”

A unistructural response typically identified only the location component: *“Geographic information is information about the exact location of something. For example, satellites and GPS can provide precise coordinates for a person’s location.”*

A transitional unistructural response began to connect place and attributes, but only through a single everyday example: *“Geographic information is information connected to a place. For example, one could use a person’s address: it combines information about the location and information about who lives there. We use geographic information every day, often without noticing it.”*

A multistructural response gave the expected conceptual components more explicitly:

“Geographic information combines location information and attribute information. Location can be expressed, for example, as coordinates or an address, and attributes may include rainfall, population, or the number of floors in a building.”

These results indicate that many students had not internalised the basic logic of GIS as a form of spatially referenced data. Because this core concept underpins the interpretation of spatial datasets and the selection of appropriate analyses, conceptual weakness at this level likely constrained performance in the later sub-tasks as well. The findings therefore suggest that difficulties with higher-level reasoning were, at least in part, rooted in insufficient mastery of the most basic GIS concepts.

4.2 Core GIS-related basics in students’ responses

Although the main emphasis here is not on students’ broader applications of GIS in the e-sports context, the essay responses to sub-task 9.2 still provide useful evidence of students’ basic GIS understanding. The strongest essay answers recognised that spatial datasets in a

virtual environment may include point-based information on events, line-based information on movement routes, and raster-like visualisations such as density surfaces or heat maps.

They also showed awareness that both virtual and real-world spatial datasets share the same core principle: they combine location and attributes and can be visualised and interpreted spatially.

However, these elements of basic GIS literacy were only unevenly present. Many essay responses remained descriptive and stayed close to the surface features of the given materials. Instead of identifying types of spatial data or discussing their structure, students often repeated what the visual materials showed in general terms. More precise observations—such as distinguishing between point, line and raster-like representations, or noting that virtual environments may rely on their own coordinate systems—were almost entirely absent from the sample. This suggests that even when students recognised that something spatial was being represented, they often lacked the vocabulary and conceptual precision needed to discuss spatial data accurately. The content analysis therefore adds a fourth layer to the taxonomic analysis: it shows concretely which GIS concepts and methods were present, missing, or misunderstood in the essay responses.

In terms of content, many students could identify plausible examples of spatial data from the virtual game world. They mentioned player or character movements, routes, death locations, dangerous areas, encounter locations, player actions, terrain, elevation differences, buildings, in-game objects, and frequently used routes. When comparing virtual and real-world datasets, students often noted that game-world data may be automatically recorded, highly precise, and comprehensive, whereas real-world data may involve measurement errors, incomplete coverage, and temporal change. These observations show that many responses contained

relevant empirical content, even when the students did not describe the data using precise GIS terminology.

A reconstructed prestructural response stayed at the level of general comparison between a game world and the real world: *“The game world is not real but more unrealistic and can be three-dimensional. In the real world there are no levels or tasks to complete, so information is not collected about you. In games and in the real world, geographic information uses satellite images and GPS. The video shows a black-and-white place with a volcano and ridges.”*

A transitional prestructural response referred to the materials but interpreted them mainly through game tactics and safety: *“Many kinds of geographic information can be collected from games. In map 9.A, the players’ movements are shown and these can be used for tactics. In 9.B, the map shows where 11 million game characters have died. From this one can study roads, urban areas, or the safest places. If this were from the real world, it could perhaps be used as a method of real warfare.”*

A unistructural response identified one relevant type of spatial information but did not yet discuss data structure in detail: *“It is easy to collect spatial datasets from a virtual game world. Figure 9.A shows data on the movements of game characters and teams. From the routes, it may be possible to infer which team won. Material 9.B shows where 11 million players have died, so it provides information about death locations. All information is saved through the computer. Geographic information can be used to improve team tactics.”*

A transitional unistructural response described several relevant examples while still remaining close to the surface of the materials: *“From a virtual game world, many kinds of spatial data can be collected. For example, the movements, routes and death locations of game characters can be stored accurately. Material 9.A shows the movement of teams on the game map, and material 9.B shows points where game characters have died. Such data can*

be used to identify dangerous places in the game world. The data are collected automatically through the game code, whereas in the real world data collection involves more limitations.”

A multistructural response identified several forms of spatial data more clearly: “*A virtual game world can produce many kinds of spatial datasets. These include player routes, point locations of deaths, and broader surface representations that show where events are concentrated. Similar principles apply in the real world, although real-world data are not always as complete or as precise.*”

4.3 Knowledge of basic spatial analyses

Students’ command of basic spatial analyses was particularly limited in the essay responses to sub-task 9.3. Seventeen percent of the sample left the response field blank, and a further large majority failed to name even one spatial analysis. Altogether, 72 of the 100 essay responses did not contain the name of any analysis or any unambiguous equivalent. Only 11 essay responses mentioned at least one relevant analysis. This makes sub-task 9.3 the clearest indicator that basic methodological GIS knowledge was weak in the sample.

Among the few responses that did identify relevant methods, the analyses mentioned were density analysis or heat maps, buffer or neighbourhood analysis, overlay analysis, route analysis, and network or connectivity analysis. Even in these cases, correct naming did not necessarily imply correct understanding. Descriptions were often brief, imprecise, or shifted quickly from the analysis itself to its presumed benefits for gameplay. As a result, only a very small number of responses demonstrated not only recall of a method name but also a basic understanding of how the method could be used to examine patterns in player movement or in the spatial distribution of deaths.

A recurring pattern in weaker responses was that students confused spatial analysis with general game strategy, personal interpretation of a map, or technological tracking in everyday

life. For example, some suggested GPS tracking of game characters as a spatial analysis, while others described how a player could inspect a map and decide where to attack. Such answers indicate that the idea of an analysis as a systematic GIS-based operation on spatial data was often missing. In other words, students frequently recognised that maps and locations matter, but they did not recognise what counts as an analysis within a GIS framework. Taken together with the results for sub-task 9.1, this suggests that weaknesses in methodological knowledge were closely connected to weaknesses in conceptual understanding. Students who lacked a clear grasp of geographic information as spatially referenced data also appeared to have difficulty recognising what kinds of analytical operations are appropriate for such data.

A reconstructed prestructural response confused spatial analysis with tracking and tactical map use: *“Game characters could be studied, for example, by using GPS to track their movements. The map could also be used to decide where players should attack.”*

A unistructural response named one relevant method and linked it to the game context: *“A heat map could be used to show where movement or deaths are concentrated and to identify the most dangerous areas in the game world. Route-based analysis could also reveal which paths players use most often and where encounters are likely to take place.”*

5. Discussion

The discussion returns to the central theoretical claim developed in the introduction and theoretical background: everyday exposure to maps, virtual environments and other geomeia does not automatically develop into formal GIS competence or critical geomeia literacy. The results support this claim in a specific way. The weakest performance appeared in the sub-tasks that required students to define geographic information and name spatial analyses, whereas responses were somewhat stronger when students could discuss practical benefits for

players, game companies and broadcasters. This pattern suggests that students could often reason about familiar uses of spatial information in an e-sports context, but many lacked the conceptual and methodological vocabulary needed to explain the underlying GIS logic. The reconstructed typical responses make this visible: lower-level answers frequently associated geographic information with place familiarity, GPS, game strategy or map-like visualisations, while only stronger responses explicitly connected location, attributes, spatial datasets and analytical methods. The combined framework of Bloom's taxonomy, SOLO taxonomy and the GeoTAITO model therefore shows not only that many responses remained structurally immature, but also where the immaturity was located: in the conceptual, representational and procedural foundations of GIS competence (Hynynen et al., 2022; Lammi et al., 2026; Moorman & Crichton, 2018; Ooms et al., 2016; Pellikka et al., 2024).

5.1 Conceptual foundations in relation to the GeoTAITO model

The first major finding concerns the concept of geographic information. The results for sub-task 9.1 were the clearest indication of a conceptual bottleneck: 71% of the responses were classified as SOLO 1 or 1A, and none reached the relational or extended abstract levels. The reconstructed responses show the nature of this weakness. At the lowest levels, students described geographic information as knowing details of a place, having an overall picture of an area, using Google Maps, or tracking a precise location through GPS. These answers were not entirely unrelated to geography, but they did not identify the defining relationship between location information and attribute information. Even some unstructural responses recognised only the location component, for example coordinates or exact position, without explaining what information was attached to the location. This suggests that the "where" component of geographic information was more accessible than the "what" component. For GIScience education, this distinction is crucial: without attribute information, location remains a position; without location, attributes cannot be analysed spatially. The low SOLO

levels in sub-task 9.1 therefore indicate a specific conceptual bottleneck in students' understanding of spatial data structures (Goodchild, 1992; Muukkonen et al., 2022).

This finding is consistent with the Finnish geomedia literature used in the theoretical background, but the present study adds a more precise assessment-based perspective. The GeoTAITO model treats awareness of geographic information and the ability to read and interpret geomedia as early but essential stages in broader geomedia competence (Lammi et al., 2026). However, the reconstructed responses suggest that even this early domain cannot be assumed at the end of upper secondary education. Students often used examples from everyday digital geomedia but did not convert those examples into a formal definition. This aligns with Lammi et al.'s (2026) observation that learners may use geomedia in everyday contexts without explicitly recognising the relevant concepts, and with Hynynen et al.'s (2022) finding that geomedia may remain a broad curriculum concept rather than an explicit classroom term. Thus, the low SOLO levels in sub-task 9.1 should not be interpreted only as individual failure; they also reveal the difficulty of turning broad curriculum language into assessable GIScience knowledge.

5.2 From recognising spatial representations to understanding analysable data

The second major finding concerns the gap between recognising spatial representations and understanding them as analysable datasets. In sub-task 9.2, students often described what the materials showed—movement routes, death locations, dangerous areas, or game-world features—but did not consistently identify the underlying data structures. Lower-level responses treated the task as a comparison between “real” and “unreal” worlds or as a discussion of game tactics. Even stronger responses commonly described routes and death locations without clearly articulating point, line, or raster-like data, coordinate systems, or differences between virtual and real-world datasets. In GeoTAITO terms, many students

could read or describe geomeia at a basic level, but fewer demonstrated the representational precision needed to treat the materials as structured spatial data (Lammi et al., 2026).

The methodological weakness was even clearer in sub-task 9.3. Seventeen per cent of the responses were blank, and 72 of the 100 responses did not name any spatial analysis or unambiguous equivalent. At the prestructural level, students treated GPS tracking, visual map inspection, game tactics, surveys, or the given visualisation itself as spatial analyses. Only a small minority mentioned methods such as heat maps, density analysis, buffer analysis, overlay analysis, route analysis, or network analysis. This shows that the main difficulty was not only terminology but the absence of a basic understanding of analysis as a GIS operation applied to spatial data. Without that methodological threshold, students' opportunities to progress towards analysing, evaluating, and applying geomeia remain limited.

5.3 Practical reasoning outpaced formal GIS understanding

The main implication for upper secondary geography is that foundational GIS competence cannot be assumed from students' everyday exposure to geomeia. In the GeoTAITO model, awareness of geographic information, interpretation of geomeia, and analysis of geomeia form a developmental progression (Lammi et al., 2026). The present results show that many students had not secured the earlier stages of this progression: their responses often remained descriptive, conceptually vague, or methodologically inaccurate.

The contrast between sub-tasks clarifies this problem. Students performed better in 9.4, where they could discuss practical benefits of geographic information for players, game companies, and broadcasters, than in 9.1–9.3, where they had to define concepts, recognise datasets, and name analyses. This suggests that applied contextual reasoning was stronger than formal GIS reasoning. Students could often explain why geographic information might be useful, but not what it consists of or how it can be analysed.

This points to a clear instructional need: students require explicit and repeated practice in connecting spatial representations to data structures and analytical operations. Familiar digital maps, games, and visualisations can support learning, but only if teaching makes the underlying GIS concepts visible. Otherwise, students may remain able to describe spatial materials without understanding the data and methods that produce them.

The geomeia work cycle helps specify where the difficulty lies. Students were more successful in discussing the use of geographic information than in explaining the preceding stages of data collection, processing, and analysis (Hynynen et al., 2023). This indicates that the final use-value of geomeia was more accessible than the GIS processes that make such use possible.

Critical evaluation should also be interpreted cautiously. The task did not directly ask students to evaluate the reliability or limitations of spatial data, so the absence of critical evaluation is not in itself a failure. However, the low SOLO levels in 9.1–9.3 suggest that the conceptual and methodological basis for such evaluation was weak. Before students can evaluate spatial data or geomeia critically, they need a firmer grasp of what geographic information is, how spatial datasets are structured, and what spatial analyses do.

5.4 Suggestions for geography teachers

The findings point to three priorities for upper secondary geography teaching. First, geographic information should be taught as a core concept rather than assumed as background knowledge. The reconstructed 9.1 responses show that many students associated it with place knowledge, Google Maps, GPS, or location alone. Students therefore need repeated opportunities to connect the concept to concrete examples of spatially referenced data in both everyday digital environments and school geography.

Second, spatial analysis should be taught as a distinct form of GIS-based reasoning. The reconstructed 9.3 responses show that students often treated GPS tracking, visual map inspection, game tactics, surveys, or the given visualisation itself as if these were spatial analyses. Teaching should therefore make common methods, such as density, buffer, overlay, and network analysis, visible as operations applied to spatial data. Students should practise naming a method, explaining what question it answers, identifying what data it requires, and judging whether it is appropriate for a given task.

Third, familiar contexts can be used as entry points, but they should not replace formal GIS learning. The stronger 9.4 responses show that many students could discuss practical benefits of geographic information for different actors. This strength can be used instructionally by asking students to move from use-value to data and analysis: what data are needed, how are they structured, what analysis is applied, and what conclusions can be drawn?

In practical terms, teaching should make the main stages of geomedia and GIS work visible: data acquisition, data processing, analysis, visualisation, and use (Hynynen et al., 2023). Task 9 shows that students may understand the final use of geographic information better than the data and analysis processes that make that use possible. The central instructional challenge is therefore to connect applied examples systematically to the concepts and methods that underpin GIS reasoning.

Conflict of Interest statement

The authors declare that they have no conflicts of interest.

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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Supplementary materia, S1

Appendix 1. Reconstructed typical responses for different SOLO classes by sub-task

The following reconstructed responses illustrate typical features of essay answers assigned to different SOLO classes in each sub-task. They are not verbatim quotations from individual candidates. Instead, each reconstruction combines recurring features observed across several responses. Lower-level responses intentionally retain conceptual inaccuracies, weak logic, and awkward formulations where these were characteristic of the response type.

Sub-task 9.1: Define the concept of geographic information. 3 points

Prestructural response (SOLO 1): *“Geographic information means knowing the details of a place, either imaginary or real, or understanding the overall picture of an area. It helps you move around easily, for example in your own home town.”*

Transitional prestructural response (SOLO 1A): *“Geographic information is all the information collected about some place and things related to it. For example, Google Maps is geographic information on a map.”*

Unistructural response (SOLO 2)

Geographic information is information about the exact location of something. For example, satellites and GPS can provide precise coordinates for a person’s location.

Transitional unistructural response (SOLO 2A)

Geographic information is information connected to a place. For example, one could take a certain person’s address. It therefore combines information about the place and about who lives there. We use geographic information every day and often without noticing it.

Multistructural response (SOLO 3)

Geographic information combines location information and attribute information. Location information can be given, for example, as an address or coordinates. Attribute information can include the number of floors in a building, the amount of rainfall in a place, population size or other statistical information.

Sub-task 9.2: Discuss what types of spatial datasets can be collected from a virtual game world. Use materials 9.A and 9.B in your answer. In addition, compare spatial datasets from a virtual game world with spatial datasets from the real world. 12 points

Prestructural response (SOLO 1)

The game world is not real but more unrealistic and can be three-dimensional. In the real world there are no challenges or tasks to complete, so information is not collected about you. The game would be really boring if it only had everyday things in it. In games and in the real world, geographic information uses satellite images and GPS. The video shows a black-and-white place with a volcano and ridges.

Transitional prestructural response (SOLO 1A)

All kinds of geographic information can be collected from games. In map 9.A, the players' movements are shown, and from these you can make tactics for your own game. 9.B is a map showing where 11 million game characters have lost their lives. From it one can study where there are roads or city-like areas or the safest places. If it were from the real world, it could perhaps be used as a method of real war.

The geographic information of games therefore focuses on individuals and strategising compared with real-world geographic information. The game world does not have the same natural forces as the real world, where places change constantly or sometimes suddenly, for

example because of an earthquake. In games only if the programmer has decided to do so, and usually not. Nothing in the real world can therefore be said for sure, but in games the player usually has a lot of information about the virtual game world. For example, from a map you can see the whole game world at one glance.

Unistructural response (SOLO 2)

It is easy to collect spatial datasets from a virtual game world. Figure 9.A shows data on the movements of game characters and teams. From the routes, it may be possible to infer which team won. The actions, meeting places and divisions of teams can also be collected. From material 9.B one can see where 11 million players have died, so one gets information about death locations. All information is saved through the computer. Geographic information can be used to polish team tactics.

Not as much information can be obtained from real-world spatial datasets compared with virtual game worlds, but it can be used, for example, in investigating crimes.

Transitional unistructural response (SOLO 2A)

Many kinds of geographic information can be collected from a virtual game world. For example, the movements, routes and death locations of game characters can be stored accurately. The blue and red lines in material 9.A show the movements of teams on the game map. The points in material 9.B show the deaths of game characters, and from this one can analyse dangerous places in the game world. It would also be possible to collect information about where players spend most time and when they perform certain actions, such as using weapons. This information can be used to improve game strategy and game development.

The data are collected automatically through the game code, and there are no limitations like in the real world. The real world changes over time, whereas the game world changes only

because of the coder. In both, movement and route choices can be studied. For example, one's own running routes and statistics can be studied with a phone GPS application.

Multistructural response (SOLO 3)

Very diverse spatial datasets can be collected from a virtual game world. Everything that happens in the game can be stored accurately. Players' movements, routes (e.g. material 9.A), death locations (material 9.B) and other actions can be presented on a map. Based on the materials, the most popular routes, the most dangerous areas and the places where players have encountered each other can be identified. In addition, information can be collected about terrain, elevation differences, building locations and other objects inside the game.

Geographic information in a game world is accurate because it is based on the game code. Game developers can use the data in game development, for example by balancing maps or improving the gaming experience. In the real world, geographic information is collected by people and GPS devices, which always involves the possibility of errors. In addition, the data obtained are not as comprehensive as in the game world, where all events can be stored.

However, the game world and the real world have much in common in that both can be used to study movement and the properties of places. In both, illustrative maps and statistics can be produced and used in planning work.

Sub-task 9.3: Name two spatial analyses that could be used to study the actions of entertainment game characters in a virtual game world. Briefly describe how they could be used for this purpose. You may use materials 9.A and 9.B in your answer. 6 points

Prestructural response (SOLO 1)

The actions of game characters could easily be analysed, for example, by GPS-locating them and their movements.

Map 9.A looks the same as the tactic boards in NHL or real-world ice hockey, and from it one could analyse that the blue team should maybe advance from below either in pairs of two or three people if it is a five-player team; grenades could be used to hold back the red team.

Transitional prestructural response (SOLO 1A)

The map in material 9.B is a spatial analysis in which players' deaths are shown on a three-dimensional map. This analysis can be used, for example, to improve the game world and adjust the difficulty level of the game.

In addition, it would be useful to ask players through a survey or interview what their favourite game is.

Unistructural response (SOLO 2)

The actions of game characters could be studied with a heat map that would show where there is the most movement or deaths. Material 9.B is a good example of this, because it shows where most deaths have occurred. The player can therefore realise that they should be careful in those areas.

By examining the most common routes, one can predict where opponents are most likely to come from and make a surprise attack.

Sub-task 9.4: Discuss what benefits an individual player, the company that developed the game, and a television channel broadcasting e-sports may gain from geographic information related to the game. 9 points

Prestructural response (SOLO 1)

Not everyone is so interested in geographic information, but some people become interested in games where the game environment is successful. The player's imagination can then develop, or they can become interested in new things, such as historical events related to the

game. Or if the game is set in Japan, the player may become interested in it, learn geography and go on holiday to get to know Japanese culture.

The player can also form groups and make friends if they know where in the world there are many players. They can also develop their language skills.

The game developers can know where in the world the game is played and increase advertising there. If the game is played a lot in America, they can add interesting American things or advertisements to the game.

The television channel also wants to know where in the world the broadcast is watched so that they can adjust the broadcasting times better, so that the broadcast does not come in the middle of the night.

Unistructural response (SOLO 2)

The individual player probably benefits the most. They see from the in-game map where their own character is moving and can also see enemies and their routes. With this, the player can plan strategy and avoid dangerous places. The company that developed the game gets an overview from geographic information of how popular the game is in different places and can then think about whether the game should be advertised or updated more. The television channel broadcasting e-sports benefits from geographic information mainly by finding out where in the world e-sports are watched the most and can use that to choose broadcasting times and programming.

Transitional unistructural response (SOLO 2A)

An individual player benefits from geographic information in an entertainment game by seeing their own location on the in-game map, and perhaps the movements of other players.

With the information, they can plan their own tactics, avoid dangerous places and thus become a better player.

The company that developed the game can use geographic information to follow how players move on the map, which areas are too difficult or too easy, and where there are bugs.

The e-sports channel would find out in which time zones broadcasts are watched. It can improve viewing figures.

Multistructural response (SOLO 3)

The company that developed the game receives feedback through geographic information about whether the game works well. For example, if it is noticed that some route is too difficult or that a field is unfair for different teams, updates can be made so that customers remain satisfied.

A television channel broadcasting e-sports can clearly show, with the help of geographic information, how the game and teams progress on the map. In addition, commentators can explain the game better and show interesting things, for example the routes used by teams and death locations. This makes viewers enjoy the broadcast more.

An individual player can develop their strategy by analysing spatial datasets. For example, by examining material 9.B, they can learn to avoid places where one easily gets killed.

During the game, it is also useful for the player to see the game map and the movements of game characters on it.

Transitional multistructural response (SOLO 3A)

An individual player benefits from geographic information in the game world in many ways.

The team routes, death locations and popular areas shown on the map help the player infer

where it is worth moving and which areas should be avoided. The player can also analyse other players’ tactics and become better when they can predict what others will do.

The company that developed the game receives vital information from geographic information. Analysis of players’ movements, death locations and actions shows which parts of the map work and which do not. With this information, the company can balance maps, fix problems and plan new areas. When the game environment pleases players more and is smooth and interesting, the game attracts old players to stay and new customers to join. Thus the company gets more financial profit from its game.

The e-sports channel uses geographic information above all in building the broadcast. A real-time map can be shown to viewers, and it helps choose the right filming places and camera angles. Viewers therefore see better what the situation in the game is.

Relational response (SOLO 4)

An individual player benefits from geographic information in the game world both during and outside the game. For example, in a war game, the map shows the locations of the player’s own team members and possibly enemies or objects in the game, as well as players’ death locations. These help the player succeed in the game and avoid being shot. The player can analyse their own and others’ actions and develop strategies. Geographic information is therefore needed both for navigating in the game world and for improving game tactics.

The company that developed the game can use the spatial data produced by players on a larger scale. From players’ movement and all their actions it can be seen how the game works, what is popular or too easy, and so on. On this basis, the company can develop the game to better match players’ preferences, for example by designing new maps or making old ones more popular. In addition, the spatial dataset can be used to make easy places more

difficult and impossible places easier. The game attracts more players when it works and is suitably challenging. In this way, the company receives more income from the game.

A television channel broadcasting e-sports, in turn, uses geographic information to offer viewers an entertaining and clear broadcast. Cameras can be positioned in advance on the basis of geographic information in likely battle locations. During the game, the situation can be explained and the players' progress can be shown on the map. A more interesting and easier-to-follow broadcast attracts more viewers, which can give the channel more advertising revenue.