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FROM DRAWINGS TO MAPS: LINKS BETWEEN DRAWING CATEGORIES AND SPATIAL ERROR IN STUDENTS' MENTAL MAPS OF THE DESERT BIOME

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Abstract. *Spatial error in the mental maps of lower secondary school students regarding the desert biome is investigated, focusing on the accuracy of desert conceptualisation and location. The aim of the study was to assess the status quo in children's conceptions of deserts among lower secondary school students, while focusing on the spatial aspects of these conceptions. A total of 592 lower secondary school students took part in the study. Students were categorized using the children's drawings method into one of six categories according to the predominant elements contained in their drawings. In the second stage, students plotted the locations of deserts worldwide in an outline map; these maps were subsequently processed to produce aggregated mental maps. The study has shown that students have rather simplified perception of deserts as areas covered with sand with minimal rainfall and specific flora and fauna. Students tend to overestimate the area of deserts significantly; they locate most deserts in Africa and central Australia, and a relatively large proportion of students incorrectly locate deserts also in Amazonia.*

Keywords: *children's conception, desert biome, spatial error, mental mapping, children's drawings method*

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Introduction

Understanding how children conceptualize geographical phenomena is vital for effective teaching. Children's intuitive ideas, or children's conceptions, have been described as basic units through which they interpret the world (Lane et al., 2019). When these internal theories conflict with scientific reality, they become misconceptions (Francek, 2013; Ma et al., 2025). Such misconceptions have been shown to persist despite traditional teaching (Laliyo et al., 2022) – i.e., lecture-based, teacher-centred, front-of-class pedagogy with predominantly passive students–emphasizing the need for more constructivist, student-centred methods (Reinfried et al., 2015; Vosniadou, 2013). Recent syntheses in geoscience education show that spatial skills remain under-practiced in secondary schools, calling for intentional spatialising of curricula (McLaughlin & Bailey, 2023).

Deserts are an ideal case for studying misconceptions due to their complexity and common oversimplifications by students and teachers (Schubert, 2014, 2015; Schubert & Wrenger, 2016). Deserts are commonly defined by extremely low annual precipitation (below 250 mm per year), yet vary widely beyond sandy stereotypes (Christopherson & Birkeland, 2017). Students have often been found to imagine deserts as vast, sandy, and hot areas inhabited by camels, cacti, and palms (Trahorsch & Trhlíková, 2021). Spatial misconceptions have been frequently reported; for example, many students have incorrectly located deserts in the tropical rainforests of the Amazon basin (Scoffham, 2019; Trahorsch et al., 2022). Media and textbooks have frequently been found to reinforce these simplistic perceptions (Dove, 2011; Lee et al., 2021). Recent research in primary education has shown that the cartographic language of widely used textbooks can be misaligned with curricular demands and systematically ethnocentric, which may depress students' regional geo-literacy; mental-map/PLK diagnostics have revealed a low intersection between academic and everyday knowledge (Binimelis Sebastián et al., 2024). Maps are spatial representations of environments, so attaining map skills requires both cartographic and language-related abilities (Heidari et al., 2024).

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Given these issues, it is necessary to examine not only children's conceptions about what deserts are, but also their conceptions about where deserts are located globally. Such spatial dimensions have rarely been studied explicitly in some science concepts, leaving gaps in our understanding of students' geographic conceptions (Scoffham, 2019). This gap is echoed in recent Western literature that urges routine practice of spatial thinking in school geoscience to support transfer across topics and scales (McLaughlin & Bailey, 2023). Large-scale evidence also reports scarcity of geographic knowledge and spatial competence among secondary students (Binimelis Sebastián et al., 2024).

While prior work on children's conceptions has clarified what learners think about biomes, it has rarely examined where they believe these biomes occur, leaving the spatial dimension of misconceptions under-specified (Arrhenius et al., 2021, 2024). Evidence from diagram-based teaching shows that student-generated representations can surface mechanism-level misconceptions and support explanation-building in Earth science (McLure et al., 2021). Spatial error matters because conceptual and locational knowledge can dissociate: students may articulate biome attributes yet systematically misplace them on the map, undermining diagnosis and the design of map-based instruction (Rey-Goyeneche & Alexander, 2021). Mental maps offer a way to quantify such locational biases at scale via aggregated patterns of placement (McLure et al., 2021; Montello et al., 2018). Our study advances this line by linking drawing-based categories of desert conceptions to measurable spatial error in mental maps of the desert biome, thereby situating the work at the intersection of research on children's conceptions and spatial thinking.

Research Problem

Most studies on children's science conceptions have scrutinised what children know but have ignored where they think phenomena occur (Balabanoff et al., 2022; Peikos et al., 2022). Even in geography-related topics, spatial judgements have rarely been examined (Dove, 2012), leaving a critical gap in our picture of students' mental models. Yet cognitive-mapping research shows that location powerfully shapes region perceptions (Paasi, 2010), and understanding environmental processes demands knowledge of their spatial context (Sternberg & Sternberg, 2016). Recent studies have confirmed mental mapping as an efficient, quantifiable proxy of geographic literacy, emphasizing the primacy of the "where" dimension and revealing substantial inconsistency in learners' spatial knowledge across cohorts (García-González et al., 2023).

This omission intersects with the broader, stubborn problem of scientific misconceptions: children construct durable naive theories that standard teaching often fails to correct (Francek, 2013). Conceptual-change strategies—cognitive conflict, guided inquiry, affective engagement–can help, but each has limits (Magana et al., 2021; Reinfried et al., 2015). Recent work has also shown that guided metacognitive reflection consolidates conceptual change (Chen et al., 2020). Effective intervention therefore begins with a precise diagnosis of existing misconceptions (Buschor & Kamm, 2015; Smith et al., 1994), including any spatial distortions.

Multiple influences shape such distortions. Geographic distance has been found to predict accuracy – near places are known better than far ones (Reynolds & Vinterek, 2016; Scoffham, 2019; Zaga & Yaar-Waisel, 2024). Textbooks and teaching resources, including school maps, can embed errors through oversimplified narratives or misleading visuals (Dove, 2011; Trahorsch & Bláha, 2022; Trahorsch et al., 2022), while popular media spread vivid but partial images of environments (Paasi, 2010; Rye, 2013). Personal factors—geographical literacy, settlement size, direct travel–further have been found to modulate understanding (Binimelis Sebastián et al., 2024; Judson, 2011; Polic et al., 2005; Schubert, 2014). Experience can correct misconceptions but may also foster over-generalisation from a single exemplar (Ahi & Balcı, 2018). These factors can also be based on the theory of multiple modes of spatial reasoning (Gersmehl, 2023), according to which map reading occurs non-linearly; the result can be significant heterogeneity in the distribution of attention to different features of the phenomenon (e.g., deserts), causing high variability in the perception of spatial location. The core problem is that persistent spatial misconceptions about the desert biome—specifically, where students place deserts—undermine regional geo-literacy and the ability to connect macro-scale drivers with local environmental contexts. Because classroom learning builds on mental maps, such distortions reduce learning efficiency and hinder transfer across topics and scales. To address this need, we quantify spatial error in students' aggregated mental maps and examine how drawing-based categories relate to that error, thus identifying concrete targets for instruction. At the same time, some studies report that questions and tasks generally do not reach a desirable level of spatiality, limiting growth in spatial reasoning (Carow & Pretorius, 2025).

In sum, students often hold oversimplified or erroneous ideas about remote natural environments, and the spatial dimension of these ideas remains under-researched. Mislocating biomes such as deserts may hinder learn-

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ers' ability to connect geographical patterns with underlying environmental processes—an educational blind spot this study seeks to illuminate.

Research Focus

This study examines lower-secondary (ISCED 2) students' conceptions of the desert biome, focusing on where they locate deserts and how they characterize them. Deserts offer an ideal testbed: they are a clearly delimited biome (annual precipitation < 250 mm) that appears in almost every national curriculum (Christopherson & Birkeland, 2017; Trahorsch et al., 2022).

Crucially, these studies have rarely examined children's spatial knowledge. Many children picture an endless, sandy expanse inhabited only by cacti, camels, and scorching sun; explanations for desert formation range from wind-blown sand to divine will (Schubert, 2014; Schubert & Wrenger, 2016; Trahorsch & Trhlíková, 2021). Learners have been found to recognise drought and desertification, yet often to misconstrue their causes (Schubert, 2015). School textbooks and popular media have been shown to entrench such misconceptions (Trahorsch et al., 2022), whereas first-hand visits or field courses have been found to promote conceptual change (Judson, 2011). Personal experience, however, has also been found to foster over-generalisation from a single site (Ahi & Balcı, 2018).

Crucially, these studies rarely examine children's spatial knowledge. Thus, the present work pairs two complementary tasks: (1) a sketch-drawing that captures the visual image of a desert, and (2) a blank-map exercise that reveals the spatial placement of the world's deserts. Focusing on Czech children aged 12–15 – an age group already taught global biomes – allows us to ask whether certain drawing types align with systematic mapping errors. By integrating content and location, the study seeks to build a fuller picture of students' mental models of extreme biomes and to identify leverage points for instruction aimed at both factual and spatial conceptual change. Such pairing directly targets the under-addressed spatial dimension documented in recent reviews of school geoscience (McLaughlin & Bailey, 2023).

Research Aim and Research Questions

This study quantifies two facets of Czech children's conceptions of deserts: (a) the visual image expressed in sketch-maps, and (b) the spatial accuracy with which students locate real deserts and test whether these facets covary. Spotlighting the neglected spatial component provides diagnostics for educational designs that can correct both factual and locational misconceptions.

Research questions

- Which landforms, organisms, and human elements dominate children's drawings of a desert?
- How accurately do children locate the world's desert regions on a blank outline map?
- Do particular drawing types (e.g., dune-centred vs oasis-centred) predict higher or lower mapping accuracy?

Accordingly, this study quantifies spatial error in children's mental maps of the desert biome and relates this error to six drawing-based categories, aiming to inform interventions that refine conceptual knowledge and strengthen global spatial reasoning.

Research Methodology

General Background

This study adopts a quantitatively oriented design that pairs the analysis of children's drawings with comparative mental mapping (Musolino et al., 2020). The approach is grounded in cognitive cartography (Montello et al., 2018), treating mental maps as outcomes of cognitive mapping, and uses children's drawings as an elicitation method for learners' conceptions. Data were collected during regular geography lessons at lower-secondary schools in northwest Czechia in 2021/2022; the sample comprises $N = 592$ students from 11 schools. The dual-task architecture captures two complementary facets of desert conceptions: (i) the predominant conceptual image (six drawing-based categories) and (ii) the global spatial placement of deserts derived from blank outline maps and processed into aggregated mental maps in GIS. The study is diagnostic in scope, quantifying spatial error and relating it to drawing categories to inform subsequent educational design.

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Participants

Participants were enrolled using intact-class, school-based sampling in participating lower-secondary schools. In line with school and parental consent procedures, all children present on the day of data collection were invited during regular lessons. No quotas or stratification were imposed; the sample therefore reflects the population available in the collaborating classes. Subgroup sizes follow the observed distribution of drawing categories; the Differentiation of desert category ($n = 18$) was retained due to conceptual distinctiveness and consistent coding. This subgroup was pre-specified in the coding scheme (Table 1) rather than created post hoc; it was retained to preserve construct validity. Eligibility required informed consent and completion of both study tasks; records with missing consent, absence on the day of administration, or incomplete responses were not included. The resulting sample comprised $N = 592$ children (the age of students being $M = 13.45$, $SD = 0.96$), of which 279 were boys and 313 were girls. A total of 11 schools from both cities and villages participated in the study. All research participants have been taught the subject matter of biomes, including deserts. For transparency, we report confidence intervals; with $N = 592$, a proportion near 0.50 has an approximate 95% margin of error of ±4 percentage points, and inferences are limited to the collaborating classes.

This study received approval from the Institutional Ethics Committee of UJEP. Written informed consent was obtained from parents/guardians and age-appropriate assent from pupils; procedures complied with international ethical standards.

Instrument and Procedures

Two tasks were used in this study: children's drawings and mental mapping. The school grade was monitored in students, while this indicator was subsequently used to compare the development of children's concepts within lower secondary education.

The application of the children's drawing has the potential to identify partially implicit perception of the studied phenomenon (Hong et al., 2021). This method is suitable in research involving participants who may have problems with written or spoken statements, yet caution must be applied when interpreting drawings in relation to children's conceptions, as the outcomes of children's drawing analysis may not correlate with the nature of the children's conceptions (Hong et al., 2021). The output produced by this method comprises drawings of the studied phenomenon, which can be subjected to quantitative or qualitative analysis (compare Rey-Goyeneche & Alexander, 2021). In the presented research, students were given the instruction to draw their idea of a desert. Students received a blank sheet of paper, size A4, and colouring pencils. In the following stage of the research, students were asked to describe in words what they drew on the reverse side of the sheet. Students therefore identified the drawn elements to facilitate identification of the individual elements in their drawings during the subsequent analysis. Students completed the task individually during a regular 25-minute geography lesson. The task was anonymous, not graded, and teachers emphasised that answers would serve scientific purposes only.

In cognitive cartography, a mental map denotes an internalised spatial representation derived from direct experience or mediated information (Downs & Stea, 1973). In pedagogical research, however, the term is sometimes reserved for concept-mapping tasks that visualise propositional knowledge structures (Gilbert et al., 2010). To prevent ambiguity, the term mental (sketch) map is used exclusively in the cartographic sense throughout this paper, referring to children's freehand spatial sketches of real-world deserts on a blank outline map.

According to Downs and Stea (1973, pp. 9), mental maps are the outcome of cognitive mapping, which is defined by the cited authors as a cognitive process involving psychological transformation of spatial information on the studied objects, phenomena and processes. This study uses the comparative type of mental maps (Musolino et al., 2020), where an individual depicts the relevant space as they perceive it, i.e., including its shape, extent, orientation, etc. These maps are often processed to create the so-called aggregated mental maps, in which lighter areas (with greater brightness) indicate a higher degree of plotting of the relevant phenomenon, in this case, the study of deserts (Bláha & Nováček, 2016). This type of map is suitable for comparing against reality and determining the degree of correctness of the localised phenomenon. These maps allow for comparison of the results of individual students (or aggregated mental maps for individual student groups) against the actual situation (in this case, defined by the desert region) or against the relevant regionalisation on the world map.

As comparative mental maps can be very similar to regular children's drawing when presenting a rather unspecific task, it was essential to structure the task well and identify in the reference framework of the regular

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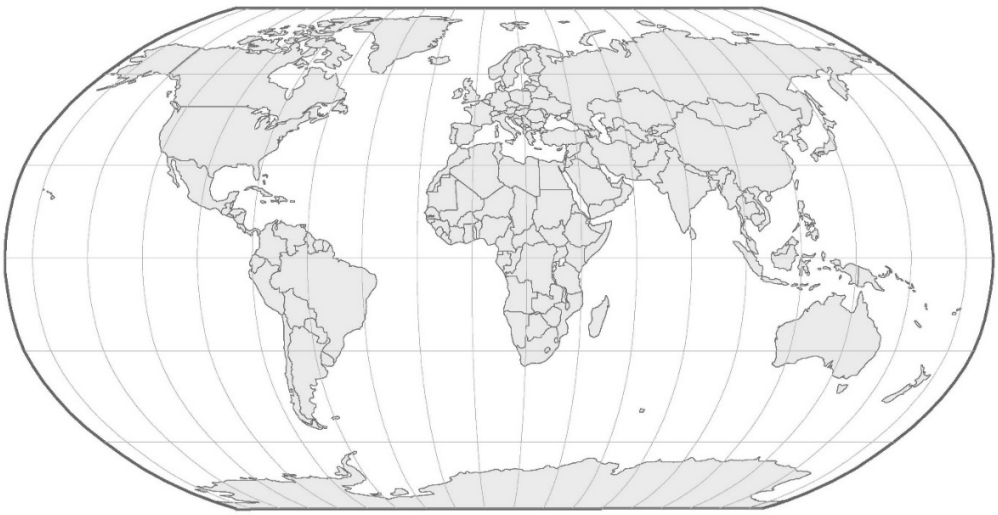
world map for the purposes of the subsequent processing in GIS. Students were therefore given a paper copy of an outline map of the world (Figure 1) with basic points of orientation (outlines of continents and states, the main cartographic parallels and meridians). Students were asked to draw the areas where they expect to find deserts in this map. The obtained maps were digitalised by scanning and uploaded to a geoinformation system (ArcGIS Pro 10.x) in the form of a grid. Individual locations of deserts indicated by students were vectorised in this program, i.e., converted to the shapefile vector data format to allow for subsequent GIS analysis and suitable visualisation of the outcome of the analysis.

Figure 1
Outline Map Used in the Research



Data Analysis

The data were analysed separately for each of the methods referred to above (analysis of children's drawing and analysis of mental maps), and the outcomes of both methods were subsequently combined for interpretation. The analysis of children's drawing focused on two aspects. In the first phase, the evaluator identified the drawn elements primarily using the student's description and entered all identified elements in the provided form. Categories for the analysis of the drawn elements were determined based on a pilot study of 66 students, and the proposed system of categories was further specified by the inclusion of individual subcategories (Trahorsch & Trhlíková, 2021). In essence, the system of categories is based on the structure of geography, as it reflects individual natural and social spheres.

In the second part of the analysis of children's drawings, the drawing as a whole was placed in one of the six categories (Table 1). The aim was to create groups of drawings according to the prevailing drawing concept. This categorisation was performed to generate several groups of individuals for subsequent use in the analysis of mental maps. As mentioned previously, the prevailing elements in drawings were the primary criterion, as this may indicate the elements students focus their attention on when interpreting the region of deserts. Once again, the system of categories was further specified based on the pilot research (Trahorsch & Trhlíková, 2021), and it was subsequently necessary to describe the categories in greater detail for the evaluators, provide examples of drawings, and add the "Biota in balance" category.

Inter-rater reliability was assessed on a random subsample of 100 drawings (≈ 17 % of the corpus). Two trained coders independently recorded every identifiable element and subsequently assigned each drawing to one of the six predefined categories. Cohen's κ indicated almost perfect agreement for element-wise coding ($\kappa = 0.82$, 95% *CI* [0.78, 0.86]) and substantial agreement for the drawing-type classification ($\kappa = 0.71$, 95% *CI* [0.66, 0.76]) according to the Landis and Koch (1977) scale; any residual discrepancies were resolved by consensus prior to analysis.

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Table 1
Desert Drawing Categories with Inclusion Criteria

Code	Category label	Operational definition (objective count rule)	Typical indicators
FL	Flora	Plant elements (cacti, shrubs, palms, grasses, etc.) constitute > 50 % of all identifiable items, and ≥ 2 distinct plant items are present. No more than 1 animal or human/built item.	Several cacti of different sizes; palm grove
FA	Fauna	Animal elements make up > 50 % of identifiable items, with ≥ 2 distinct animal types (species) depicted. ≤ 1 plant or human/built item.	Camel caravan, snake, scorpion, bird silhouettes.
BB	Biota in Balance	Both plant and animal elements represent 25–50 % each of identifiable items (neither group dominates).	Cactus–camel pairs; oasis scene with palms and camel.
DD	Desert Differentiation	Drawing explicitly depicts ≥ 2 distinct physical desert types (e.g., sand sea vs. rocky desert) or labels different desert forms.	Sand dunes separated from gravel field; notes such as "sandy desert" vs. "rocky desert."
SE	Socio-Environmental	Human or built artefacts total ≥ 3 items or constitute > 25 % of identifiable items.	Houses, tents, vehicles, pipelines, tourist figures.
NL	Desert without Life	No plant, animal, or human/built elements present; scene entirely abiotic.	Only dunes, rocks, sun; barren landscape.

Aggregated mental maps were created, and indicators of successful localisation were calculated for the purposes of the analysis of mental maps in the first stage of the analysis. Aggregated mental maps were created by overlaying layers of individual desert drawings in GIS. The subsequent stage of the analysis of the data obtained through this method involved a qualitative analysis of the indicators of successful plotting (localisation) of deserts. Specific definitions of the world's biomes needed to be used when calculating these indicators; this study utilised regionalisation according to Dinerstein et al. (2017, Figure 2), as the spatial data of this method is accessible, and the nature of regionalisation is similar to that used in the Czech school atlases and other scientific monographies (Christopherson & Birkeland, 2017).

Three indicators were calculated for the purposes of the quantitative analysis. Firstly, it was the indicator of successful plotting (D_1), which shows the proportion of students localising deserts in areas where deserts are in fact located. The degree of correspondence of plotting with the scientific specification of a desert is the second indicator (D_2); this indicator shows the proportion of the area of deserts (based on its scientific specification; Dinerstein et al., 2017) actually plotted by a student. These two indicators are also interpreted as a single result using the index of successful plotting (i_d), which is calculated as the product of both indicators. The value of this index is within the interval <0; 1>, where 0 means that none of the student's plotting falls into deserts and therefore the student's plotting does not capture any part of the actual area of deserts. On the other hand, value 1 as the value that can be theoretically attained means that the student plotted all deserts, and their plotting is consistent with the scientific specification of deserts.

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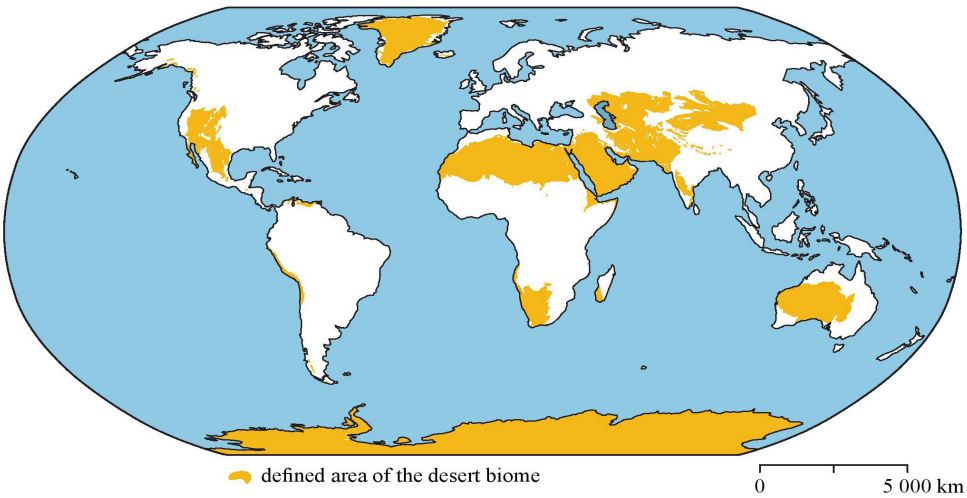
Figure 2
Delineation of Deserts Used in Data Analysis (source: Dinerstein et al., 2017)



The calculated values of the three indicators (D_1, D_2, i_d) were subjected to a quantitative statistical analysis. All analyses were conducted in SPSS (version 25). Data normality was screened with the Kolmogorov–Smirnov and Shapiro–Wilk tests; all variables were non-normal: for D_1, $D(592) = .030$, $p = .040$; $W(592) = .990$, $p = .001$; for D_2, $D(592) = .149$, $p < .001$; $W(592) = .823$, $p < .001$; for i_d, $D(592) = .531$, $p < .001$; $W(592) = .168$, $p < .001$. $N = 592$ $N = 592$ $N = 592$ $N = 592$ $N = 592$. The Mann–Whitney U test was used for two-group comparisons. Differences in spatial accuracy (i_d) across drawing categories and grade levels were tested with the Kruskal–Wallis test followed by Dunn's pairwise tests with Bonferroni adjustment. Cohen's d for two independent groups and eta-squared (η^2) for three or more groups were reported. (Cohen, 1988). Associations between the number of elements and i_d were examined using Spearman's rank correlation (ρ). Alpha was set at .05, which is a standard value for educational research. Given the small Differentiation subgroup ($n = 18$), estimates and pairwise contrasts involving this category are treated as exploratory and interpreted with caution, with emphasis on effect sizes rather than broad generalisation.

Research Results

Children's Drawing Analysis

Students drew a mean of 5.26 elements per drawing ($M = 5.26$, $SD = 1.96$). Younger students drew more elements than older students; while the difference in the number of elements drawn is statistically significant, the effect size of age on the number of plotted elements is weak ($H(3) = 8.549$, $p = .04$; $\eta^2 = .01$). Post hoc analysis indicated a significant difference between the 6th and 7th grades ($U = 47.372$, $p = .04$). No other pairwise differences were significant. More than one half of the drawings included sand, sun, and cactus (Table 2). The table shows great variability of the results, as only five elements appeared in more than one quarter of all drawings, while the remaining identified elements (96 in total) appeared in less than one quarter of all drawings, of which 80 elements appeared in less than 5% of the drawings. While there are elements appearing jointly throughout the research sample, there are many inter-individual, i.e., very specific elements (for example, Minecraft elements).

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Table 2
Overview of the Most Frequently Depicted Elements in Desert Drawings

Category	Element	Absolute frequency of drawing	Relative frequency of drawing (in %)
Surface and rocks	Sand	575	97.1
	Rock, boulders, rocks	109	18.4
	Mountain range	55	9.3
	Dune	52	8.8
	Sun	405	68.4
Climatic and hydrological conditions	Sky	172	29.1
	Cloud, clouds	50	8.4
	Lake	37	6.3
	Wind, sandstorm(s), tornado	20	3.4
	Water	19	3.2
Plants	Cactus	376	63.5
	Palm	115	19.4
	Bush	113	19.1
	Tree (deciduous, coniferous, dry)	55	9.3
	Grass	52	8.8
Animals	Camel	190	32.1
	Snake	63	10.6
	Bird	45	7.6
	Scorpion	40	6.8
	Lizard	36	6.1
Complex elements	Oasis	54	9.1
People	Individual (local)	58	9.8
	Individual (unspecified)	31	5.2
Manmade elements	Pyramid	94	15.9

The drawings were included in one of the six groups, depending on the elements prevailing in the drawings (Table 1). The analysis of drawings has shown that drawings focusing on the biota as a whole (26% of the respondents) or on vegetation as a whole (29% of the respondents; see also Figure 3) prevailed in the overall results. The dominance of the socioeconomic category (29% of the respondents) with prevailing elements of a socioeconomic character (people, dwellings, tourism, etc.) is a relatively significant finding within the categories. Although the socioeconomic phenomena are not as frequent as natural elements in the drawings, in the absolute comparison of the elements, students paying attention to the presence of the socioeconomic aspect usually included several of these elements in their drawings. A desert is perceived as without life by just under 10% of respondents. Students who are aware of the differentiation of deserts are a relatively specific group (3%; Figure 3); elements suggesting that these students are capable of drawing more than one type of desert (for example, gravelly desert, polar desert, etc.) were identified in the drawings of these students.

The difference in the representation of individual types of drawings depending on the school year is statistically significant (χ^2 (15, NN = 592) = 25.7, p = .04). The analysis of standardized residuals showed that the overall differences between classes are mostly contributed by significant deviations in two categories: in the 8th grade, the category of drawings Without life and in the 6th grade, the category of Fauna. Cramér's V = .042, indicating a very small effect; therefore, the practical significance of these differences is limited (Figure 4).

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Figure 3
Example of Drawing of a Desert (Category Flora on the Left and Desert Differentiation on the Right)

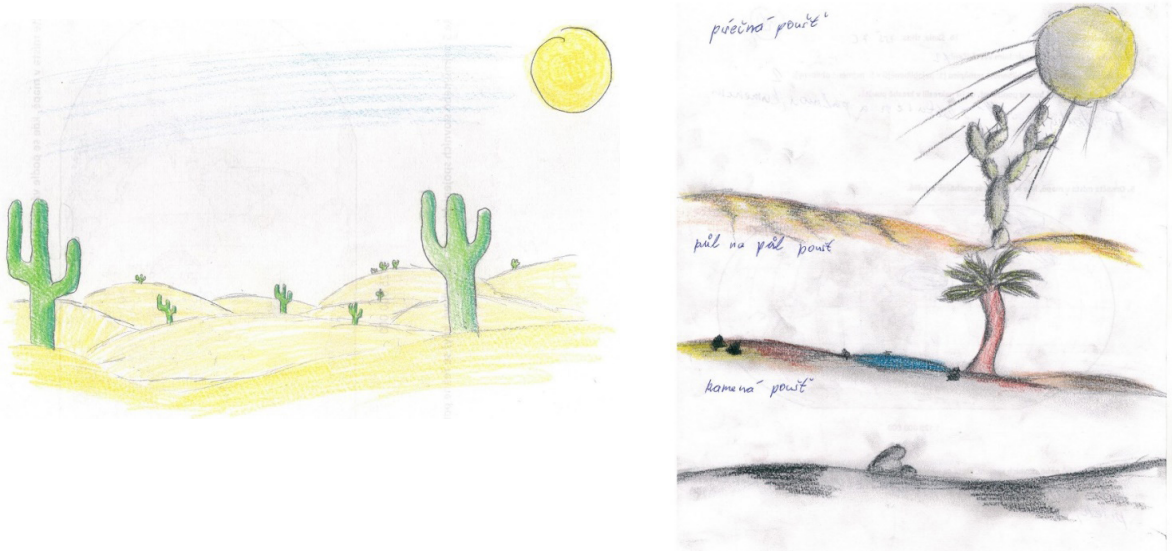
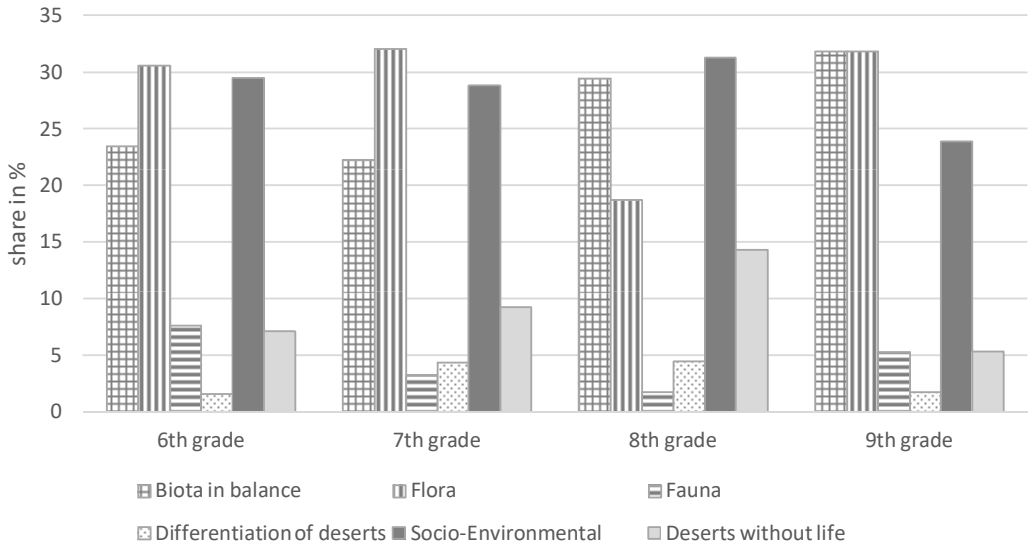


Figure 4
Development in Representation of Desert Concept Types According to Children's Drawings in Lower Secondary School



Mental Mapping

Within the research cohort, 3% of students (n = 19) were unable to plot the location of at least part of the deserts correctly (i_d = 0). The remaining students were able to plot correctly at least parts of deserts in the outline map. The average proportion of locations plotted in the maps that are actually desert was 42% with the standard deviation SD = 21 (in other words, on average 42% of the locations plotted by students in the outline maps were correct; conversely, 58% of the locations plotted in the outline maps were incorrect, and these areas are biomes other than deserts). The average proportion of the plotted area that is actually desert and therefore was plotted correctly was 17% (SD = 14.6) in the research cohort. This result shows that students tend to overestimate the area of deserts, as a large part of their plotting (83% on average) does not correspond with deserts. However, the

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standard deviation values show that the success rate of the plotting differs greatly among students and therefore is highly variable. The average value of the index of successful plotting is $i_d = .37$ ($SD = 0.11$).

The aggregated mental map shows that students mostly plot deserts in northern Africa (Sahara) and central Australia, but deserts are plotted in the western parts of North America or central Asia far less frequently. The prominence of the Sahara and the Australian Outback likely functions as exemplar-based anchors in students' mental maps. Such anchoring can prompt over-extension from these iconic cores into adjacent semi-arid regions, increasing spatial error. Rather surprisingly, a relatively high percentage of students plots deserts in central parts of South America, where tropical rainforests are located (Figure 5).

A Kruskal–Wallis test showed that age had a significant effect on both accuracy metrics and the composite index (for D_1, $H(3) = 47.59$, $p < .001$; for D_2, $H(3) = 22.83$, $p < .001$; and for the i_d, $H(3) = 35.54$, $p < .001$). However, the associated effect sizes were small (for D_1 $\eta^2 = .076$, for D_2 $\eta^2 = 034$, and for i_d $\eta^2 = .055$), indicating that grade level explains only about 5% of the variance. Although mean point-accuracy rises from 35% in the first grade of lower secondary to 50 % in the final grade, students still misplace desert locations in every second attempt, and the share of correctly delineated desert area reaches one fifth (22%). The sizeable standard deviations (≈ 20%) further show a wide spread of individual performances, with substantial overlap between grades. In practical terms, age-related gains are present but modest. The modest age-related gains suggest that once a 'hot-and-dry' schema is established, later instruction tends to add details without reorganizing the underlying spatial template. This inertia may explain why older students still over-extend deserts despite increased factual knowledge.

Figure 5
Aggregated Mental Map of the Entire Research Cohort (N = 592)

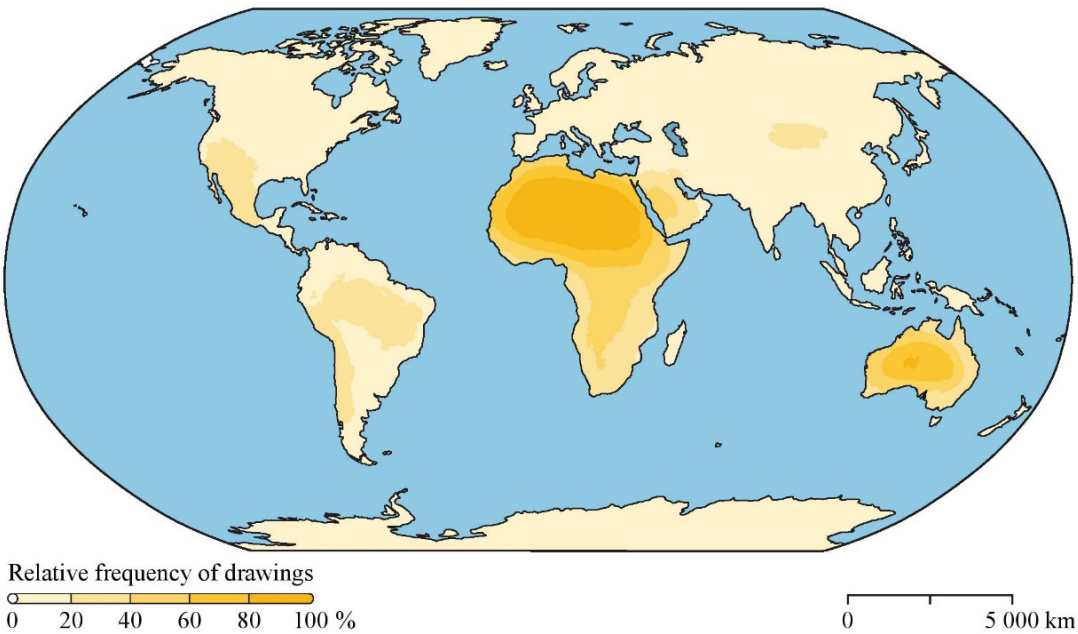

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Table 3
The Development of Indicators of the Success of the Localization of Deserts

School grade	Age	D_1 (M)	D_1 (SD)	D_2 (M)	D_2 (SD)	i_d (M)	i_d (SD)
6th	11–12	34.66	20.75	14.60	12.20	.06	0.09
7th	12–13	43.56	19.59	14.94	12.18	.07	0.08
8th	13–14	42.98	20.42	17.56	17.46	.10	0.13
9th	14–15	49.54	20.29	22.05	17.33	.13	0.14

From Table 4 it is evident that students in the Desert Differentiation category –those who explicitly distinguish between more than one physical desert type—achieve the greatest spatial accuracy. Although this group is the smallest (n = 18), it records both the highest proportion of correctly placed deserts and the largest overlap between the sketched and the real-world desert boundaries. Of course, it is necessary to take into account the fact that the number of this group is relatively small compared to other categories. Even though the Desert Differentiation category has the smallest number of students, the variability of results is average compared to the other categories. Children whose drawings emphasise Socio-Environmental elements are the least accurate. This likely reflects a narrative framing that prioritizes 'what happens there' over 'where it occurs', diverting attention from the global distribution of the desert biome.

A Kruskal–Wallis test confirmed overall differences among categories, and most pairwise contrasts reached the 0.05 threshold (for D_1, $H(5) = 20.05$, $p < .001$; for D_2, $H(5) = 23.83$, $p < .001$; and for i_d, $H(5) = 24.52$, $p < .001$); however, estimates involving Desert Differentiation are less precise due to the small subgroup (n = 18). Bonferroni-adjusted post-hoc Mann–Whitney tests (SPSS) showed that Desert Differentiation differs significantly from three other groups: Socio-Environmental (p = .001), Balanced Biota (p = .008), and Biota-dominant (p = .013). No significant difference was observed between Desert Differentiation and Desert without Life; all other pairwise contrasts were non-significant at α = .05.

Table 4
Comparison of the Success of Plotting Deserts and its Variability According to Children's Drawing Categories

Categories according to children's drawings	Proportion of students (in %)	D_1 (M)	D_1 (SD)	D_2 (M)	D_2 (SD)	i_d (M)	i_d (SD)
Flora	29.05	42.13	20.53	14.33	11.28	.07	.07
Fauna	4.73	40.64	21.54	16.51	12.02	.09	.08
Biota in Balance	25.84	41.34	20.43	15.57	13.74	.05	.10
Desert Differentiation	3.04	58.65	14.13	36.10	22.66	.23	.18
Socio-Environmental	28.55	39.05	21.06	17.34	15.64	.09	.12
Desert without Life	8.78	46.30	21.84	19.16	16.46	.11	.13

The aggregated mental maps (Figure 6) visualise these disparities. While the Desert Differentiation map aligns more closely with reference desert regions, the small size of this subgroup (n = 18) limits the generalisability of this pattern. Sketches in the Socio-Environmental category often displace deserts towards the Amazon Basin—an area actually occupied by tropical rainforest—whereas differentiation drawings, though few, include a noticeable cluster correctly positioned in Antarctica. Together, the findings suggest that a physically grounded understanding of desert typology is linked to markedly higher spatial accuracy, whereas importing socio-economic imagery tends to reinforce a persistent geographical misconception.

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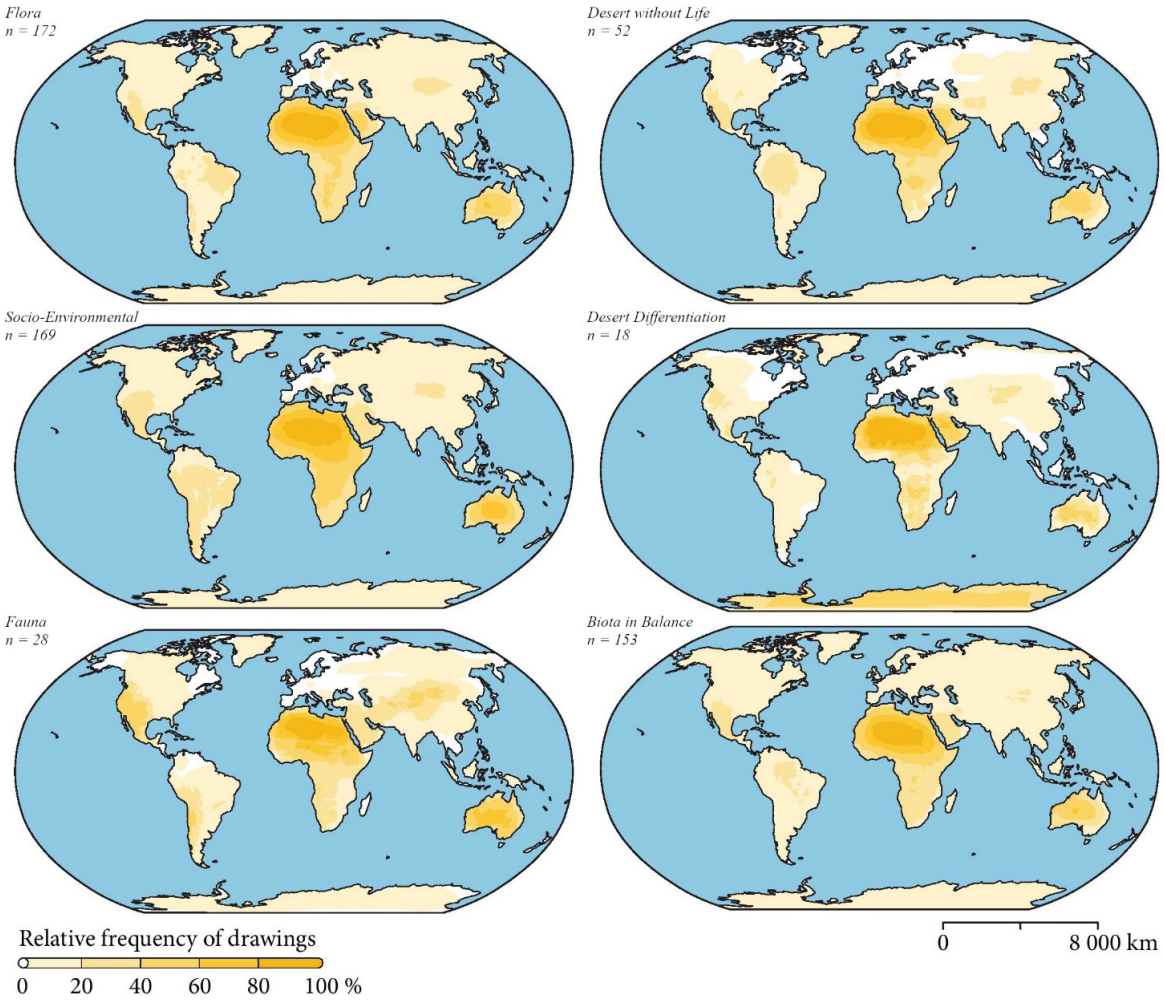
Figure 6
Aggregated Mental Maps of Deserts for Student Categories Identified According to Children's Drawing



Discussion

Results indicated three main findings. First, students' representations of deserts were focused primarily on the sandy cover of these areas. Second, spatial error was systematic in both magnitude and location: deserts were overestimated in area, placed mainly in Africa and central Australia, and a noticeable share of students misplaced deserts into the Amazon Basin. This Amazon misplacement is consistent with exemplar-based reasoning and the conflation of 'dryness' narratives with rainforest media frames, a pattern reported in school geography contexts (Schubert, 2015; Scoffham, 2019; Rey-Goyeneche & Alexander, 2021). Overestimation appears driven by climate-belt schemata that treat deserts as broad 'hot-and-dry' zones, inflating boundaries in Africa and Australia. Misplacements in Amazonia suggest a conflation of aridity with other environmental problems (e.g., deforestation, seasonal drought, wildfire). This mechanism is consistent with the neurocognitive model of parallel processing and attentional direction (Gersmehl, 2023). Third, representation type related to accuracy more strongly than age; effect sizes for grade were small. These effects suggest that once a 'hot-and-dry' schema forms, later teaching adds details without reorganising the spatial template, consistent with conceptual-change accounts that require targeted reconstruction (Reinfried et al., 2015; Vosniadou, 2013).

Students in the Desert Differentiation group achieved the highest accuracy with the lowest within-group dispersion, whereas sketches dominated by socio-economic motifs were the least accurate and tended to

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cluster over tropical South America (Figure 6). Because this group reflects recognition of contrasting desert types rather than a generic schema, its apparent advantage is theoretically coherent; nonetheless, it should be replicated with a larger sample before broader claims are warranted; claims about the relative advantage remain tentative. When recognizing contrasting desert types, students can focus on mechanistic location cues (latitude belts; Gersmehl, 2023). By contrast, socio-environmental drawings highlight human–environment stories (e.g., water scarcity, settlements) and offer few cues about location. When placing deserts, students may then default to familiar images (dunes, camels, oases) instead of using process-based cues that predict where deserts actually occur (latitude belts, subsiding air, rain shadows, continentality) – (Arrhenius et al., 2021). This pattern is consistent with exemplar-driven reasoning: students generalise from a small set of vivid 'desert' images and extend them to places that look similar in media or memory, even when climate patterns would rule these locations out (Schubert, 2015). A likely mechanism is an attention shift from spatial analysis to interpretation, consistent with the three-facet model of map use and with common perceptual grouping in map reading (Gersmehl, 2023). When cartography-specific language is thin, students also produce fewer cartographic concepts on sketch maps, which can surface as over-extended cores or misplaced outlines (Heidari et al., 2024).

These patterns align with studies reporting students' desert conceptions as large sand areas with a narrow set of species (Schubert, 2014; Schubert & Wrenger, 2016). Likely influences are familiar: media images, limited first-hand travel, and school instruction. Similar factors shape ideas about other geographical phenomena and biomes (Rye, 2013; Rey-Goyeneche & Alexander, 2021). Such influences help explain the preferred locations (Africa, central Australia) and the occasional appearance of cultural landmarks in otherwise mainly physical-geographical sketches. Our pattern parallels center-anchored mapping: salient/near or heavily mediated regions receive disproportionate attention, while less-exposed areas are either omitted or misassigned (Reynolds & Vinterek, 2016).

Overestimation of desert extent aligns with work showing that students generalise spatial context for remote regions (Polic et al., 2005; Scoffham, 2019). Our task design may have amplified this: the blank outline map offered no elevation or climate cues, making desert boundaries harder to infer and encouraging extension of the Sahara into semi-arid margins. Perceptual grouping and nonlinear magnitude perception in map reading can bias area judgement on outline maps, consistent with modes of spatial reasoning (Gersmehl, 2023).

The large standard deviations in most groups showed substantial individual differences. The Differentiation group was an exception: although small (n = 18), it appeared to combine higher accuracy with lower dispersion, suggesting that a more articulated concept of deserts stabilises spatial performance. By contrast, socio-economic sketches varied widely and often drifted toward the Amazon, indicating that importing cultural motifs does not ensure correct localisation.

What matters is guiding students toward contrastive, physically grounded representations and tying those contrasts to the map. To improve spatial accuracy, teaching should make the link between concept and location explicit: students should justify each placement with process maps (pressure belts, isohyets, prevailing winds) rather than surface features alone. Taken together, these patterns suggest that classroom and media emphases on striking desert imagery (dunes, camel caravans, 'empty interiors') foreground memorable narratives at the expense of distributional nuance. Brief, contrastive tasks that confront such images with precise cartographic delineations (hyper-arid vs. semi-arid vs. seasonal dryness) may accommodate students' spatial schemata.

Implications for Pedagogical Practice

Based on the results, it is possible to propose several pedagogical practices to support students' conceptualisation of the spatial organisation of deserts. Contrast-rich mapping tasks: Teachers should assign sketch-map activities that require students to locate at least two contrasting desert forms (e.g., erg vs. hamada desert, hot vs. cold), followed by peer discussion of why each belongs where it was drawn. Such tasks operationalise the benefits observed in the Differentiation group and can be implemented with minimal resources (blank world outline, coloured pencils).

Concept cartoons targeting misconceptions: The Amazon misplacement highlights a persistent confusion between humidity gradients and latitude. Concept cartoons depicting students' alternative ideas (e.g., "The biggest desert is the Amazon") can prompt argument-driven inquiry: learners must marshal climatic evidence to defend or refute each claim, thereby linking disciplinary content with spatial evidence.

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Progressive GIS visualisations: Aggregated maps similar to Figure 6 can be exported from free platforms (e.g., QGIS, ArcGIS Online) and projected in class. Visualising the class's own "desert cloud" alongside the real distribution fosters metacognitive reflection: students immediately see the gap between their collective mental map and reality and can iteratively refine their sketches (Chen et al., 2020). Increasing the spatiality of assessment prompts can normalise reasoning with spatial concepts and representations, beyond memorisation (Carow & Pretorius, 2025).

Limitations

The presented study naturally has several limitations that need to be taken into account while interpreting the results. Firstly, it is important to note the selection of a reference map (specification of biomes) for comparison of the scientific specification of biomes with diagnosed children's conceptions of the specification of deserts. The availability of primary spatial data for this topic is greatly limited, and work with secondary data (e.g., georeferencing in GIS) increases the likelihood of imprecise spatial specification and therefore potentially also incorrect calculations. In addition, the results need to be interpreted with a certain degree of spatial generalisation, which is also due to the relatively small scale of the source map. It is also important to note that there are several delineations of deserts (compare Christopherson & Birkeland, 2017), and minor differences can be found between these localisations. The differing versions of localisation therefore affect the results achieved. As the authors have clearly stated the source of the data used for the analysis of students' plotting of deserts, this limitation of the study is deemed adequately argued. The absence of qualitative data (e.g., interviews with students) limits the possibility of deeper interpretation of the motivations and sources of students' misconceptions.

The results and the overall interpretation of the data may be affected by the differing numbers of students in the analysed categories. Although the sample of students was relatively balanced with regard to the relevant grade, a greater level of variability was reflected in the categorisation of students into groups according to the drawings of the desert. The small size of the differentiation subgroup (n = 18) increases sampling variability and limits generalizability. Unequal subgroup sizes, particularly for Desert Differentiation, reduce power and widen uncertainty around estimates; post-hoc contrasts involving this group should therefore be viewed as exploratory despite α adjustment. Generalisability is limited. We therefore interpret its spatial error patterns as preliminary and hypothesis-generating rather than definitive. Retaining this category preserves construct validity, as its drawings were conceptually specific; however, conclusions about between-group differences should be read with caution until replicated in larger samples or in different conditions.

Conclusions and Implications

Using a sample of 592 lower-secondary students, we linked six drawing-based categories of desert conceptions to measurable spatial error in mental maps. Misconceptions proved spatial as well as conceptual: students tended to overextend desert regions and cluster them in emblematic areas, with category differences indicating that more physically differentiated conceptions align with higher spatial accuracy. Aggregated mental maps make these biases visible at the class level and can serve as formative feedback and a baseline for re-mapping after teaching. As a concrete step, a brief 'overlay-and-remap' routine can operationalize this: project the class aggregated map, overlay a vetted desert-distribution (process-based) reference map, and ask students to correct three overextensions and one omission with a one-sentence rationale. A short follow-up remap then provides a quick check of reduced spatial error and shows which drawing-category profiles still require reinforcement. In sum, reducing spatial error requires strengthening the concept–location link and confronting exemplar-driven placements with process-based maps.

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Declaration of Generative AI and AI-assisted Technologies

In line with JBSE's policy, we disclose the limited use of Generative AI. ChatGPT (OpenAI) was employed solely for minor language editing and APA-7 formatting checks and to help in analysing the literature used; no AI tools were used to generate content, analyse data, or interpret results, and all substantive text and claims were authored and verified by the authors. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of Interest

The authors declare no competing interest.

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