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The Process of Information Integration in Children's Spatial Cognition: An Analysis of Newly Acquired Knowledge and Mapping Rates via Fieldwork

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ABSTRACT

In Japan, children may need to evacuate independently when natural disasters occur while adult support is unavailable. Effective evacuation may depend in part on children's internal representations of the environment, or cognitive maps. This study investigated the development of children's cognitive maps through fieldwork, focusing on qualitative changes from route-map to survey-map representations and the factors associated with individual differences in spatial learning. Two fieldwork sessions were conducted with 94 fifth-grade students in Tokyo as part of disaster prevention education. Students drew hand-drawn maps of an assigned area before and after the fieldwork and completed a landmark recall list after the second session. Sixty-four valid responses were quantitatively analyzed by comparing students who changed from route-map to survey-map representations (Group A) with those who remained at the route-map stage (Group B). The results indicated that the two groups recalled a similar number of landmarks acquired during the fieldwork. However, Group B represented fewer of these landmarks on their post-fieldwork maps and showed a high concentration of landmarks along a single road. The average mapping rate was 26.8% in Group B, compared with 76.0% in Group A. Group A also expanded the number of roads represented on their maps and distributed landmarks across multiple interconnected roads and intersections. These findings suggest that the qualitative development of children's mental maps may depend not only on the amount of information recognized during fieldwork but also on how that information is spatially integrated within a network of roads and intersections. For disaster prevention education, it may therefore be useful to encourage children to use landmarks as spatial anchors for connecting multiple roads and intersections.

Keywords: Disaster prevention education, Child development, Spatial cognition, Mental map

INTRODUCTION

In recent years, natural disasters such as earthquakes, typhoons, and floods have become increasingly severe and frequent globally. Japan is also exposed to a wide range of natural hazards, including major earthquakes, typhoons, floods, and landslides. In response to this situation, disaster prevention education—such as evacuation drills and the utilization of hazard maps—is

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being actively promoted in elementary schools, and local governments are also requesting families to confirm their evacuation sites at home.

However, many conventional initiatives face a structural issue in that they are limited to specific scenarios, such as "under school supervision" or "at home." In the actual living environment in Japan, children spend a significant amount of time acting without adult support, such as commuting to school on foot without parental accompaniment or playing in local parks and shopping districts after school. Actual disasters are highly likely to occur during these times when children are alone; thus, there is an urgent need to foster children's ability to independently assess situations and autonomously select safe evacuation behaviors in the event of an emergency.

From the perspectives of cognitive psychology and disaster research, it has been pointed out that evacuation behavior during disasters requires "instantaneous spatial judgment." Modern people have largely lost the habit of carrying paper maps, and smartphone-based map services may become unavailable because of communication or power failures during an actual disaster. Therefore, when forced to evacuate via unknown routes during a disaster, action selections directly linked to survival will heavily depend on the internal spatial representations based on the child's individual experiences and memories, namely, their "cognitive maps (mental maps)." Fostering the early development of children's immature mental maps is a highly critical issue in constructing highly effective disaster prevention education.

THEORETICAL BACKGROUND AND RELATED RESEARCH

The concept of the mental map (cognitive map) was first systematically presented by Tolman (1948). It is a subjective spatial representation based on an individual's experiences, attention, and knowledge, and has been shown to possess different characteristics from objective coordinate systems like survey maps. LRS model as a framework for describing the development, Lynch (1960) classified and defined the components of space into five elements: Paths, Edges, Districts, Nodes, and Landmarks, stating that these interrelate to form a mental map.

Regarding the development of spatial knowledge, Siegel and White (1975) proposed the Landmark–Route–Survey (LRS) model as a framework for describing the development of spatial knowledge from landmark knowledge to route knowledge and, ultimately, survey knowledge.

Stage 1 (Landmark Knowledge): Characteristic objects in the environment are remembered as individual landmarks, with limited knowledge of their spatial relationships.

Stage 2 (Route Knowledge): Routes connecting familiar landmarks are represented as sequences, while relationships among different routes may remain limited.

Stage 3 (Survey Knowledge): Spatial information is organized into a more comprehensive representation that captures positional relationships among multiple routes and landmarks.

Downs (1973) and Iwamoto (1981) similarly demonstrate that children's spatial cognition develops in stages from a linear "route map" aligned with movement experiences to a planar and overarching "survey map." Furthermore, in a typology study of hand-drawn maps by elementary school students conducted by Teramoto et al. (1991), it was demonstrated that spatial cognition transforms from a route map-like cognition in lower grades to a survey map-like cognition in higher grades as students progress.

On the other hand, expansions to Siegel & White's stage development model have also been discussed. Montello (1998) argues that the acquisition of spatial information is continuous, accompanied by knowledge of positional relationships from the initial stages, and points out that development should be understood by distinguishing not only quantitative changes but also qualitative aspects such as the meaning and structuring of spatial information. Additionally, Wakabayashi (2008) suggests the possibility that routes and surveys develop in parallel and are used selectively, while Ishikawa & Montello (2006) point out that there are significant individual differences in spatial learning abilities, and without sufficient training, cognitive maps may become distorted.

While the "hand-drawn map method" is commonly used to externalize cognitive maps, as Hart et al. (1973) point out, there is a risk of underestimation in children because, even if their cognitive map is developed, their drawing skills on paper may be immature. However, since Japanese third-grade elementary school students have completed basic learning of map symbols and compass directions, it is expected that fifth-grade students (11 years old), who are the subjects of this study, are capable of map expressions that can withstand analysis. Previous studies by Oka & Mori (2025) have also shown that conducting fieldwork promotes the cognition of intersections and main roads, contributing to the growth of mental maps. However, studies that detail cognitive transformations before and after fieldwork as qualitative structural changes are not yet sufficient.

Research Objectives

Previous studies have primarily focused on whether the typology of hand-drawn maps changes before and after fieldwork. However, to better understand individual differences in children's spatial cognitive development, it is also important to consider the characteristics of their initial spatial representations.

This study examines whether increases in the amount of retained information are associated with the development of children's cognitive maps, while also considering whether qualitative changes in the organization and spatial integration of information contribute to this development. To address these questions, hand-drawn maps produced by fifth-grade elementary school students before and after fieldwork were compared with a subsequent landmark list.

The analysis focuses on students who initially produced route-map representations and subsequently either changed to survey-map representations or remained at the route-map stage. By comparing these two

groups, this study investigates differences in the organization and spatial integration of information that may be associated with qualitative changes in children's cognitive maps.

Experiment and Survey Design

In this study, an experiment was conducted targeting 94 fifth-grade students at Aijitsu Elementary School in Shinjuku Ward, Tokyo. It was conducted during regular class hours as part of a disaster prevention education program titled "Let's become 'Doctors of Our Town' so we can help ourselves and our friends during a disaster!"

Implementation of Fieldwork

Fieldwork (FW) was conducted twice in total: the first on October 7, 2025, and the second on October 17, 2025. Students formed groups of 4 to 5 members based on the proximity of their home locations. One university student accompanied each group to ensure safety, but they were instructed not to provide any advice regarding route selection or recorded content. During the FW, students used a dedicated app on provided tablet devices to place pins on the map and took photographs on the map whenever they identified locations that they considered dangerous or safe in the event of a disaster. For safety while walking, text input on the tablet was prohibited, and detailed records were handwritten on separately provided paper memos. Additionally, a "presentation session" was held between the first and second FWs, where each group shared the information on dangerous spots they had discovered.

This design allowed students to conduct the second fieldwork session using not only their individual knowledge but also knowledge about potential hazards shared by other groups.

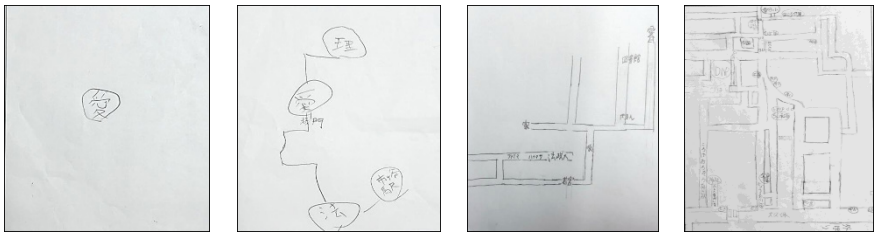
Acquisition of Hand-drawn Maps and Landmark List

Previous investigations revealed that asking students to draw a map "from home to school" yielded only route maps with low information volume. Therefore, to control for differences in prior knowledge among students, this study divided the area radially into eight sections (wedge shapes with a central angle of approximately 45 degrees) centered on Aijitsu Elementary School, assigning each student one specific section that did not include their own home. For the identical assigned section, students drew a "pre-hand-drawn map" before the first FW and a "post-hand-drawn map" after the second FW, relying solely on memory without external information (such as Google Maps) or consulting others. Furthermore, after the second FW concluded, a "landmark list" was created. For this landmark list, students were asked to "describe everything in the order of what left an impression on them," including buildings, shops, signs, and intersections they remembered within the walking area, and were also asked for a free description of "what they were conscious of while memorizing." This procedure allowed us to

identify landmarks that were remembered but not necessarily integrated into the spatial structure of the hand-drawn map.

Typology of Hand-Drawn Maps and Definition of Analysis Target Groups

Among the 94 subject students, the maps of 65 students (64 valid responses) from whom both pre- and post-FW hand-drawn maps were collected were evaluated by classifying them into the following four stages, following previous studies (Figure 1).



No Map Sketch Map Route Map Survey Map

Figure 1: Examples of hand-drawn maps.

No Map	Blank paper; shows no intention to draw a hand-drawn map.
Sketch Map	A hand-drawn map is drawn, but it is too fragmented to be called a route map.
Route Map	Only one route connecting certain points is drawn, lacking a comprehensive, overhead perspective.
Survey Map	In this study, a survey-map representation was operationally defined as two or more routes to a single destination are drawn, depicting a wide area comprehensively.

Table 1: Classification results of hand-drawn maps.

	No Map	Sketch Map	Route Map	Survey Map
No Map	0	3	1	0
Sketch Map	0	18	8	0
Route Map	0	0	22	6
Survey Map	0	0	0	6

Table 1 shows the aggregated results of classification changes, with rows indicating the pre-fieldwork classifications and columns indicating the post-fieldwork classifications. From Table 1, an improvement in typology was observed in 18 out of 64 students (28.1%), while 46 students (71.9%) showed no change in typology. Since this study focuses on the "qualitative structural transformation from the route-map stage to the Survey-map stage," the main

analysis targeted 28 students who were classified as the "route-map stage" at the pre-map stage. Among these, 6 students who grew into the Survey-map stage after the FW were defined as "Group A." Out of the 22 students who remained in the route-map stage, 6 students who exhibited positional relationship collapses were excluded, and the remaining 16 students were defined as "Group B." The structural differences between these two groups were comparatively examined.

Quantitative Analysis I: Structural Features in Pre-Hand-Drawn Maps

To verify what differences existed in the spatial cognitive structures of both groups at the initial state before conducting the FW, the structure of the road network and the placement of landmarks were analyzed.

Number of Utilized Roads (RVS) and Number of Intersections

Rather than the mere total number of drawn roads, the "number of independent roads on which one or more landmarks are drawn" was defined as the Road Variety Score (RVS). The analysis results of the pre-maps showed that Group A's RVS was distributed between 5 and 9 (all students had 5 or more), and the number of intersections was 4 to 8 (median 6.0). In contrast, Group B's RVS was concentrated between 0 and 4, and the number of intersections remained at 0 to 6 (median 2.5). As a result of an independent samples t-test, significant differences were observed in both the RVS and the number of intersections between the two groups at a 5% significance level.

Total Number of Landmarks and Landmark Concentration Rate

The total number of landmarks on the pre-maps was 5 to 12 (median 7.0) for Group A and 1 to 11 (median 3.5) for Group B, indicating that Group B tended to have a lower information density. Furthermore, as an index to measure the placement status of information, the Landmark Concentration Rate (Main Road Concentration Rate) was defined as "the number of landmarks on a single road where the most landmarks are drawn divided by the total number of landmarks." A higher value indicates that information is dependent on a single route. As a result, Group A's concentration rate was low, ranging from 16.7% to 40.0% (mean 24.6%), showing a tendency for landmarks to be drawn across all routes. In contrast, Group B reached an average of 51.3% (median 50.0%), with half of the information concentrated on a single road, and some students even had a concentration rate of 100%.

While Group A's concentration rate remained stable at a low level even as the number of landmarks increased, Group B tended to maintain a high degree of dependence on a specific single road regardless of information volume. From these results, it became clear that Group A, which achieved growth later, had already managed landmarks in a distributed manner prior to experiencing the FW and was prepared to utilize a "multi-faceted road network (framework)" incorporating multiple roads and intersections.

Quantitative Analysis II: Transformation of Spatial Cognition Through Fieldwork

The changes in hand-drawn maps before and after FW were compared based on the shifts in various indicators.

Changes in the Number of Landmarks

In the post-maps after FW, the average number of newly acquired landmarks for Group A was 9.1. Led by a prominent increase from 5 to 26 for Student B in Group A, landscape stimuli were steadily drawn onto the map as "new information." On the other hand, Group B's newly acquired number remained at an average of 3.1, with many students unable to break out of the dense zone of 0 to 4, indicating a stagnation in integrating information into the map. As a result of an independent samples t-test, significant differences were observed in both the increase in the number of landmarks and the number of new landmarks between the two groups at a 5% significance level.

Changes in the Number of Utilized Roads (RVS)

Group A's RVS expanded significantly from a pre-average of 5.7 to a post-average of 12.0, with values increasing for all students. In contrast, Group B's post-RVS averaged 2.8, with the increase remaining within the range of 0 to 4, showing no expansion of the road network. As a result of a Mann–Whitney U test, a significant difference was observed in the increase in RVS between the two groups at a 5% significance level.

Changes in Landmark Concentration Rate

The landmark concentration rate of Group A remained relatively low, at approximately 20%, both before and after the fieldwork. In contrast, Group B maintained a higher concentration rate of approximately 50% both before and after the fieldwork, indicating a continued tendency to concentrate a large proportion of landmarks along a single road or a limited road network. A Mann–Whitney U test showed no significant difference in the change in landmark concentration rate between the two groups at the 5% significance level.

These results suggest that the two groups differed primarily in how newly acquired information was represented on their maps, rather than in the overall degree of landmark concentration. Group A maintained a relatively distributed representation of landmarks across multiple roads, whereas Group B tended to continue representing landmarks within a more limited road structure.

Quantitative Analysis III: Integration and Omission of Cognitive Structures (Expression Gap)

The gap arising between children's "memories in their heads (landmark list)" and their "actual map expressions (hand-drawn maps)" was examined, analyzing how the objects of focus during FW were integrated into or omitted from cognitive structures.

Divergence Between Recalled Landmark Information and Represented Landmark Information

Comparing the number of landmarks described in the "Landmark list" (Recalled landmark information volume), Group A averaged 9.3 and Group B averaged 8.4, showing no large gap between the two groups. This corroborates that Group B students also identified and recalled a similar number of landmarks during the fieldwork, successfully discovering and memorizing objects. However, when it came to the number accurately drawn on the map (Represented landmark information volume), Group A achieved 7.4, whereas Group B dropped sharply to 3.9.

Mapping Rate

The mapping rate, calculated by dividing the Represented landmark information volume by the Recalled landmark information volume, reached an average of 76.0% for Group A, with individual mapping rates concentrated in the 70–90% range. In contrast, the average mapping rate for Group B remained at an extremely low level of 26.8%, with many students distributed in the 0–40% range.

Representation of Newly Acquired Information

The proportion of "new discoveries" not present on the pre-map among the information described in the landmark list (new discovery ratio) was high for both Group A (81.1%) and Group B (72.9%), showing that Group B also acquired much new knowledge during FW. As a result of a Mann–Whitney U test, no significant difference was observed in the new discovery ratio between the two groups at a 5% significance level. However, the number of those potential new discoveries (Group A average 7.4, Group B average 6.3) actually drawn onto the post-map (integrated number) plummeted to 2.1 for Group B, compared to 5.4 for Group A. As a result, the drawing rate for new landmarks was 76.3% for Group A and 31.7% for Group B. As a result of a Mann–Whitney U test, a significant difference was observed in the drawing rate of new landmarks between the two groups at a 5% significance level.

The results suggest that Group B's difficulty was not simply a lower number of recalled landmarks or insufficient attention, but rather a difficulty in spatial integration in the "integration process" of correctly positioning and placing recognized information (points) onto the map representing spatial structure (surface).

Discussion: Factors for Route Map Stagnation and Mechanisms for Leaping to Survey Map

From quantitative analyses and statistical backing, it became clear that a distinct divergence exists between children's "recognition of information" and "expression on a map" in the growth of mental maps through fieldwork. Group B, which stagnated at the route-map stage, functioned normally up to the "recognition" stage of discovering objects and understanding their

meanings in the landmark list. The primary factor behind their markedly low mapping rate despite this is an excessive reliance on a "linear structure where information is simply lined up along a single road. "In this single-road-dependent structure, specifying the "positional relationships" of landmarks slightly off the road or information spanning multiple routes becomes extremely difficult. As a result, even if they could verbally describe on the sheet that "there was a shop called XX," they could not convert this into spatial coordinates indicating "which road and in what orientation it is adjacent to," which is believed to have caused a massive omission of information (ower representation rate).

In contrast, Group A, which grew into the Survey-map stage, utilized landmarks not merely as fragmented scenery but as "clues (markers)" for recognizing and remembering new roads. With the conviction that "because this building is here, this road certainly exists," they distributed landmarks across the entire area without depending on specific main routes, thereby possessing numerous location-specifying anchors such as "this shop is between that road and that road." This enabled them to link a multi-faceted road network combining multiple intersections and roads within their brains, allowing them to accurately place newly acquired information within the appropriate spatial locations on the map, ultimately realizing a high mapping rate.

CONCLUSION

Through a comparison of hand-drawn maps and landmark list targeting fifth-grade elementary students, this study provided a new perspective on the "development through increased information volume" assumed by Siegel & White's LRS model. It became clear that children's mental maps do not automatically transform into survey maps simply by increasing the retained information. Analysis revealed that stagnating students were not suffering from insufficient attention or lack of motivation; rather, they could not break free from a reliance on a specific single road, leading to omissions during the information integration stage. The findings suggest that the decisive factor for embedding acquired information into the brain as a practical cognitive map rather than fragmented knowledge—in other words, for qualitatively growing a mental map from a route map to a survey map—is not the "recognition volume (input)" of information itself, but that "integration" for positioning recognized information into spatial coordinates is an indispensable process.

In situations where adult support is unavailable during a disaster, Survey-map stage spatial comprehension ability is required for children to protect their own lives and select optimal evacuation behaviors. In future disaster prevention education, it is extremely important not only to have children memorize dangerous spots and markers but also to instill in them the habit of "structuring the entire space in daily life by connecting intersections and multiple roads starting from landmarks, without relying on specific main routes." It is strongly anticipated that the findings of this study will contribute to the establishment of a foundation for highly effective disaster prevention education for children with undeveloped mental maps.

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