PÉTER BAGOLY-SIMÓ, ZSOLT PALATINUS, NIKOLAUS VON SCHMETTAU, DANIEL SCHOLL, AND ANETT KÁDÁR

17 Towards an Improved Map Skill Acquisition through Educational Media: Methodological Approaches and Future Steps

17.1 Introduction

Maps bear great relevance to both individuals and societies, as they assist (daily) wayfinding and navigation in various indoor and outdoor spaces. Concurrently, maps disclose historical information and store spatial information in a particular format that stands, along with pictures, paintings, movies, and written texts, for a unique cultural artefact allowing human beings to communicate about their environment.

Given their multiple importance, formal education has set an emphasis on educating young individuals to decode, interpret, evaluate, and produce maps. The main rationale is to foster students' spatial orientation and thinking – an endeavour primarily tied to geometry (in mathematics) and geography.

Traditionally, geography curricula have continuously contributed to developing students' spatial orientation and thinking. Generally, geography curricula entail specific requirements concerning cartographic content, maps, and map skill acquisition. Textbooks play a crucial role in providing all stakeholders of the teaching-learning process with one example of how the curricular recommendations can be interpreted (Bagoly-Simó 2017). Therefore, textbooks, often undergoing a rigorous state approval process, are expected to entail ways of dealing with cartographic content and map

skills. Unlike other subjects, geography heavily relies on a multitude of educational media. Despite the variety of possible media, textbooks continue to play a leading role in geography classrooms (cf. Bagoly-Simó *et al.* 2019; Hemmer and Hemmer 2021).

Therefore, this chapter turns to textbooks and their role in map skill acquisition. It will first investigate methods and approaches to analyse Geography textbooks as educational media. The subsequent section looks at ways to explore students' textbook usage by means of eye-tracking. Finally, the third main section proposes the usage of additional physiological data that, along with eye-tracking allows to collect better evidence for an improved understanding how students work with tasks targeting map skill acquisition.

17.2 Textbook Content

Previous work explored various facets of maps and map skills in geography textbooks. While early studies linked map skills to globe skills (Hawkins 1977), over the last two decades, scholarship navigated textbook tasks and their contribution to spatial thinking (Jo and Bednarz 2009, 2011). More specifically, studies investigated selected skills, such as map interpretation (Gillen *et al.* 2010).

Systematic studies on specific map skills used the Map Skills Model (Hemmer *et al.* 2010) as a framework to explore how textbooks dealt with map reading and evaluation. Based on the PISA model for reading literacy, the Map Skills Model distinguishes between graphical decoding, use of information from within the map, and use of external information. Thereby, continuous and discontinuous text elements play an equally important role. Unlike continuous text, maps require an initial (a) decoding of colours, symbols, and geometry. Only subsequently can students proceed to (b) map description by looking at individual elements. Such skills facilitate (c) map interpretation consisting of exploring the relationships between several individual elements depicted in the maps. Traditionally, students solely rely on map content; however, advanced map interpretation also requires the

consideration of additional and external sources (e.g. atlas, digital maps, graphs, texts). Such external sources are vital for (d) map evaluation targeting both content and structure (i.e. map design). Using the Map Skills Model as reference, Bagoly-Simó and Hemmer (2010) analysed Romanian lower secondary geography textbooks and found that tasks primarily facilitated map description followed by interpretation and decoding. The analysis of Bavarian lower secondary geography textbooks (Hemmer *et al.* 2013) produced similar results. Bagoly-Simó and Binimelis (2021) moved the focus on the early years of primary education and compared Catalan and German textbooks for integrative subjects also entailing geographical content and skills. The results showed a strong emphasis on decoding with an occasional consideration of description. Overall, the textbooks lacked any consistent progression model. Also, Bagoly-Simó and Binimelis (2021) diagnosed an alarmingly limited diversity of cartographic representations included in primary textbooks.

Despite the increasing interest in maps and map skills, a range of facets central to student learning remain untouched. Designing strategies to support students during map skills acquisition requires evidence that past studies only presented partially. In the following, this chapter suggests possible avenues for textbook and educational media research with a special emphasis on maps and map skills.

Unlike general education or media studies, subject education (in our case, geography education) spotlights subject-matter knowledge. Therefore, when exploring maps and map skill, *cartographic content* constitutes the first dimension in need of consideration. The early stages of map skill acquisition traditionally rely on cartographic knowledge (Hüttermann 1998). Students first require knowledge of the map's structure, namely content, scale, orientation, legend, and title as these elements are essential for map decoding, reading, interpretation, and production alike.

Another element of basic cartographic knowledge is the typology of projections and their role during map production. Particularly (mass) media often uses maps exhibiting different projections, leading to significant differences in spatial extension and relative size. Therefore, introductory knowledge needs to cover why there are different projections and

how they impact map content, and, ultimately, the readers' perception of the very content.

Absolute location primarily relies on geographic coordinates. Consequently, basic cartographic knowledge also entails matters of longitude and latitude, parallels and meridians, and their representation on both analogue and digital maps.

Finally, map typology traditionally covers survey, physical, and thematic maps. While basic cartographic knowledge habitually merely introduces these map types, it also supports highlighting different ways of representing content (chromatic coding, symbols, etc.).

Bagoly-Simó and Binimelis (2021) analysed Catalan and German primary textbooks and found modest cartographic content hardly able to support knowledge-based map skill acquisition. Historical studies could help uncover trends impacting cartographic content, particularly because of competencies-based education. Also, additional studies could explore the overall distribution of cartographic content across educational levels. Looking beyond the representation of basic cartographic knowledge in geography textbooks, future studies could investigate digital maps and Geographic Information Systems. Also, a stronger emphasis on the variety of cartographic representations, particularly considering their share and distribution across textbooks for several grades, seems like an important endeavour.

Along with basic cartographic knowledge, textbooks also introduce *map skills*, which constitutes the second avenue of research in urgent need of further evidence. Textbooks traditionally introduce map skills through units dedicated to basic cartographic knowledge. However, countries may opt for quite heterogeneous approaches, such as starting from a more pictographic or experience-based approach and slowly moving into maps and cartographic content (cf. Bagoly-Simó and Binimelis 2021). Various models, both normative (Catling 2018) and empirically validated (Hemmer *et al.* 2010), describe possible avenues for textbook authors to implement map skill acquisition. Despite a growing body of literature on map skill acquisition, within national settings, praxeology seems to still play the decisive role in shaping how textbooks introduce and further develop map skills (cf. Hüttermann 1998). Mapping such approaches would help gaining valuable

insight into decades of praxeological knowledge widely accepted in teacher communities and serving as grounds for educational media development. Data could then help to revisit variables and dimensions of the existing map skill acquisition models.

A third main area of future research seems to coagulate around *progression*. As Bagoly-Simó and Uhlenwinkel (2017) point out, already at curricular level, progression requires urgent attention. Concerning map skills, first studies already indicate that neither individual books nor those published for a specific educational level, such as primary (cf. Bagoly-Simó and Binimelis 2021) or lower secondary education (Bagoly-Simó and Hemmer 2010), implemented a consistent progression model.

(Textbook) Tasks constitute a core indicator of progression. While Bloom's taxonomy continues to be influential, at state level and within individual subjects, models further developed its units. Concerning geography textbooks, authors (Bagoly-Simó and Hemmer 2010; Hemmer *et al*. 2013; Bagoly-Simó and Binimelis 2021) used three performance levels to explore map skill progression: reproduction, reorganization and transfer, and problem-solving. Future studies might investigate textbook and educational media tasks' distribution across performance levels. Based on evidence from three national settings (Bagoly-Simó and Hemmer 2010; Hemmer *et al*. 2013; Bagoly-Simó and Binimelis 2021), tasks tend to primarily focus on reproduction and reorganization. Transfer and problem-solving – two essential mental operations – constitute the exception. Certainly, map skill acquisition strongly relies on cartographic media used during teaching and learning. Therefore, future studies should jointly explore cartographic materials and tasks.

Finally, future studies could explore the way textbooks and educational media implement *text-image integration*. Previous results already uncovered various patterns of discontinuous text usage in Geography textbooks. It seems important to further investigate the value textbooks dedicate to maps. For instance, ideally, maps should never serve decorative purposes. Instead, they should carry additional information complementing that presented in the continuous text. Also, map skill acquisition largely depends on whether textbook tasks reference maps included in textbooks and actively require students to use them during task processing.

Also, the variety and quality of maps included in the textbook, constitutes an essential dimension of map skill acquisition in need of further exploration. Along these lines, studies contrasting the share of maps with that of other discontinuous text elements (e.g. pictures, graphs, cartoons, cf. Bagoly-Simó and Binimelis 2021) could offer further evidence on types of maps and the progression based on which textbooks introduce them. Also, studies that explore referenced external maps, such as atlases, digital map repositories, cartographic apps etc. would shed light on the variety of representations and also sources of cartographic representation relevant to school and beyond.

17.3 Using Textbook Maps: Eye-Tracking

While textbooks and educational media entail the required tools, most stakeholders are interested in how to use maps and how to acquire, apply, and further develop their map skills. Over the last two decades, academic research on maps increasingly turned to eye-tracking as a research method. Facilitated by the easy access to eye-tracking technologies, a multitude of disciplines (Holmqvist and Andersson 2017) started exploring various aspects of maps using the technology. Although there were hardly any studies prior to 2000, their number has increased significantly in recent years (Płużyczka 2018). Eye-tracking bears the key advantage of objectivity as it records eye movement, offering scholars access to what their participants do instead of what they choose to communicate when processing, for example, questionnaires or answering interview questions. Jarodzka *et al.* (2017) argue, eye-tracking focusses on how users interact, in visual terms, with interface designs. In contrast to other methods, such as loud thinking, walk-along interviews, experimental settings, or evaluation studies, eye-tracking discloses eye movement while interacting with a map, in most cases, during problem-solving.

Given its potential, eye-tracking rapidly gained popularity in research on maps (Krassanakis and Cybulski 2019). Eye-tracking allows to explore cartographic symbols and their design principles with the finality to reveal

what makes maps more legible and thus more effective. For example, Brychtová and Çöltekin (2017) focused on the links between legend hues and spatial distances, while Dong *et al.* (2018) investigated the usability of flow maps through comparisons between straight lines and curves and line thicknesses and colour gradients.

Eye-tracking also boosted research using interactive maps as stimuli by shifting the focus away from static maps (Göbel *et al.* 2019). Popelka *et al.* (2022), for instance, analysed the variety of methods users applied during map comparison in an ESRI environment. Göbel *et al.* (2019: 663) developed FeatureEye Track – a novel methodological approach to '[…] log the cartographic features that have been inspected as well as the mouse input during the interaction with digital interactive maps'. Overall, as Krassanakis and Cybulski (2021: 5) conclude, '[…] eye-tracking technology has substantially contributed to the experimental cartographic research'.

Broadening the methodological spectrum – particularly concerning experimental settings – bears potential for studies on maps and education. Using a rather broad definition of education, scholarly work explored various facets of maps and map skills.

Behnke's (2016a, 2016b, 2017, 2021) studies are located at the intersection of textbook design and usage. Based on the model of usability parameters of well-designed geography textbook visuals (Behnke 2021), an experimental setting served to map students' design preferences. While maps only played a marginal role, the results showed that students only considered maps entailing additional information to that presented in the continuous text and were more likely to glance at maps when textbook tasks explicitly required them to do so.

Eye-tracking also initialized what Zyszkowska (2015) describe as the cognitive-digital stage of perceptual research exploring map perception using software. Keskin *et al.* (2020) explored the cognitive processes of expert and novice map users during map-related information retrieval using maps of varying difficulty levels. In contrast, Dong *et al.* (2019) looked at the impact of geography courses on students' abilities to work with maps. While the stimuli contained terrain visualizations, the results still confirmed the positive impact of geography courses on undergraduates' map-based spatial ability particularly regarding spatial orientation and visualization.

Beitlova *et al.* (2020) embedded eye-tracking into a broader methodological framework. Based on an online questionnaire, the authors identified the most popular atlas along with how 600 geography teachers used it in their classrooms. A subsequent eye-tracking study uncovered differences in how teachers and students solved map-related tasks. Interestingly, the teacher preferred to rely on her knowledge instead of consulting the map while students encountered a range of challenges due to poor cartographic visualization.

Havelková and Gołebiowska (2020) used constructed stimuli resembling thematic maps to identify differences between less and more successful map users. The results allowed for the identification of less successful individuals' specific behaviour during task processing, namely a clear preference for faster and less cautious solutions as compared to their successful peers. Some of the most important challenges students encountered originated in legend use and handling map layout and content.

Overall, eye-tracking as an (additional) research method, has contributed significantly to better understand various facets of map production and usage (incl. map skills). While cartographic research may define a different research agenda, formal education could benefit from operationalizations relying on eye-tracking in many ways. First, future studies could systematically apply (experimental) designs *across stakeholder* and *age groups*. Studies focusing on young individuals and the early years seem crucial, as most studies tend to primarily turn to upper secondary school or university students; however, despite clear evidence against initial rigid timelines (cf. Piaget and Inhelder 1975), basics of spatial orientation and thinking remain tied to the early years. Second, *longitudinal studies* connecting various levels of formal education could help better understand how spatial thinking develops over time and what strategies individuals apply in various settings, such as the geography classroom or activities outside of school. Mobile eye-tracking devices already offered significant insight into adults' strategies and could serve as a starting point to work with groups of individuals in various settings across the educational levels. Third, *evaluation studies* looking into textbook and educational media design could better explore the role and configuration of maps. Thereby,

studies on tasks dedicated to map skill acquisition and development could play an essential role. Finally, with the rise of AI, other promising areas are *virtual* and *augmented reality*, and *digital formats* involving maps and cartographic representations. With the increasing number of students gaining primary and, often, sole experience with digital maps, eye-tracking combined with other methods could contribute to exploring other avenues of map skill acquisition.

17.4 Looking Beyond Eye Movement: Physiological Data

While eye movement allowed a better understanding of how individuals work with maps, their diagnostic relevance remains limited. Recently, eye-tracking studies enriched their data sets by also collecting additional physiological data, such as EEG (cf. Keskin *et al.* 2020; Fairbairn and Hepburn 2023).

The motivation for looking at physiology in relation to cognitive effort has been fuelled by ideas laid out in ecological psychology and the E3 (embodied, embedded, enactive) approach of cognition. According to these theories, specific organismic behaviour including cognitive effort should be better understood as an interaction between various active levels of the environment and the organism (Gibson 1979/1986; Turvey *et al.* 1981; Goldfield 1995; Reed 1996; van Lier 2004). From a physiological perspective, data registered by receptor cells, neural pathways, muscle fibres, and the neurophysiological events (eye movements included) should be understood within the context of the actual task and environment within which the coordination of the behaviour is being carried out (e.g. van Orden *et al.* 2003, 2005, 2010; Holden *et al.* 2009). It also must be emphasized that both the topology and the strength of the interaction may vary in time depending on contextual factors (Saltzman and Holt 2009; Gorochowski *et al.* 2012). Registering or calculating these changes are indicative of the interdependency among the individual, the task, and the events in the environment.

The real challenge of this approach is to find the appropriate measures in the highly complex cascading dynamics of physiological data, the ones that may index reliable correlations between recurrences and changes in behaviour that are linked to the task at hand. So far, multifractal measures, such as MFDFA or direct estimations of the width of the multifractal spectrum are among the most promising methods research used to identify cognitive transitions and task-related effort.

The potential benefit of these new methods is that they offer informative connections between the fluctuation of physiological processes without facing the challenges of estimating actual gaze positions and their dynamics. Another advantage of multifractal analysis is that the method is rather agnostic about the type of collected data if it has been recorded with a high and stable resolution. Movement data recorded using motion capture, accelerometers, and cameras (including eye tracker cameras) generally provide a good source, but cardiologic readings and a wide range of modern wearable sensors are also suitable for data collection.

Among the difficulties are that the analytical tools require higher levels of statistical skills, processing power and large digital storage capacity. Another challenge is the fact that research into visual search and problem-solving is relatively new and has mostly focused on reading behaviour. However, there are rather promising attempts to combine visual search, reading and problem-solving. In a recent study, multifractal detrended fluctuation analysis demonstrated the organizational structure of the data reflecting the ocular activities of the subjects under the different tasks (Freije *et al.* 2017). The most promising route to take, therefore, is to collect eye movements and other physiological measurements alongside in a map reading test and investigate how these methods complement each other. Both theoretical and applied usability entails that researchers can identify differences between expert map readers and beginners in movement patterns and dynamics due to differences in cognitive coordination during the task. The classification of these differences may help in turn to evaluate teaching methods by which reliable and enduring map reading skills are formed.

17.5 Students, Teachers, and Maps

Map skills allow individuals to decode, interpret, evaluate, and produce cartographic representations. Thereby, scholarship on cartographic representations seems equally important as work on map skill acquisition and development. Viewed from the perspective of education, this chapter offered a brief insight into three possible operationalizations worthy of further exploration. Combined with other methods, eye-tracking can facilitate a better understanding of how students work with maps, use them to solve problems, and apply their skills in various contexts within and outside of school. Looking at formal education as an ecosystem, future research should also turn to the other stakeholders of the teaching-learning process, particularly teachers. Initial teacher education seems essential in equipping future generations of teachers to design teaching-learning situations including adequate educational resources to best support students' map skill acquisition and development. Similarly, continuous education formats might also support in-service teachers in updating their rich praxeological knowledge based on novel evidence.

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