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Proliferation of Cartographic Education in the Age of Big Data

Liqiu MENG

Chair of Cartography and Visual Analytics, Technical University of Munich, Munich 80333, *Germany*

Abstract: Maps have long been a part of everyday life for the general public, and even more so in today's knowledge society. No doubt, cartography as a profession of map design is assuming a more important role in the formation of intellectual skills in terms of spatial reasoning. Since its emergence as an academic discipline about 100 years ago, cartography has undergone many paradigm shifts. Its interaction with other disciplines has also constantly unfolded. These changes have left traces in cartographic education programs. In the age of big data, however, we are facing four fundamental challenges: (1) cartographic courses are being marginalized or even disappearing from degree programs in geospatial sciences; (2) the role of cartographers is increasingly eclipsed as a side effect of participatory cartography; (3) cartographers are blamed whenever something goes wrong with map use; and (4) professional map publishers can hardly compete with online mapping platforms dominated by Internet giants. Based on a contextual analysis of this seemingly gloomy situation, the paper reveals a number of proliferation points for the design of future cartographic curricula. First, cartography, once dedicated to supporting geospatial sciences, is thriving in the soil of data science, mapping not only the earth or other celestial bodies, but literally any kind of virtual space. Second, cartography has benefited from theoretical and technological advances in cognitive sciences, especially non-intrusive user studies, so that spatial cognition is becoming an integral component of cartographic education. Third, the role of scapegoat for wrongdoing of maps has accentuated cartographer's overarching responsibility for quality and ethical issues in the geodata value chain. Finally, the diversification of the labor market requires new approaches to prepare future talents for a coopetition-oriented ecosystem in the marketplace.

Key words: transdisciplinary; spatial cognition; transparency; inclusiveness; online mapping platform

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1 Historical Background of Scientific Disciplines

For thousands of years, science was conducted by a small group of generalists and polymaths who were capable of thinking, observing, synthesizing knowledge, and understanding the natural and social environment in a nutshell. Science was treated as an all-inclusive knowledge system. There were different schools, each with some guiding philosophy but without disciplinary division. It was only after the First Industrial Revolution in Great Britain, the French Revolution, and the Napoleonic Wars that the production and dissemination of knowledge became more accelerated and highly specialized, leading to the emergence of scientific disciplines in the 19th century society. Each scientific discipline functions as a subject domain for teaching and learning in schools and a structured unit of knowledge in higher education systems. Some fundamental aspects of a discipline remain invariant and serve as anchor points for

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First author: Liqiu MENG
E-mail: liqiu.meng@bv.tum.de

comparing individual achievements of knowledge production[1]. A close coupling of the disciplinary structures in science and the higher education institutions was realized for the first time at reformed German universities in the first half of the 19th century and then rapidly spread to other countries[2]. Since then, it has been a public perception that people who major in a discipline become specialists and form a scientific community.

The boundaries between different scientific disciplines are neither predetermined nor free of overlap, but depend on the conditions of their constitution and on their relations of cooperation and competition. A discipline can be transformed into a new paradigm or branch out at turning points marked by ground-breaking works with a new theoretical reference framework or a new systematization of the known facts. Different disciplines have differing social impacts and visibility. Their interactions are asymmetrical. Some disciplines play the role of a shared foundation for a number of other disciplines in the processes of knowledge creation. However, the entire scientific system has neither a fixed center nor a fixed hierarchy. It is simply in the dynamic process of uninterrupted evolution, in which some disciplines grow and expand, and others become inactive, shrink or disappear. Some branches become independent disciplines with their own profiles, and therefore exist side by side with the parent disciplines. New disciplines arise, often at the interface between different disciplines.

We may be insensitive to every small step of change. But if we look at a discipline on a long enough time scale, we may be surprised. For example, if we observe the entire lifespan of the cartographic discipline since its inception 100 years ago, some paradigm shifts and their reflection in the curriculum become immediately apparent. The following sections address a number of challenges in the age of big data, which are also proliferation points for cartographic education.

2 Challenges and Proliferation Points of Cartographic Education

2.1 The specificity of cartography in geospatial sciences

Among all geospatial scientific disciplines, geography is doubtlessly the one with the longest tradition. It has been continuously present in the curricula of basic education for the last 500 years. The elementary geography teaching has enlightened humanity with knowledge about the shape and size of the earth, its position in the universe, its physical structure, surface features and climate, as well as the people who interact with the earth and the characteristics of the different continents and countries. Geography was taught in schools for centuries, but not taken seriously at universities until the colonists began to divide the world. In the early 19th century, geography as a scientific discipline reached its greatest intellectual significance[3]. At the same time, geodesy and geology, which were treated as parts of geography, developed into independent disciplines and started to flourish at higher education institutions.

Today, geography is generally regarded as the study of places and the relationships between people and their environment. It remains an established subject in school and university curricula, and is often interpreted by the public as an umbrella concept for all geospatial scientific disciplines. Geodesy is concerned with measuring position, orientation, shape, size and gravitational field of the earth as well as tracking changes in geodynamic phenomena. As a natural science and engineering discipline, geodesy serves both exploratory and practical applications. In the beginning, it was taught at military schools mainly for territorial maintenance and expansion, and later entrusted with a mission of public services. Geology describes the structure of the earth on and beneath its surface, and the processes that have shaped that structure. Its emergence in the 19th century was largely triggered by economic motives and practical needs of the mining industry. In the course of its development, it acquired a more scientific research content and therefore often used as an interchangeable term with geoscience. All three disciplines-geography, geodesy and geology-carry the prefix "geo", which refers to the earth in Greek, the respected first language of science in the western world.

Cartography was a subdiscipline of geography, geodesy and geology, and supported these parent disciplines with maps as tools for exploring the earth and communicating the research findings before it became an independent scientific discipline in the early 20th century. The birth of cartography was set by the German geographer Max Eckert (1868—1938) who published two volumes on "map science" in 1921 and 1925[4]. As a relatively young discipline, cartography is dedicated to the science, technology and art of making and using maps. Its early curricula content was characterized by cadastral mapping focused on property boundary beacons, topographic mapping for military purposes, and general map production, which were supported by the elaborated theory of map projection. Later, the curricula content was extended to thematic mapping and national atlas production as an expression of postwar economic development. Students were exposed to further cartographic theories that deal with the geoinformation flow from reality through cartographers and maps to users, such as semiotics, modeling, and communication. And then, computer-aided mapping tools made their way into curricula, and became the most rapidly evolving course content. The advent of the Internet has enabled online mapping technologies, leading to more radical changes in the cartographic discipline.

In the recent century, geography, geodesy and geology have been stratified into many new branches as demonstrated in Fig. 1. During this time, cartography has grown through its interaction with these geospatial sciences and a younger discipline-photogrammetry and remote sensing. It also played a key role in shaping another discipline-geoinformatics-since 1960s. The number of maps has increased exponentially, making the data, concepts and findings in geospatial sciences more visible and easily accessible. However, degree programs of cartography have not grown accordingly, rather, they have suffered a global contraction. Cartographic courses have also become marginalized or even disappeared in the degree programs of geography, geodesy, and geology. To counteract this unbearable fact, the panicked cartographic community tried to rebaptize the old-fashioned term cartography as geovisualization in the technical literature, but in vain.

If we make a self-critical analysis in retrospect, we can see that the conventional way of measuring the visibility of a discipline by its profile and scope does not apply to cartography. What matters for the growth of cartography is neither whether it has a distinctive profile nor whether it has a large enough scope, but its connections with many geospatial sciences as shown in the schematic in Fig.2. The term cartography does not carry the prefix "geo", indicating its transdisciplinary nature and the freedom of visualizing not only the earth and other celestial bodies, but literally any kind of virtual space. Geovisualization as a substitute for cartography may have some short-term appeal, but it implies an effort to bundle cartography with geosciences, which would unnecessarily limit the subject domain.

Cartographic education involves various relationships-between cartography and other disciplines, between different people such as cartographers, system developers and users, between different models of the reality such as digital landscape (primary model), map (secondary model) and mental map (tertiary model), between map content and use purposes, between different levels of detail, etc. Cartographers judge the quality of a map more by its relative fitness than by absolute geometric or topological measures. The fitness constraint has enforced the cartographers to transfer their expertise to other disciplines and to determine which parts can be reused. Map designers know very well that a map should reflect not only the distribution patterns of the underlying data, but also take into account the limited capacity of human visual perception. Therefore, it is a common practice to show no more than 7 classes in a choropleth map[5]. Map designers know very well how to approach the truth more efficiently with the help of persuasive functions and storytelling techniques. They are also good at conducting transformations, for instance, from one display surface to another, and from one scale to another. The aesthetic value of a map is another example about fitness. It is not an objectively measurable value, but a changing relationship between the viewer and the map.

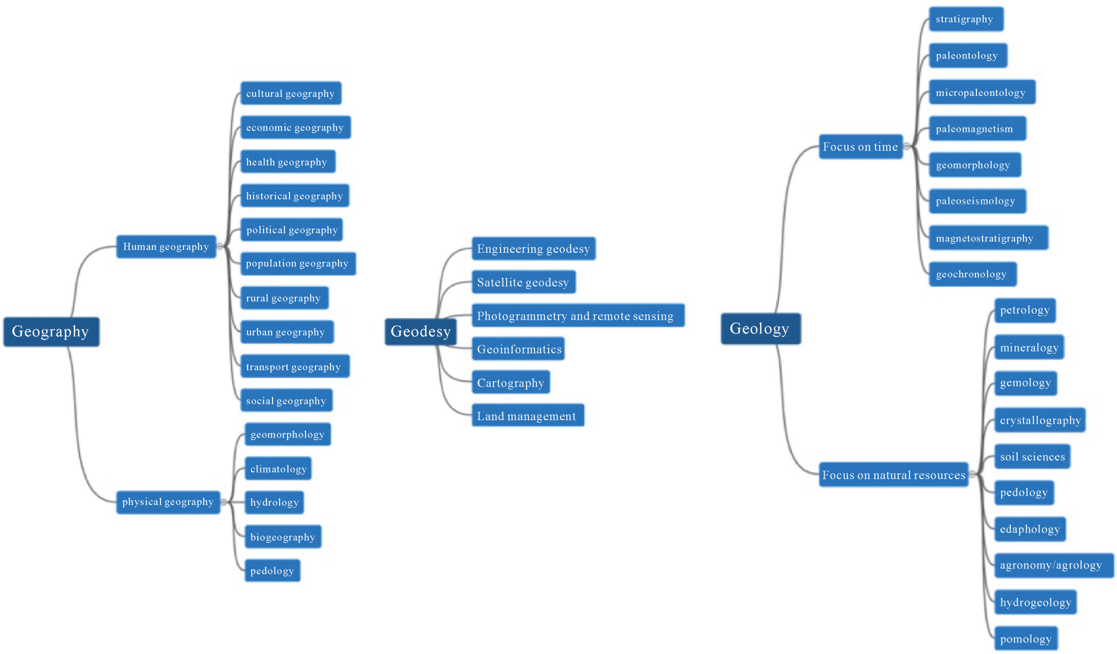


Fig.1 Exemplary specializations in the university curricula of geography, geodesy and geology

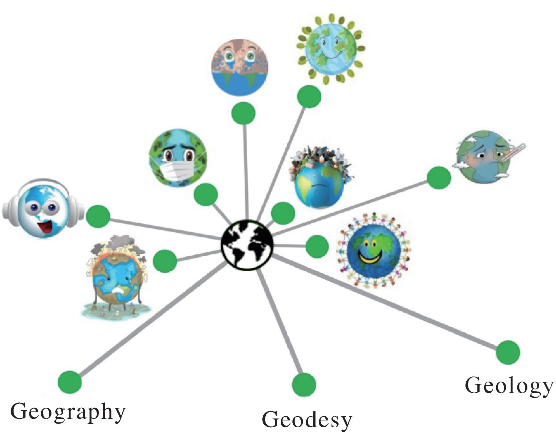


Fig.2 The transdisciplinary nature of cartography

2.2 Spatial cognition of map users

Based on the aforementioned special characteristics of cartography, we naturally have good reason to believe that the more relationships cartography has to deal with, the stronger it becomes. However, this does not seem to be proven yet because the popularization of participatory cartography has blurred the boundary between mapmaking and map use, thus causing an unusual structural change. Maps are increasingly shared. Shared maps are extended to shared mapping tools. Users are more and more empowered and positioned at the center. They are no longer passive information receivers or service consumers, but co-creative prosumers. Consequently, mapmakers are relegated to the background.

With a minimum training, users can now operate open-source mapping tools and create their own maps via a few mouse clicks as a result of "do-it-by-yourself". This gives an impression that map design could be fully computerized. Cartography has no more secrets, therefore, no more reason to exist. The panicked cartographic community wonders whether openness and user-friendliness make the otherwise interdisciplinary cartography completely undisciplinary.

If we take a close look at the problem, we will find that the design recipes or rules in open-source mapping tools claim only the externalized part of cartographic knowledge. Choosing from a limited number of map projections, thematic map templates, statistical charts, and color scales has led to a growing number of similar looking and dull maps on the Internet, thus promoing the so-called "sterile cartography"[6]. A good design is not just a mathematical transformation or symbolization with known parameters, but a creative assembly that also requires the skills of spatial cognition as internalized cartographic knowledge.

Spatial cognition is a fundamental element of cognitive science that emerged in the 1950s. Fig.3 summarizes the popular recording techniques applied in neural sciences and medical sciences. With temporal resolutions from less than 1ms to 1s they may reveal the function from a single cell to a brain region. The functions of more than a dozen brain regions related to human sensory and cognitive abilities have been already identified as shown in Fig.4. More spectacularly, 3D Polarized Light Imaging based on microscopy technology, brain slicing and supercomputing, is now paving the way for the understanding of not only the individual brain cells, but the nerve fiber pathways of an entire human brain (Fig.5).

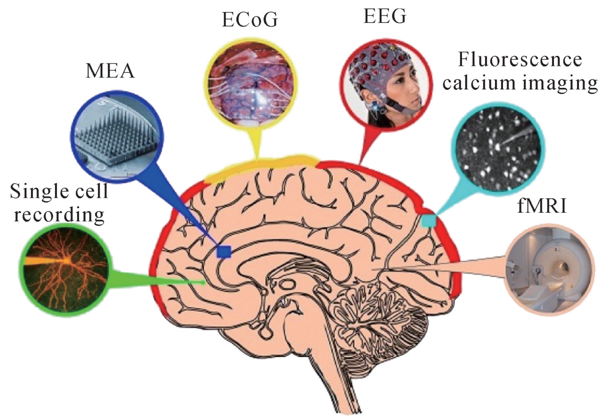


Fig.3 Sensory techniques for recording brain activity (see in https://qbi.uq.edu.au/brain/brain-functions/how-measure-brain-activity-people)

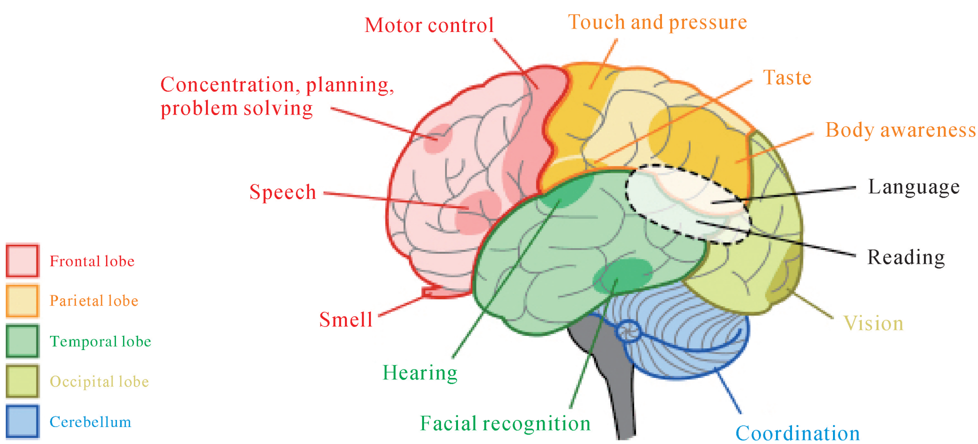


Fig.4 The discovered functions for more than a dozen brain regions (see in https://askabiologist.asu.edu/sites/default/files/resources/articles/nervous_journey/brain-regions-areas.gif)

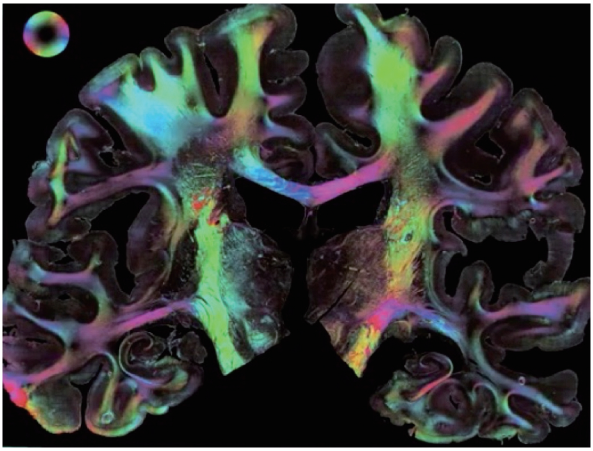


Fig.5 The technology of 3D polarized light imaging presented by Jülich research center, Germany (see in https://www.youtube.com/watch? v=PTOQFo1GJaI)

Two of the non-invasive recording techniques are widely used to study brain activities related to spatial cognitive tasks such as localization, orientation, estimation of distances and relations between objects. The functional Magnetic Resonance Imaging (fMRI) is used for mapping the active neural areas based on blood flow in the brain with a fairly good spatial resolution. Whereas the ElectroEncephaloGram (EEG) is used to track dynamic brain states via electrodes placed on the scalp with a fairly good temporal resolution. Furthermore, inexpensive eye-tracking devices have become the favorite experimental lab aids in cartographic education. Human spatial cognition abilities or disabilities can be partly revealed in the eye movement patterns for various indoor or outdoor map use tasks. New theories and methods from cognitive sciences can facilitate cartographic research on topics such as spatial representations in the mind and robotic simulation of human behavior in the mobile environment. Cartographers will continue to benefit from advanced non-invasive tracking techniques, thus gain more insight into fine-grained spatial cognition functions of the human brain.

Over the past decade, the cartographic research community has intensified user studies in the laboratory and in real-world scenarios, focusing on the understanding of user behavior when interacting with maps and mixed reality for navigation as well as spatial learning purposes[7-9]. The corresponding research findings are being progressively integrated into teaching modules of cartographic degree programs. It is worth mentioning that two Erasmus Mundus Joint Master Degree Programs-"Cartography" run at the Technical University of Munich, the Technical University of Vienna, the Technical University of Dresden and the University of Twente, and "Copernicus Master in Digital Earth" run at the Paris-Lodron University of Salzburg, the University of South Brittany and the Palacky University Olomouc-are increasingly devoting their master's theses to topics related to user experience and user-centered visualization of geospatial data.

Cartography will not decline because of its openness. On the contrary, the openness is an outreach strategy in both directions. Map users' contributions are the most valuable data sources for the improvement of map design. Spatial cognition is becoming an integral educational component of scientific cartography and geoinformatics. Students majoring in cartography will learn how to understand and present not only the earth as a complex system, but also the human brain as another complex system.

2.3 Ethical values in the geodata value chain

In the recent two decades, we have experienced an upsurge of location-based services. No one would deny the ubiquitous role of maps coupled with the function of global positioning. A modified version of American ballad would apply: wherever you go, whatever you do, maps will be right here waiting for you.

In pre-digital times, maps were both storage media of spatial information and interfaces between reality and users. Today's maps are mainly thin interfaces connecting users and thick databases. If a map works properly, users hardly notice its existence. Any interfaces are invisible in their best shape. Well-designed maps allow you to concentrate on your tasks at hand, rather than how and where to click which functions. But as soon as something goes wrong, map designers are immediately visible. Who else can be a more suitable scapegoat to be blamed!

The wrong-doing that manifests on a map is highly complex with multiple causes. Errors, biases and noise can occur anywhere and propagate all the way from data acquisition, processing, visualization and interpretation. A thorough detection of these causes is challenging. While it is relatively straightforward to determine geometric and topological deviations against the ground truth or database specifications, semantic errors, biases and noise are difficult to define due to missing references. It is even more difficult to judge the wrongdoing in relation with changes in social conditions and power structures of different user groups.

The fact that there is hardly any way to escape blame for the wrongdoing seems to be unbearable, but it also accentuates cartographer's overarching responsibility for quality and ethical issues in the geodata value chain. The development of cartographic discipline has been always accompanied by a reflective assessment of what purposes and whom maps serve. In conjunction with research on critical cartography[10], best practices are increasingly being integrated into cartographic curricula to demonstrate how ethical appeal through transparency and inclusiveness can foster user trust and willingness to engage in the design loop[11].

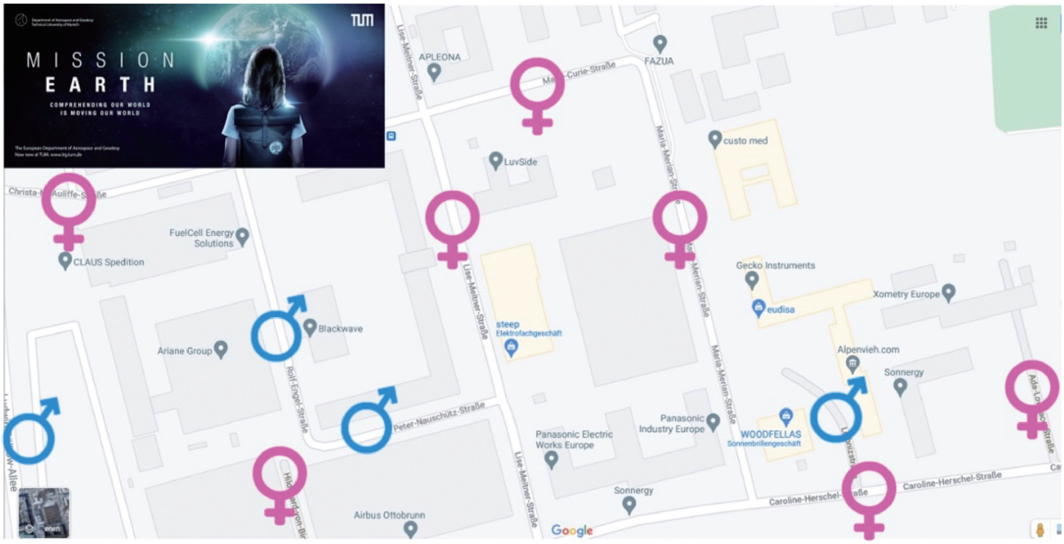
As the cartoon in Fig.6 implies, a map can intuitively visualize a location-based supply of textile products. Similarly, the transparency of a cartographic process can be expressed as being composed of traceable steps such as different data sources, applicable processing algorithms, map design options and dissemination channels. Users who are sufficiently informed of the working principles of individual steps will be more confident in dealing with flaws in the maps.

Fig.6 Intuitive visualization of site-specific textile products[12]

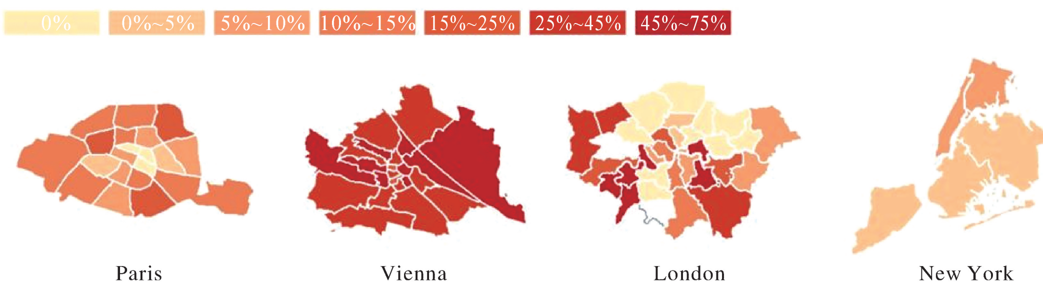
The inclusiveness in cartography is typically reflected in the involvement of diverse participants in map design and user test. The dedicated commissions for children and visually impaired users of the International Cartographic Association have continuously documented various profound initiatives, such as Barbara Petchenik Children's World Map Drawing Competition since 1993, and tactile mapping[13-14]. The inclusive value can be also manifested in highlighted mapping content such as gender diversity and internationalization as shown in Fig.7.

Multiple worldviews represent a further common practice of inclusiveness in cartography. Each single worldview carries the value of its author explicitly or implicitly. Different worldviews may share some common values, but they can be conflicting in some other aspects. It is better to expose these different worldviews rather than forcing an integrated or a dominant one. The Nunaliit Atlas Frameaork launched by the Geomatics and

Cartographic Research Centre at Carleton University is a good example of promoting the equal partnership between the Inuit knowledge system and Western systems. The knowledge of indigenous people, the placenames in their own languages, their understanding of indelible relationship with the earth as a living Gaia as well as their "cry of the earth" against the accelerating climate change and environmental crisis are insightful for the development of a sustainable world and therefore should be echoed in cartographic education programs[16].



(a) Gender diversity in person-titled street names in a campus of the Technical University of Munich, with blue and pink denoting male and female names, respectively



(b) Internationality in person-titled street names, with bright to dark red denoting the increasing number of street names honoring foreigners[15]

Fig.7 Ethical appeal for gender diversity and internationalization

2.4 Coopetition-oriented talent cultivation

In the age of big data, easily accessible mapping platforms are springing up like wildfire. They work globally or regionally, inviting users to contribute, validate and share data. These platforms are operated by non-profit or for-profit organizations. Non-profit mapping platforms usually provide open source mapping tools and free basic data within administrative jurisdictions or research test areas. They address topics of public interest and support citizen science. Maps in these platforms serve as a common hub for visual analysis of topographic and thematic information in various scale ranges or as a shared interface for the collection of crowdsourced data. Two examples are shown in Fig.8 and Fig.9. The one represents a crowdsourcing platform for environmental data operated by openSenseLab. The other is an open portal for climate events created in a research cluster[17]. Non-profit mapping platforms rely on public funding, project funding and/or crowdfunding, which might not be sustainable.

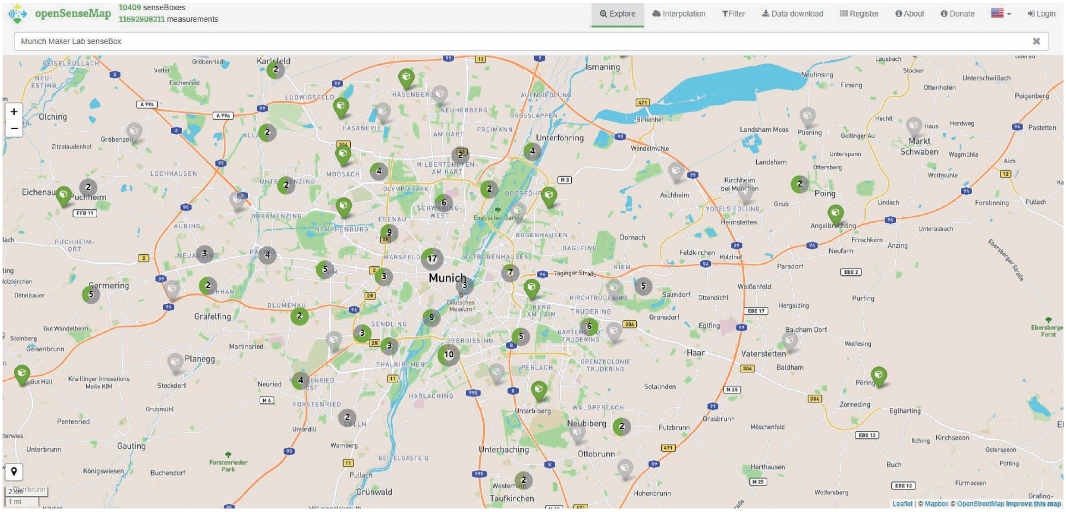


Fig.8 The interface of openSenseMap showing the locations and the aggregated number of sensing contributions in graded circles (active sensors in green and less active ones in grey) (see in https://opensensemap.org)

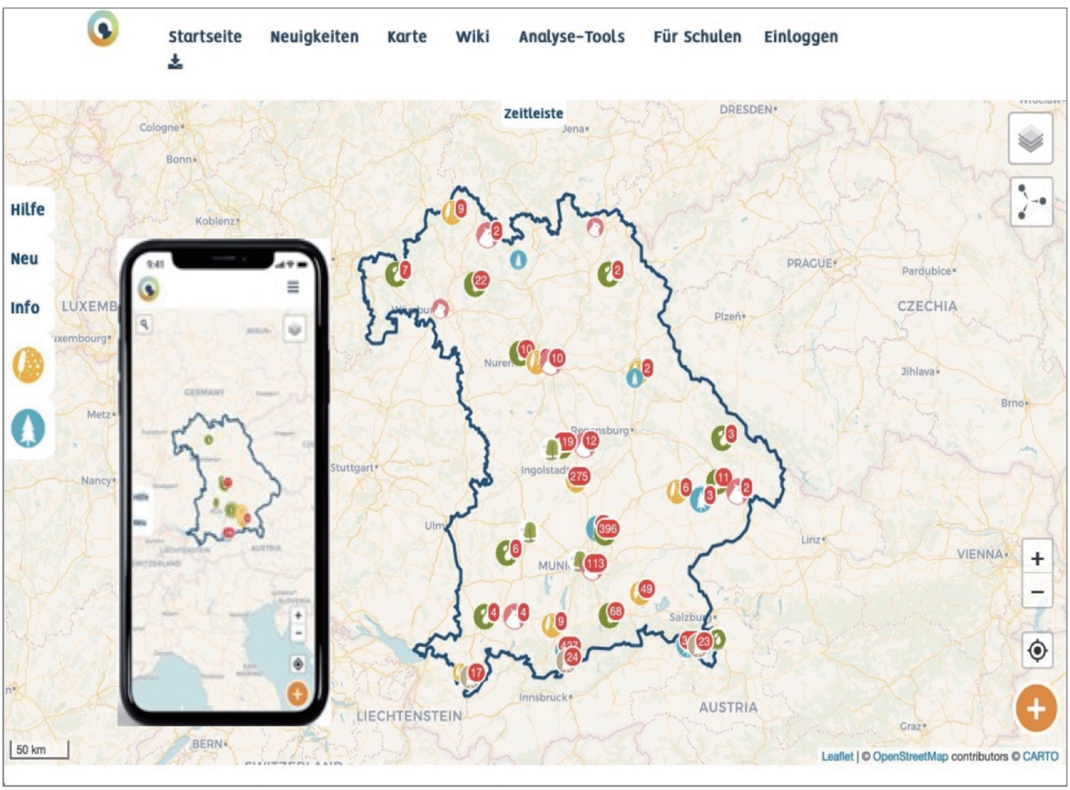


Fig.9 The interface of an open portal showing the number of different types of crowdsourced climate events in Bavaria, Germany

For-profit mapping platforms are mainly driven by three categories of owners following different business models. The first category is represented by traditional map publishers or authoritative map suppliers that typically offer online map services, charging unit prices and license fees. Their platforms are also marketing venues, with interfaces that reveal the geographic coverage, different design styles and multiple scale ranges of available map services. Users are supported with free viewing and query functions. Startups of mapping services represent the second category. They provide professional design solutions for niche markets. Often they choose to cooperate with data suppliers or use quality-assured open data to minimize costs and lower product prices, thus improve the competitiveness in the market. The third category is represented by the Internet giants that have emerged "at the core of the gig economy as well as the new platform-as-a-service business model"[18]. Based on the "toothbrush" principle invented by Larry Page, the former CEO of Google, that a potential company is worth acquiring only if it offers products that are used once or twice a day like a toothbrush, maps obviously belong to our daily necessities, and mapping companies are therefore worth acquiring. These Internet giants have quickly grown to dominant players and game changers of for-profit mapping platforms by coupling zoomable maps, satellite imagery and street views with search engines. Two target groups benefit from these platforms-commercial users that pay for displaying their locations with links to online ads, and end users who enjoy daily services such as positioning, routing, exploring nearby points of interest for free.

This third category of platform owners has made a genius contribution to democratize the power of maps and location intelligence at a global scale. However, new concerns arise with a close analysis of the underlying business model. The investment from commercial users supports the platform owner to provide the latest location-based services for free, thus attract as many end users as possible, who are potential customers of commercial users. In the end, it is the end users who pay the commercial users directly and indirectly to cover the maintenance cost of the platform. In this smart cycle, everybody seems to be a winner. The platform owner is the biggest winner, sitting on the asset of user data. In the long run, it tends to monopolize the market. When all competitors are driven out of the market, nothing can be free any more. Outside of the cycle, professional map publishers are losing many of their customers to free platforms. Some map publishers have to be merged. Some simply go bankrupt after centuries of operation. Some surviving publishers must tolerate the ads to take up nearly half of the overall display surface, making the online use of the map an unpleasant experience. Emotionally disturbed users are reluctant to purchase these maps, no matter how good the quality is.

In recent years, various initiatives have been triggered by the alarming monopolistic trend in the online mapping market. Cartographic professionals have realized that they should contribute their expertise not only for their business benefit, but also for the welfare of society and a sustainable development of cartographic discipline. National and regional mapping agencies have continuously re-engineered their geodata infrastructure through decentralized data acquisition, 3D urban modeling, and semantic enrichment of cadastral and topographic data[19-20]. The ICOMP initiative was launched by publishing and software companies with the aim to restore a healthy competitive online marketplace (see in https://en.wikipedia.org/wiki/Initiative_for_a_Competitive_Online_Marketplace). Large enterprises and Internet giants have been increasingly engaged in building cloud computing platforms. Small and medium-sized enterprises may move a significant portion of their routine activities to cloud computing platforms, thereby reducing their IT costs and better concentrating on their cartographic expertise[21].

There is still a long way to go till an ecosystem with the desirable diversity of map services is established. The ethical issues addressed in the previous section provide a good starting point for the reflection of involved legal and social issues in the curricula. Cartography educators are responsible for raising learners' awareness that coopetition, or cooperative competition, is an effective anti-trust measure and a necessary means of optimizing the allocation of research and development resources and protecting cartographic intellectual property.

3 Outlook

Universities are places for knowledge collection, generation and dissemination. Without the knowledge accumulated in many academic disciplines over many generations, we can hardly justify our today's society as knowledge society. The grand topics we face today, be it climate change, health, renewable energy, clean water, etc., are all cross-disciplinary. Intellectuals in the knowledge society have to gain a holistic understanding of interactions between various disciplines. They must possess the fundamental skills including literacy, numeracy and graphicacy in the sense of text handling, numerical computing, and spatial reasoning. No doubt, cartography plays an important role in forging the intellectual capacity of digital natives.

Another noteworthy fact is that the speed of knowledge aging is proportional to the speed of technological development. This urges people to update their knowledge and skills at different stages of their lives and careers. To meet the market demand for re-education, large corporations have started their own universities and a large number of private training institutions have also emerged (see in https://elmlearning.com/blog/the-corporate-university-shift). With the diversification of educational opportunities and the popularity of online courses, many young people no longer see degree programs as their only option. Meanwhile, universities are more convinced than ever that higher education must evolve not only in pursuit of economic growth and efficiency, but also with the values of resilience and sustainability in mind.

Like other science and engineering disciplines, cartography is currently concerned with a profound educational reform that includes elements such as:

- incorporating technology ethics into curricula to foster a trustworthy learning habit driven by both curiosity and societal benefit,
- modularizing courses to improve on-demand delivery, reusability and efficient updating, and
- participating in life-wide learning to disseminate cartographic knowledge among the public, and promote the cross-disciplinary understanding among cartographic professionals.

Once a discipline dedicated to supporting geospatial sciences, cartography is thriving in the age of big data on the heels of the burgeoning data science. Cartographic educators should take advantage of this favorable opportunity to incorporate multiple proliferation points into the curriculum.

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