A Framework for the Computer Aided Spatial Education through Geographic Microworlds

Thanasis Hadzilacos
thh@cti.gr

Manolis Koutlis
koutlis@cti.gr

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Computer Technology Institute
Department of Computer Engineering
University of Patras
P.O.Box 1122, GR-261100, Patras, Greece

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Thanasis Hadzilacos
thh@cti.gr

Manolis Koutlis
koutlis@cti.gr

Computer Technology Institute
P.O.Box 1122, 26110, Patras, Greece
Tel. +30 61 992061, 220112
Fax: +30 61 222086

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Abstract

This paper specifies the requirements of computer aided educational software for geography. For this it draws on two lines of research: one is education and in particular the utilization of computers as an aid to teaching and learning; the other is psychology of space cognition. Understanding -and misunderstandings- of spatial concepts as well as geographic skills needed -and often lacking- are translated into requirements for geographic education. The concept of Logo-like microworlds is used to host these requirements in the form of software (authoring) environment prerequisites.

1. Introduction

A frequent observation regarding people's understanding of and reasoning on spatial and geographical matters, is that “common sense understanding and use of spatial information and spatial relations is error ridden, naive and very incomplete, resulting in misconceptions and misunderstandings” [10] and that “knowledge of the environment is incomplete, distorted, asymmetric, discontinuous, and imperfectly coordinated” [18].

Not neglecting the fact that these inadequacies stem in part from the inherent complexity of spatial concepts, this paper builds on the premise that education, especially at the elementary school, can play a major role in enchancing geographical understanding and developing appropriate skills. Further, it is motivated by the conviction that in conjunction with possible advancements at the level of curriculum design, teaching methods and pedagogical approaches (see for example [25]), geography education can greatly benefit by the introduction and use of computer technology in the teaching process.

Based on this position, the main target of this paper is to specify the requirements and design principles of suitable software tools for the computer aided teaching and learning of geography and related subjects. To this effect, the authors have drawn upon research findings in the fields of psychology, geography and education, and, with no intention of directly contributing to research in these areas or taking sides in well known controversies, have adopted specific views and integrated them with the purpose of specifying the envisioned tools.

The overall contribution of this work lies in the identification of the implications of current understanding of spatial cognition to the design and implementation of state of the art educational software that could aid the teaching and learning of geography. This work is part of on-going research and development for the construction of software tools, which while specific to the area of geography education, will be generic enough to:

- enable researchers to build testbeds for their assumptions about cognitive aspects of geographical understanding and reasoning,
- allow the practicing teacher to build course material according to a specific pedagogical approach that is judged suitable,

- provide children with a computerized geographic playfield in which to express and test their ideas.

The rest of this paper is organised as follows: Section 2 summarises our view of the fundamental considerations governing the activity of teaching in general and the successful use of computers in education in particular. Section 3 presents the pertinent background from research in psychology of spatial cognition and geography; from each point, corresponding educational goals are determined. Section 4 presents specific requirements for geography “microworlds” -computer educational reconstructable environments suitable for teaching particular concepts and skills. Section 5 discusses technical requirements for building a computer environment for authoring such microworlds. Finally in Section 6 we present our conclusions and our plans for future work.

2. Some remarks on education and the use of computers

For the purposes of this paper and risking oversimplification of a deep concept loaded with long and heated debates, namely education, we shall view school education as, among other goals, aiming to:

- teach concepts and principles, and
- develop and cultivate specific skills

Teaching, as the means for achieving the above, provides suitable and effective learning environments and at least involves the following considerations:

a) Curriculum design. It is lead by the disciplines (geography in our case), and the relevant educational goals. Issues such as children's weaknesses and strengths at the various ages [9], and the interdependences among the various concepts [25], determine the content of the specific courses.

b) Educational methods and strategies. While the main concern of teaching is to create environments conducive to learning, learning itself is largely determined by the individual's inner cognitive functioning [21]. Thus pedagogical approaches rely mainly on educational, cognitive, and experimental psychology, fields that have much to offer as far as spatial cognitive issues are concerned.

c) Tools and materials. Their nature, design and use, are lead by (a) and (b). Depending on the beliefs about the nature of learning, follow the development and application of tools that enhance learning. For example, “by and large, computers in education have been used to implement the accumulation model of learning: with technology we can transfer knowledge to the students faster” while on the other hand, the same technology has been utilized to support alternative educational approaches, such as the “learning by doing” one [23].

The question of if and how the introduction of computerized tools in the educational course really advances learning, and of what are the determinants for positive results, is the subject of a whole lot of current discussion [2, 23, 5, 6, 7, 11, 12, 14, 19, 22, 23] and will not be addressed here. We will instead build upon some more or less generally accepted approaches where computers successfully fulfil educational expectations. Relevant educational research points out some general guidelines that contribute to effective learning:

a) “Students learn well when they are engaged in active exploration, interpretation and construction of ideas and products” [11]. Teachers should set up situations which will lead the child to question, experiment, and discover facts and relationships, in other words should provide children with the possibility of guided discovery [9].

b) “Children should be encouraged and given the opportunity to learn by doing, by building and manipulating artifacts” [23]. On building a similar argument, in [17] a number of strategic advantages regarding externalized thinking are listed:

- Direct sensory involvement with materials provides sensory nourishment, “food for thought”.
- Thinking by manipulating an actual structure permits serendipity, unexpected discovery.
- Thinking in the direct context of sight, touch, and motion engenders a sense of immediacy, actuality, and action.
- The externalized thought structure provides an object for critical contemplation as well as a visible form that can be shared with a colleague or even mutually formulated.

c) Children should be provided with rich information and the best materials and tools [11].

d) “Children should be provided with challenge, with novel experiences, with a context of some legitimate inquiry, a real task in which they have some personal interest and investment” [23], as “the individual confronted with an unresolved situation that he finds fascinating and worthwhile to resolve, stands a far better chance to develop his thinking abilities than a person presented with a puzzle he deems uninteresting” [17].

In this context, analysis of the issues and concepts involved in geography education and study of relevant teaching/learning approaches that would be applied, aids in identifying specific requirements that will in turn shape the design and implementation of effective computerized tools.

3. Understanding of space and educational goals

During the last decade, the multidisciplinary study of spatio-geographical cognitive issues has revealed a number of interesting results, which while originating from different contexts and needs (like that of representing and manipulating geographic entities and concepts in GISs) could well find their place in a renewed educational approach for the discipline of geography. In the following we discuss a number of factors that are found to influence and determine human understanding of the geographical world, and try to draw the relative conclusions with respect to our quest.

a) Experience of geographic space is not homogeneous, but varies with scale [4, 10, 16]. Different categories of space can be distinguished according to the means and cognitive level of their perception as well as the cognitive functions that are involved in the understanding and manipulation of each one.

What follows in our context, is that children could be stimulated to think in terms of, and about all space categories. Moreover, they could be taught to flexibly switch their thinking among them, and translate geographic concepts from one space category into another. Such transformations provide new mental perspectives, and different "thinking vehicles" for the manipulation of the original entities as entities of the newly translated space, thus facilitating the comprehension of the spatial properties and issues involved. Maps for example, by representing large-scale spaces on small-scale spaces (paper), allow people to experience geographic space as a small-scale object in a familiar way [16].

b) Irrespective of scale, any environment involves a number of spatial components [10]: Location of occurrences, spatial distributions of phenomena, regions of bounded areas of space, hierarchies or multiple levels or nested levels of phenomena, networks of linked features, spatial associations, and surfaces of generalizations of discrete phenomena.

Children could become aware of these spatial components and of their inter-relationships. They could be taught how to identify them, and induce the implied semantics, as well as how to recognize, apply and manipulate fundamental spatial concepts such as nearest neighbor or distribution and region membership.

c) Perception of space is in most cases dominated by the visual sense [16, 17, 4]. A number of visual cues such as atmospheric perspective, height in plane, relative size and focus, guide our everyday spatial perception. The stable spatial world of recognizable three dimensional objects and landscapes that we see, is "the result of an unconscious resolution of the dissonance between optical and perceptual reality" [17]. Optical reality is the "unreliable visual situation in which solid objects appear to change size and shape", and is ruled only by geometry, while perceptual reality is "the everyday experience in which we involuntarily adjust the ever-changing images of optical reality". Although we rarely view objects head-on, we always perceive them this way, and "orthographic projection" is used to graphicaly sketch perceptual reality. On the other hand, "perspective", is the graphic equivalent of optical reality.

Children could be trained to identify and effectively utilize environmental cues. Moreover, they could learn to see and draw perspective's spatial cues and translate orthographic views into perspective ones. Such exercises greatly heighten the awareness of the structure and form of spatial configurations.

Further, this tight connection of spatial cognition to the visual sense, makes the former a fine candidate for the development and cultivation of what in [17] is refered to as "visual thinking". Specifically, it is argued there that "the visual vehicle with its ability to facilitate holistic, spatial, metaphoric, transformational operations, provides a vital and creative complement to the reasoning, linear operations built into the vehicle of language." Some of the basic mental operations of visual thinking (that is some of the active ways that visual images are formed and manipulated spatially) are: pattern seeking (filling-in, finding, matching, categorizing, pattern completing), image rotations, orthographic imagination (ability to imagine how a solid object looks from several directions), imagining dynamic structures (folding patterns or solving knots) visual reasoning (spatial analogies, visual induction and deduction) and visual synthesis, in which parts are creatively synthesized into a whole, a new identity that is more than the sum of its parts.

Children could be equiped with a variety of mental operations and become able to move freely from one operation to the other. At the same time, they could learn to utilize several vehicles of thought and readily transfer their thinking from one vehicle to another, as “turning of thinking to a particular vehicle, opens the door to mental operations associated with that vehicle” [17].

d) Information about the environment is understood only as it is relevant to the goals, needs or psychological state of the individual at a given moment; human intentionality and purpose are factors which greatly influence the understanding of geographic space [4]. Different persons led by different concerns develop different understandings of the “same” spatial characteristics; even the same person could at times have radically different views about the same spatial situations. Compare the view of a military agent to that of an artist, and of a real-estate agent, and to that of a farmer, about the same valley that happens to lie next to a country's border-line.

Children could be guided to actively view the environment under different perspectives and through different contexts. Spatial reasoning will switch accordingly, and through the combination of the different observations an integrated understanding will be achieved.

e) Spatial perception is not the perception of space as such but of the relationships between the objects within [17, 4]. The representation (at least at a conceptual level) of spatial configurations takes the form of structural descriptions which specify the relations among the critical spatial components, relative to a frame of reference [3].

In forming such descriptions children may have difficulties in choosing the suitable spatial relationships if certain spatial concepts have not yet been sufficiently elaborated. Geography courses could address such weakness and provide exercises for the comprehension of spatial relations such as: left of, right of, beside, above, below, behind, in front of, near, far, touching, between, inside and outside [16]. Further, because of the fact that some environmental features inherently bear strong associations with certain spatial relationships, their appearance as pairs, although incorrect in certain cases, is regarded as “natural” thus driving children to form wrong descriptions [3]. Suitable exercises could also alleviate this.

The greatest difficulty that children face, concerns the establishment of appropriate reference frames [3]. They either fail to apply systematic frames of reference, a vital prerequisite for tasks such as map reading, or to utilize multiple reference frames of different kinds (egocentric, allocentric, coordinate), or to translate among them. Suitable scenarios which would confront children with situations that exercise such abilities could enhance their skills. For example experience with Logo-based microworlds that enabled children to navigate a “turtle” on the computer screen, by utilizing various frames of reference at will, showed a gradual shift from utilization of strict egocentric to coordinate reference frames without any special guidance or difficulty: “using analytical cues... was rather a matter of learning the rules of a new game, that is a new framework of knowledge” [14].

R. Downs in [15] discusses a similar issue and supports that children, in order to understand the hierarchical relations among geographical entities, would need first to understand inclusion and transitivity, have a vocabulary of geographic terms, and have a graphic or linguistic way to express their ability. Apart from the obvious point that education could equip them with the necessary knowledge together with ways and tools for expressing it, by reversing the argument we could state that geography by providing a tangible testbed, is the first step for the comprehension of the other more abstract and general concepts.

f) Geographical understanding is deeply shaped by culture. Differences in spatio-geographical cognition that stem from different cultural backgrounds, are usually projected to variations in the relative verbal expressions. For example, the primitive notions on which the spatial knowledge system is claimed to be built up, and out of which all other spatial concepts are gradually derived, are “neareness” in the Western cultures, but “movement”, “dimension” and “volumeness” in the Navajo (indian tribe) [20]. Other examples are the variations of the use of prepositions in locative expressions, and the adoption and utilization of “unusual” reference frames by people on many islands, as discussed in [16].

From a pedagogical point of view, this observation dictates that geography teaching “can be more effective if it starts from, and feeds on, the cultural knowledge or cognitive background of the students and thus, education in formal skills should differ in contents or themes and in strategy” [20].

So far, we have discussed some approaches that would hopefully lead to the development and cultivation of a holistic geographic understanding by children. But, recalling our earlier assumption about the two main streamlines of school education, children should also develop and exercise specific abilities and skills. In [10] R. Golledge identifies the following as “a must”:

a) Map reading which basically involves symbol identification and orientation. Moreover, in [15] G. Head introduces the idea of viewing maps as graphical languages is supported. As such, maps carry their own grammar and syntax and map reading should be taught as a kind of another language. Elaborating on the effects of the utilization of graphical languages in [17] McKim argues that each graphical language automatically sets your thinking into certain mental operations, and that by changing from one to another graphic language to another, you change your point of view: “you cannot use orthographic projection for example without using the operation of rotation; the head-on viewpoints of this language insist that you consider dimensioning and proportional relationships”.

b) Map sketching (model construction), which involves the ability to integrate information about landmarks and routes into an organized whole contained within some bounding scheme or frame of reference. G. Allen etal in [1] report that in a related undertaking, “children successfully constructed accurate successions of intersections of a just learned maze, while at the same time children failed to select the correct direction at the intersections. Fundamental to the former success was their ability to invoke `stands for' relationships between the maze and the model, as well as their ability to construct temporal successions, while the latter deficiency is acknowledged mainly to their failure to apply a systematic frame of reference”.

c) Direction giving and following, which involves image and verbalization of memory, and ability to give and comprehend directional and distance estimates as required by navigation. Related experiments discussed in [1] report that verbal description of a just learned maze route was a qualitatively different task compared to other tasks of spatial expression, in which significant age-related differences were observed. This lead to the conclusion that “verbal mediation is of central importance in providing a description of a route and plays a useful role in constructing a model of a spatial layout”.

d) Way finding, which involves spatial sequencing, path integration and short-cutting procedures. A number of cognitive models of navigation that are discussed in [24], could serve as reference for the setup of relevant exercise scenarios.

4. Geography through microworlds

In direct correspondence with the points discussed in the previous section, and mainly based on the view that “the rationale for microworld building is that pupils learn through active construction of their own knowledge; through play within a microworld, children come to understand its features, features that have been `planted' according to apriori learning objectives” [12], we identify the following requirements that geography microworlds should meet:

a) Allow the visualization and direct manipulation of spatial components and relationships as well as geographic concepts and phenomena, for various space categories. Microworlds could enable children to study and step by step direct simulations, relating both to large-scale spaces such as the sun-earth-moon motion, and to small-scale spaces such as a forest fire on a local mountain. Children could visualize the interdependences and comprehend the roles of the various parts in the evolution of a phenomenon, experiment with what-if scenarios by altering parameters, or perform GIS-like operations such as produce thematic views, issue queries, and so on.

b) Allow the construction and manipulation of landscape models and maps, in two and three dimensions. Microworlds could, for example, provide children with the means to piece together environmental “components” and build models of virtual areas (under the guidance of a system that would maintain spatial integrity), translate between perspective and vertical views, rotate, transform and spatially manipulate the models. Further, they could produce various kinds of maps, and realize virtual walk-throughs in a 3D environment under some specific inquiry that the scenario dictates, using a number of navigation and metric tools that will be offered.

c) Allow the concurrent access and manipulation of multiple views of the same phenomenon, visualization or simulation, as mentioned above. This would allow the creation of appropriate conceptual links, and the realization of relevant metaphors.

d) Provide a framework of Logo-style programming (commanding) [12, 14, 19], applied on landscape layouts and maps. Scenarios could be set up where children would navigate “turtles” (metaphors of their body on the map) through a set of suitably chosen commands (their definition and usage implying elaboration on spatial concepts and relations), to drift around with the purpose of achieving some specific goal dictated by the scenario. Again, scenarios could address various geographic scales, from cross-continent trips (for example re-creations of famous discovery missions), to in-town ones (where the mission could be to lead the turtle through the `best' path to exit the town). Interesting variations could be devised, by providing different kinds of available commands that children could use, or by allowing the use of only one, or more than one of different frames of reference for children to be based upon.

e) Provide access to various kinds of associated multimedia information. Microworlds could benefit by libraries of rich material of texts, pictures, photographs, videos, maps, narrated annotations, sound effects, etc, and create realistic and attractive presentations. For instance, a scenario could present children with a number of photographs of the local surroundings, then proceed to abstractions of those images to graphic layouts that could be geometrically studied and manipulated, and finally reach the construction of maps, thus achieving a smooth and comprehensive conceptual transition.

f) Provide the means for the composition of multimedia documents. Microworlds could be designed that would ask children to write compositions describing their experiences from virtual trips, annotating them with pictures, refering to maps or drawing figures, and thus providing a medium for the synthesis of a number of ways of expressing spatial knowledge.

g) Support collaborative work between students. A possible scenario, could allow one team of children to build landscape models while another team would navigate turtles and search around for some hidden “treasure” in that area. Another scenario could allow a number of children to navigate different turtles (from individual stations) in order to meet some common goal.

5. Towards the design of a Geographic Microworld Authoring Environment

How microworlds featuring the characteristics described in the previous section will be realized? One way is of course to develop a number of individual applications, each addressing some particular area, and then let researchers, teachers and children to experiment with their features. Although reasonable, this approach carries a big disadvantage: no matter how well those applications have been designed, or how many features they support, they will very soon fail to meet the all-evolving requirements of their users, as teacher's educational goals and approaches shift, and children come with new ideas that they like to experiment. In other words, users will be “locked” in the specific points of view embedded in the applications.

In addition, it is commonly agreed that the best courseware designers are teachers and students, and as such, should be supported and provided with tools for designing on their own. Programming environments (often called authoring systems) based on this idea include, among others, “Boxer” [5, 6], “Hypercard” [2], “Logo” [12, 14] and its derivative “Lego-Logo” [22], “Playground” [7] and “Rehearsal World” [8]. All these, provide general high level programming and data constructs, together with a consistent framework for the building of applications based on those constructs.

The key to the successful utilization of those systems by their “programming illiterate” users, was early stated in [26]: “we need to shift our attention away from the detailed specification of algorithms, towards the description of the properties of the packages and objects with which we build; the main goal of a programming system should be... to provide a set of tools of generating, manipulating and integrating those descriptions”.

In our case, by narrowing the range of the target microworlds to deal explicitly with geographic entities and concepts, we allow optimization of the specification of an authoring system towards this direction. We propose that such a system should involve:

- Geography-domain specific high level constructs which would play the role of basic building blocks. These could range from static data, to fully operational applications, each featuring a special purpose pre-defined behavior.
- Ways for integrating those constructs in operational wholes and thus developing microworlds. Specially designed programming (scripting) languages, or graphical programming methods could be utilized, tailored to the nature of the basic building blocks and the operations that should be handled. Either way, flexibility and simplicity, as well as straightforwardness of expression is a basic requirement, dictated by the particular end-user community, that should be met.
- A framework that would provide tools for the manipulation of the building blocks (allow customization, extension, even creation of new ones, etc), and for the creation and handling of microworlds (specify behavior, group them to form new entities, reuse common microworld parts, etc).

Concerning the design and implementation of such an environment, a number of interesting issues in the field of computer science have to be addressed. We mention a few.

- Specification of the basic building blocks, should carefully consider issues such as reusability, behavior abstraction, data exchanging and sharing, as well as communication and synchronization among them.

-Specification of a programming framework for the definition of microworld behavior, involves research in the areas of programming languages and techniques, as well as user interface specification and design.
- The general but crucial requirement that microworlds should be able to run on relatively small machines which typically schools or even children can afford, may give rise to the need for alternative design approaches and algorithms than those adopted in existing GIS or 3D modeling and graphics systems, that in many cases assume abundant resources.
- Another consideration refers to whether such an environment should be built from scratch, or be pieced up by suitably linking existing applications and tools.

Topics like these will be the subject of future study.

6. Conclusions and future work

We have seen how misunderstandings and inabilities in spatial concepts and skills lead psychologists into an analysis of human cognition of space; this analysis was used to derive goals for education in geography. We could have equally well derived the corresponding questions for research: instead of stating for example that children should be trained to think and utilise all space categories (referring to objects of different scale) one could state the question “at what age are children able to mentally manipulate objects of different scales and switch from one to another”? These educational goals in turn were translated into application requirements for software to support such education. Again, the exact same functional requirements would satisfy needs for software to help research in spatial cognition.

Research in the utilisation of computers in education has lead, among others, to the concept of “microworld” as the suitable software environment in which children can learn by playing and discovering. We do not pretend to be ignorant of the controversies around such research, but for our purposes here, i.e. the functional specification of educational software, it turns out that microworlds are also a quite suitable vehicle, which was another reason we adopted it.

This work is part of a high interdisciplinary long-term project. It brings together research in several fields of psychology, education, geography and computer science. Its true test will take place when software built on these specifications -which we are in the process of writing- will be used in classrooms and research settings -which we intend to do in actual teaching conditions in Greece. However, until then, the authors would welcome criticism, especially from people whose toes we may have -knowingly or inadvertently- stepped on.

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