GeoMaps: An interactive application to enhance map comprehension skills of students

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***Abstract*—Geography education requires the use of spatial thinking and reasoning to understand and interpret maps. Effective usage of geographical maps is a crucial skill to be developed for students. However, it has been found that students' ability to use maps to describe and analyze natural phenomena to find solutions to geographical problems is inadequate. One reason for this shortcoming is difficulty in comprehension of maps given in textbooks or reference books, which is preliminarily due to inherent limitations with paper-based maps. Sophisticated technology-based map applications are available like interactive maps, Augmented reality-based maps, 3D view maps, etc. But there are few learning activities around these, leaving the students confused as to how these can be used in different contexts to solve problems. GeoMaps is an interactive application to improve map comprehension skills of students, which includes ability to identify, correlate and synthesize information from multiple perspectives in a map. The activities in GeoMaps are based on authentic geography problems. To solve these problems, students can overlay multiple maps to correlate various features, and choose corresponding filters to focus on particular information. The preliminary feedback from potential users is promising, encouraging us to explore this idea at a broader context.**

Keywords-component; spatial skills; geography; maps; interactive maps; map comprehension skills

I. INTRODUCTION

Geographic skills are important to be built at the school level. These skills are crucial as a geographically informed person can see the meaning in the arrangement of things on Earth's surface, can see relations between people, places, and environments, and can apply spatial and ecological perspectives on life situations [1]. Experts have emphasized that spatial skills are central to geography and recommended that enhancing spatial thinking should be one of the key goals of geography education [2].

Spatial thinking involves using and organizing spatial concepts, images maps and graphs, and other visual objects [3]. Comprehending spatial information involves not only understanding spatial concepts, but being able to use that knowledge and skill set to make decisions and solve problems [2]. Teaching with maps enable students to learn through maps— that is, to think spatially—in various reasoning and problem-solving contexts in the classroom and real world [3].

It is often observed that students lack the ability to use maps to describe and analyze geographical phenomena. One difficulty is that the maps in textbooks are often designed poorly and hence cannot be used effectively [4]. Paper-based maps are usually over-cluttered with information resulting in poor-readability of captions and icons. Referring to other perspectives for a given map is tedious as the other maps may be on different pages or even in different books. Due to size and cost constraints, only a limited set of maps can be made available in school textbooks or map books. Most map-related exercises are isolated and lack context. Thus, students fail to see the relevance of these problems in their lives.

Social studies education has focused on rote memorization of events and places, rather than focusing on using techniques that address higher-order thought processes [4]. Thus, there is good reason to develop new ways of teaching-learning that would enhance these skills and excite students in the subject.

Our solution aims to develop map comprehension skills in students. We define map comprehension skills to broadly consist of 1) Ability to identify perspectives of map required to solve a geographic problem 2) Ability to correlate multiple perspectives of a map to describe/analyze geographical phenomena 3) Ability to synthesize this information along with other relevant concepts to find a solution to the problem. Our solution supports learners to use multiple map perspectives simultaneously and synthesize this information to solve real-world problems. The solution also addresses the related concerns like cluttered maps. The intervention is called GeoMaps [5] and provides students with a real-world situation for which they have to find a solution through reasoning with appropriate maps. Students can use multiple perspective of maps to solve this problem – all this on a single screen, without losing the context of the problem.

II. RELATED WORK

Interactive Maps are standalone map-centered programs that respond onscreen to user activity and help promote information exploration and understanding [4]. These maps are more flexible in their use than paper-based maps, since they allow users to explore data and visualize and analyze visual patterns on the computer screen.[4]. We review some available computer-based interactive maps solutions.

FingerTrips [6] aims to transform the experience of learning geography by offering students journeys via touching a 3D augmented tangible map. On this map, students travel with their fingers, feel the distances and the altitude differences and interact with cultural information at several stations of their journey, to solve the given treasure hunt.

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Story Maps [7] combines interactive maps with stories to tell spatial narratives. ArcGIS StoryMaps [8] are Web applications developed within the Environmental Service Research Institute's Web-based GIS platform, ArcGIS Online. Map maker feature can be used to create custom maps to enhance digital storytelling. Text, photos, and videos added to existing ArcGIS web maps and web scenes to create an interactive narrative that can be published.

School Bhuvan – NCERT [9] is a portal providing map based learning for students. The portal provides layers related to geographical perspective "Political", "Agriculture", "Water", "Soil", etc. and students can also create annotations on the map. Windy.com [10] provides visually appealing maps with prediction-based indicators and layer areas. It has satellite overlay of features such as wind direction, speeds, distance or route planning and even air pollutant levels however topography or river maps are not available.

MapMaker Interactive [11] allows a user to choose from a variety of base maps. Interesting datasets with regard to agricultural production and wildlife amongst other things are available Wide collection of layers that are dynamic and also related to geography elements of high school but lacks other maps such as river maps which are important from a high school student perspective.

Google Earth [12] renders a 3D representation of Earth based primarily on satellite imagery. The website maps the Earth by superimposing satellite images, aerial photography, and GIS data onto a 3D globe. It allows users to see cities and landscapes from various angles. There is also an option to view real pictures of particular place (uploaded by users).

The above tools provide interactive maps with features like adding layers, filters. Some tools are quite visually appealing [10] [11]. Some allow multiple layer overlaying [9], while others restrict to viewing only one layer (perspective) of map. Despite the presence of many such map based tools they can't be easily integrated with the present school curriculum due to the lack of relevance to the curriculum or since they have been designed with a different purpose such as navigation (for example, [12][6]). Though these have sophisticated interaction features, these systems are inadequate for self-learning and need to be repurposed accordingly. There are no specific narratives or learning activities around most of them. The maps in School Bhuvan [9] are aligned to curriculum, however the learning activities are not available. Help manuals and guidance to use the tool are available, but how students and teachers can use it for understanding or solving geographic problems is missing. Usage of these systems is thus at user discretion in absence of guidelines for educational purpose.

Our solution, GeoMaps extends the core-feature of some existing systems [9][10][11] i.e. use of "perspective" layers on a given map dynamically. In addition, GeoMaps builds learning activities around the given interactive map, thus making it a suitable learning tool. Each learning activity starts with a narrative about a real-life geography problem to be solved using the given map and its perspectives. Multiple perspectives along with their related information can be used simultaneously. Relevant guidance is available throughout the activities. Maps in the activities are aligned to curriculum.

III. GeoMaps: Pedagogical Design

GeoMaps is designed primarily for self-learning or as supplementary learning that can be facilitated by a teacher.

A. Context and Target Audience

The context of GeoMaps is high-school geography, typically class VIII-X. While interacting with GeoMaps, the student is given various activities which need to be solved using given geographic maps. It is assumed that the students are already familiar with using maps and have been solving map-based exercises as a part of their curriculum. The activities in GeoMaps include problems or issues based on real-world situations. The students are then encouraged to solve these problems using the various perspectives of the given map. Example problems include: "*Find a perennial river where canal can be built to solve the drought problem in the state of Uttarakhand*", "*Identify places in India which are suitable for growing maize, given maize requires climate characteristics like ....*". Such problems require students to locate, analyze and synthesize related geographic information.

Students can solve the given problem by overlaying relevant map layer(s) and choosing appropriate filters over the given outline map. The solution can be marked on the map itself. Along the way the system provides relevant guidance and feedback in response to student actions.

B. Theoretical Basis

- Multiple Representations: Multiple representations support the construction of deeper understanding. When learners integrate information from various external representations, they can achieve insights that are otherwise difficult to achieve with only a single representation [13]. Multiple representations can reduce cognitive load and improve students' conceptual understanding by linking and transforming between representations [14]. In GeoMaps, multiple representations of a given map are made available in the form of different perspective layers. E.g. in Fig. 1 one can see different representations of India, namely, map with political information, map with drainage system, as well as relevant textual information. Learners can thus use these multiple representations as required to construct deeper understanding of geographic information of the given region to solve the problem.
- Scaffolding & Formative feedback
Principles of good feedback practice recommend that: i) feedback is provided in a timely manner, close to the act of learning production, ii) feedback focuses not just on strengths and weaknesses but also on offering corrective advice, iii) it directs students to higher order learning goals, and iv) it involves some praise alongside constructive criticism [15]. In GeoMaps, when learners select an answer, the system immediately gives them feedback whether the answer is right or wrong and corresponding remedial action. When the student answers the given problem incorrectly the system provides pop question which provides hint to proceed towards a solution.

- <u>Cognitive Load</u> - Meaningful learning requires that the learner engage in substantial cognitive processing during learning, but the learner's capacity for cognitive processing is severely limited and can lead to cognitive overload [16]. In GeoMaps intrinsic cognitive load is reduced by providing a basic outline map and then adding information to it as required. Unlike intrinsic load and extraneous load, higher levels of germane load are viewed as more useful to the learning process [17]. Germane load is addressed by giving a context to the problem to be solved and connecting it to real life.

C. Learning Activities

Learning activities in GeoMaps are aligned to 'Analyze' and 'Evaluate' levels of revised Bloom's Taxonomy. Currently, activities in GeoMaps are based on one or more topics related in Class VIII-X Geography textbooks of Maharashtra State board [18].

The principle of constructive alignment is followed, i.e., students construct understanding by doing the learning activities which are systematically aligned to the intended learning outcomes and to the assessment tasks [19]. Activities are designed to enhance all or sub-set of map comprehension skills of the student. Each activity opens with the description of the problem using an engaging narrative. Once the student has read the description, she/he can proceed further to main map workbench where an outline map related to the problem, and available layers and filters are provided. Using the given layers, the student can try to find the answer, and if found, mark it on the map. The system gives immediate feedback on whether the answer is right or wrong. If the answer is wrong, hint in form of quiz is provided for solving the problem.

E.g. An engaging narrative related to drought situation in a part of India is presented and suggests the student to find a suitable 'perennial river' to construct a canal to tackle this. Student can overlay suitable layer from "Political", "Rivers", "Physical" layers, etc. (see Fig. 1), in the outline map of India. This activity requires use of "River" and "Political" layer to choose appropriate river based on location. "Filters"- "Sources" and "Directions" of "River" layer can be used to identify perennial rivers. On finding suitable river, the student can click on the name of the river in the map. The system gives instant feedback 1) If student selects a perennial river but not suitable to solve this problem, reason as to why the chosen perennial river is not suitable is given, and student is encouraged to find the appropriate one. 2) If the option selected is a non-perennial river, system flags it and a hint that will help student understand perennial rivers, is provided in the form of a pop-quiz.(See Fig. 3) 3) If the chosen river is right, the concept learnt in this activity gets added to the notepad area and the student is encouraged to try out a new activity. In this example, the map comprehension skills being addressed are 1) Identifying relevant perspectives of map ("Rivers" and "Political") 2) Correlating these perspectives (by overlaying the layers) 3) Synthesizing this information to find perennial rivers (rivers with "Source" in the Himalaya).

Currently three learning activities are available, and others are being designed and developed.

IV. GeoMaps: Technological Design

A. UI Design Overview

The layout of GeoMaps consists of five segments which are placed into three columns. The interactive map region is placed in the middle column so as to invite the users gaze to the area of action. The right column consists of the map layers and filters the user can manipulate. The filters are activated corresponding to the layers chosen by the user and are color coded to aid intuitive usage. The left column consists of the prominent activity description that is structured as a conversation from an animated character. The notes section at the bottom left logs the learning gains of the user at each stage of the activity. The interaction-based scaffolds and answer responses appear as pop-ups. The various design aspects of the system were decided to incorporate intuitive use[20] [21].

The application was developed using a UI/UX design tool (Adobe XD) [22] as a high-fidelity prototype. Schneiderman's principles [21] such as consistency, informative feedback and reduced short term memory load, were followed in designing this tool. A web-based version is under development and will be available for use soon.

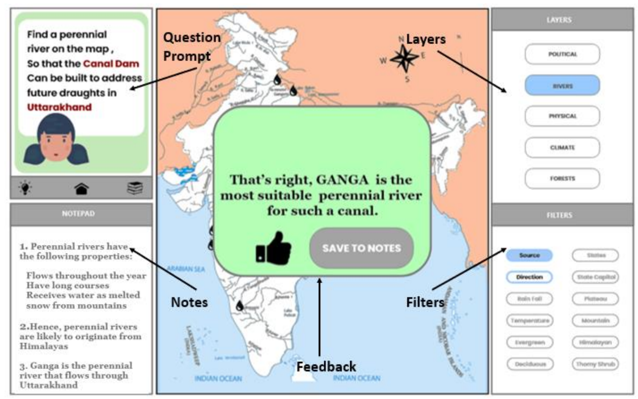

Figure 1. A Sample Activity Screen in GeoMaps

B. Features

- <u>Real-world problems and narratives:</u> Problems based on real-life situations like environmental problems, business decisions, natural phenomena, etc, are given instead of toy problems or out of the context exercises
- <u>Feature to add/remove layers:</u> Perspectives of a given geographic map can be overlaid to correlate the perspectives. E.g. for India country Map the perspectives available are "Political" boundaries, Climate (rainfall, temperature), Physiographic divisions, drainage system, forests, etc.
- <u>Appropriate filters for a layer can be chosen:</u> Filters are associated with specific perspectives and add a level of detail to each perspective in the given map. So, once a perspective is chosen, one or more filters can also be selected to bring in the corresponding details (Fig. 2). E.g, "Climate" layer can have filters like "Rainfall, Temperature., Physiography layer can have filters like "Mountain Ranges", "Plateaus", etc.

- Marking on the Map: Instead of solving on paper or selecting an option on the screen, the answers can be marked on the given map itself.
- Spot Feedback & Hints: For every action on the map feedback is provided. Also, guidance is provided on how to proceed further. Relevant hints are given if the user is unable to proceed further in solving a problem. The feedback and hints are displayed right at the place where the answer was marked by student (Fig. 3).

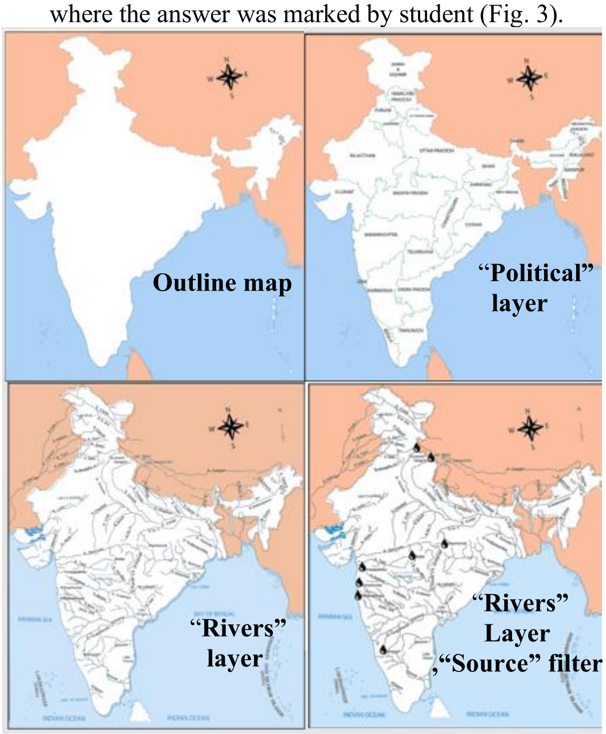

Figure 2. Layers and Filters in GeoMaps

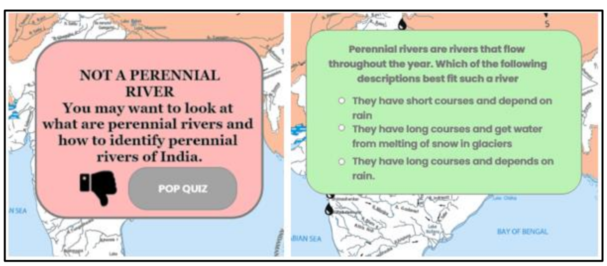

Figure 3. Spot feedback and hints

- Notes: On successful completion of an activity, the related points to remember are automatically recorded by system in “Notes” section. This can be used by the student for subsequent activities as per requirement

V. GEOMAPS: USER EXPERIENCE

A. User Experience

GeoMaps was showcased in a popular college science and technical festival which has a footfall of about thousands of visitors. GeoMaps exhibit grabbed attention of about 150 visitors comprising school students, teachers and parents. It was also reviewed by institute faculty, research students, and corporate professionals who visited the exhibit. Among the visitors, 15 students had a complete hands-on experience with GeoMaps. The session consisted of three phases. In the first phase, overview of how to use GeoMaps was given to user by the researcher. In second phase user was encouraged to attempt solving one activity. Alongside a textbook was kept for easy relatability and quick reference. The learner interacted with the system and completed one learning activity. During this user interaction session, the researcher assumed role of an observer, making note(s) of any particular deviations from a user’s expected behavior. The researcher also provided guidance if the user was stuck at particular part and sought help. Such instances were noted down by the researcher. In the final session, an interview was conducted immediately after users finished interacting with the system. The interview was semi-structured consisting of questions like *“Did you like the system” “Would you like to use this system if setup in your school” “Was it easy to use”? “Do you see any benefits of using this over textbook maps that you use?” “Any suggestions in the layout?”, “How can we make it useful for you?”* The interview phase lasted for about 3-5 minutes. User’s responses were recorded on paper by the researcher. Fig. 4 shows a class VIII student interacting with GeoMaps.

GeoMaps was also showcased at a teacher training workshop where 70 principals of reputed high schools from various parts of India participated. Demonstration on GeoMaps from student perspective was given by author and the co-author to the principals in groups, with each group consisting of 7-8 principals. Since it was a large group, individual interviews could not be taken. Clarifications sought/Questions asked by each group were noted by the authors. Feedback given by principals on possible modes of adoption and suggested changes for the same were also noted.

B. Feedback & Observations

A preliminary analysis of student interviews showed that many students found GeoMaps to be a “cool” way to interact digitally with their textbook maps. They found it interesting to fiddle with the various layers and filters to find solution to given problem. They also liked the feature which allowed them to mark the answer on the map itself. Some tried out various options randomly to curiously find out what is feedback given for those options. A recurrent query was regarding the availability of application for use. Another common feedback was to add more, and elaborate activities involving multiple perspectives of the maps. Feedback from principals was also positive. A common query from principals primarily was availability of this for schools and whether it can be extended to support more activities suitable to other classes and topics in geography. Few principals raised the question about where this application stands in comparison to Google Earth and other interactive map-based applications.

Some visitors mentioned that the there is too much text given in the activity description and suggested a concise version instead. Some said that the places which can be marked on the map needs to be more intuitive. Our observation was that the question area in activity screen was not intuitive as users had to be explicitly told to refer to it at that location. We also felt instruction for "clicking" for answer on the map should be a system message, as it was required to be told orally. This gave us valuable inputs to enhance the design of our intervention and include more activities.

Figure 4. A Class VIII student solving an activity in GeoMaps

VI. CONCLUSION

GeoMaps was developed to enhance the spatial skills of students in form of map comprehension skills. Currently the system's high-fidelity prototype is available. Preliminary feedback provided useful insights on acceptance of such a system by its potential users, usefulness of its features and what improvements need to be done to make it technologically better and pedagogically stronger.

A complete web-based system with learning usage /interaction tracking facility is being made available soon. Redesign includes a more visually appealing UI, considering the age group of students. Elaborate activities requiring usage of multiple perspectives (layers) need to be developed. The marking option on the map can be made more intuitive. The map can also have some "hotspots" pointing to elaborate information about specific place.

A significant extension which would ease adoption of GeoMaps is development of AR-based app for smooth integration with the textbook/map book maps. While GeoMaps is primarily designed for self-learning, it can be used as an instructional tool. The instructional version can have the outline map, and options for layers and filters which teachers can use in their geography class as per the topic or concept being taught.

An immediate future task is our plan for a systematic usability and learning study with potential users focusing on relative advantage of GeoMaps over paper maps. We also wish to explore unconventional uses of interactive maps to integrate the historical and temporal perspectives. The core idea of layering, filtering can also be extended to other subjects like biology, or mechanical engineering drawing where spatial thinking and reasoning is required.

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