From Geography to Physics: How does geography help students learn motion?

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Abstract. The GPS units are presented as a powerful technology enabling students to learn basic ideas of motion, along with concepts of physical geography. The use of GPS technology in this way is a form of studio based education (close-to-life collaborative construction contexts). Such a context enables students to construct and analyze their own data, thus providing an opportunity to develop critical graphicacy along with the subject knowledge. We also discuss the impact and significance of such studio based education for learning.

1 Introduction

The concept of motion is introduced at an elementary level and forms the basis of learning physics. The basic concepts in motion such as position, displacement, velocity, acceleration need to be understood in different contexts and representations by the students. But numerous literature studies have shown that these concepts are prone to errors from students and even teachers. The comprehension of graphs of these dynamic quantities presents a formidable challenge to the students. Many studies mention the common problems that students encounter in visualizing the graphs of these physical quantities [McDermott et al., 1987], [Beichner, 1994]. Understanding graphs in itself presents a major challenge to the students, especially when they are given out of context. In *Critical Graphicacy* by Roth et al. [Roth et al., 2005] understanding of all forms of graphics is not an easy skill. Also students are not provided with any opportunities that will enhance their ability to create and analye their own real world data. In this article we are suggesting some activities that could provide a context of learning motion by using a GPS unit. This we think will provide the students with opportunities to learn the subject matter in a closer-to-life-context.

The use of a GPS we think will also provide the students with an idea about the magnitudes of the quantities involved. Also, the use of GPS serves another purpose of mapping the local area by the students themselves. This will lead to collection of data for a Geographical Information System (GIS). Collection and collation of GIS data can lead to a lot of other projects and activities by the students.

Such use of GPS devices has been reported by [Budisa and Planinsic, 2003], [Larson, 1998], [Biermann and Nelson, 2000]. The average cost of the GPS unit has come down considerably and technologies enabling the use of data obtained from the GPS have proliferated in computers, cars and mobile phones and other data collection devices. A lot of Free Software programs are available which can interpret the GPS data meaningfully. The main program that we have used in our study is Tango-GPS[1], which is a Free Software. Given the current trends, the GPS may become a default feature in many of the electronic gadgets to come.

In the rural areas in India most of the houses, road, villages are not mapped, the mapping itself will be of relevance in this context. We have done a few pilot studies for this in the Khalapur *taluka* of Raigad district near Mumbai. The preliminary results of this pilot activity are encouraging. The mapping of the local area can be an incentive for the students to work with the GPS units. Apart from the GIS data, the data logged in the GPS unit can be used to teach basic concepts of motion, connecting them to real life situations and experiences, apart from geography. Teaching motion in such a context, where ideas from geography and physics and mathematics have been merged, will present the students with good opportunity to make connections between the concepts which otherwise may remain disconnected. In this particular article we will be concentrating on how the teaching basic mechanics can be achieved by using GPS.

2 The GPS technology

The Global Positioning System or the GPS technology was initially developed for military purposes, but it was then later released for civilian use. Several technical monographs exists explaining the working of GPS and the interesting physics that is involved in its functioning. For a primer on the GPS technology please see [Cornwall, 2000]. But we need not be concerned here with the actual working of the GPS technology, but rather the use which can be made from data obtained. In spite of all the advanced technology involved in working of a GPS, it offers the end user a very accurate determination of user's position on the Earth. The accuracy of the observations for the common hand-held GPS devices is $\pm$ 5 meters, considering that the Earth is a sphere with radius of about 6400 km, this is an extremely accurate reading.

Some of the GPS units and now the smart phones come with their own maps and enable users to see their location on a base map, which can be Open Street Map, Google Maps or Google Satellite Maps. For the stand-alone units that we used in the pilot mapping studies, the data is stored on the device and can be retrieved on a computer. When this device is connected to a laptop, we can get a 'live' feed on the computer of our position, speed and direction in which we

[1] http://www.tangogps.org/

are heading. A lot of programs are available for this doing GPS/GIS related information.Tango-GPS is one of the programs that enables one to plot the GPS log files which are collected during tracking.

2.1 Our GPS Unit

Some years back we had developed a stand alone GPS unit during a hackers meet on GIS/GPS systems in the Gnowledge Lab of Homi Bhabha Centre for Science Education (the details of the workshop can be found here). Mostly this unit was used for the pilot studies that we have done in rural areas near Mumbai. One of the needs for developing such a unit at that time was that in commercial units, the unit is more of a black box, with almost no information about the electronics inside the box. The unit that was developed was based completely on concept of *free software* and *free hardware*. The design details and technical specifications of the GPS unit can be found here . This will enable the spread of the development work that we have done to others seamlessly. The use of Free software and hardware in education forms one of the mandate of our Lab. Now with the proliferation of the GPS units, which are now integrating with other technologies like mobile phones, this initiative was a good learning experience for us.

3 Physics from GPS Units

The basic data that all the GPS units generate have at least the following, apart from other data: Latitude, Longitude, Altitude, and a time-stamp. Most of the GPS trackers that we have seen, and the one developed by us, have a time base of 1 second. So what we essentially observe is the position of the unit on the surface of Earth with an interval delay of 1 second. This, along with the final accuracy of about ± 5 meters, are the limitations to use of GPS for very small distances travelled, but when longer time and distance is involved the process smoothens out. All other quantities like the direction of travel, position on the ground, velocity is derived from this data.

The sample log file from a GPS unit has the following format:

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19.647364,73.475067,287.5,0.0,87.6,5.7,2010-11-13T04:39:15Z
19.647365,73.475065,287.4,0.2,79.1,5.7,2010-11-13T04:39:16Z
19.647364,73.475063,287.2,0.3,71.6,5.7,2010-11-13T04:39:17Z
19.647364,73.475062,287.1,0.2,64.3,5.7,2010-11-13T04:39:18Z
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The first three entries in each row are the latitude and longitude (in degrees) and altitude (in meters), whereas the last entry is the time stamp. The data above can be plotted on in any of the GPS softwares that are available. The background map for the tracks can be chosen as per the requirement.

We can see the full track of a vehicle with all the turns and twists. All the data required to analyze this path is available to us in terms of the log file of the track. When a GPS unit is attached and has a fix on the satellites, the software interface provides us with our speed and heading (the direction in which we are travelling), and altitude in meters.

3.1 Processing the data

How do we process this data? If seen from an analysis point of view each line of the file contains the data in following way.

$$(X, Y, Z, T) \tag{1}$$

Thus we have the data for the position as a function of time. But the format of X, Y are in degrees of latitude and longitude, so before it can be used for measuring quantities in terms of length units a conversion has to be done. The time difference between each measurement is 1 second. For junior students this conversion may be directly given, whereas for the senior students they can be asked to analyze why this particular transformation was chosen. This can lead to further questions about the shape of Earth and the units that we use to measure it.

Once this conversion is done we have our data in meters instead of degrees of latitude and longitude. The altitude Z does not require a conversion as it is in already in meters. Thus we have the variables that we have mentioned

$$(X_i, Y_i, Z_i, T_i) \tag{2}$$

corresponding to each time the GPS device has taken a reading.

Thus we have the basic data of position as function of time for further analysis. We can derive physical quantities like velocity, acceleration, momentum and force [later two if the mass of the moving object is known]. This we think is one of the best data-logging that is possible, in which the students can relate to the data, which they have also experienced.

4 From Concrete to Abstract and back

According to stage theory of Piaget the transition from concrete operational to formal operational stage presents during the middle school level. In the concrete operational stage the child understands the world from experiences that are concrete, whereas in the formal operational stage the child thinks more abstractly, logically and can reason from a given situation. A concept is linked to both concrete and formal operations. For example we can get distance and speed and forces as concrete sense experiences when we are moving from one place to another. The same experience can be represented on a graph, which would be very formal and abstract presentation of the same sense experience. Only when we are able to make the transition between the concrete to formal and back again, we can say that we have learnt the concept. In case of motion this would mean that we should be able to translate our motion experiences to graphs, and in the other case we should be able to make sense of graphs of motion by knowing what kind of motion it would represent. We think that it is important for students to have the opportunities to achieve this transition. This is in tune with the *constructionist* theory proposed by Seymour Papert [Papert, 1980].

In a constructionist theory all the learning happens in context of a construction. The construction tasks that a learner has, can be different for the same construct, and will be dependent on the previous knowledge that the learner has. Each construction opportunity will enhance the learners understanding of the concepts involved in that construction activity.

Experience with GPS device allows learners to do this translation from concrete to abstract and back. Mapping of an area is a very concrete experience that students can have and this is something which directly relates to their sense experience and idea of space. Mapping of an area with aid of GPS also allows students to see their local area in a much larger context. Once this data is put on a map, we can relate to our local experience to a global one. Also, the same data can be used for achieving understanding the abstract concepts of graphical representations of physical quantities.

The use of GPS/GIS units can relate to different topics and subjects at different grades. Some of the concepts and the subjects that can be touched upon by the use of this technology are illustrated in Figure 1. Many of the concepts appear in different grades and in different subjects. All these concepts can be linked through the GPS technology. And this relation will not be a one way relation, but rather it will be rather a feedback relation which will enhance all the involved concepts and their relationships. By the use of GPS technology the transition between concrete and abstract will be reinforced amongst different concepts. Also the linkages that the concepts have in different subjects will get enhanced by their use in different contexts.

5 Relating GPS/GIS to graphicacy

In an earlier study we have reported an quantitative analysis of Indian textbooks, from grade 5 to grade 10 [Dhakulkar and Nagarjuna, 2011]. The subjects included textbooks of science, mathematics and social science. sample of textbooks that we had chosen for this study were the National Centre for Educational Research and Training (NCERT) textbooks. NCERT is the apex body for designing curriculum and textbooks in India. The NCERT textbooks provide a framework for all other textbooks that are produced in the country. In the analysis we found out that the graphs in the textbooks are under-represented and underused. The graphs when present were not linked with other subjects, even though many times there were ample opportunities to do so. Also we found that there were very little scope for students to collect and analyze the collected data.

Various different studies including the National Curriculum Framework (NCF) 2005 indicate that the students must be empowered to collect and analyze their own data [NCF, 2005]. If the subjects in the school education like science, mathematics, and humanities do not include a reflexive component that allows students to critically evaluate the knowledge claims, they will always be subject to some form of indoctrination [Roth et al., 2005]. As the NCF 2005 [NCF, 2005] puts: "Science education in India, even at its best, develops competence but does not encourage inventiveness and creativity . . . inquiry skills should be supported by language, design and qualitative skills. Schools should place much greater emphasis on co-curricular activities aimed at stimulating investigative ability, inventiveness and creativity, even if these are not part of the graduating exam." According to Roth et al. education for a critical graphicacy would mean providing students with the opportunities to interrogate the different means of representing the world [Roth et al., 2005]. The GPS technology satisfies the above mentioned criteria. The use of GPS in contexts that are relevant will provide students with such opportunities and will help them develop an aspect of critical graphicacy.

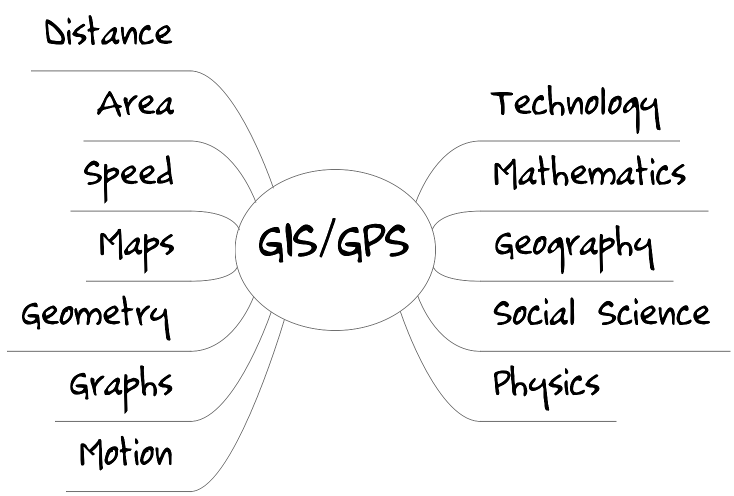

Fig. 1. Some of the concepts and subjects to which we can relate to by GPS/GIS technology.

6 Some of the suggested acitivities

From the few studies that have been reported we present some of the activities that can be performed by the students using the GPS units.

6.1 Mapping of the local area

This activity can be a very concrete experience for students, to get a sense of space and direction and see their activity of mapping their locality on a global scale. This can provide a rich context for student to learn about surrounding geography and can perhaps lead to collection of GIS data. The concept of vectors plays an important role in developing conceptual structures in regard to motion at the elementary grades [Larson, 1998] gives an intersting example for use of GPS for activities in which one tries to measure the displacement vectors. Also inspiring is the outdoor vector lab as suggested by [Erdman, 2004]. By use of the open layers technology in use at the Open Street Map the mapping activity can be linked with flora and fauna, seasons watch, migration patterns in animals etc. By using the mapping data as a base, several other kinds of social, natural sets of information can be layered to create a very useful and rich education to every school student.

6.2 Making sense of sense experience

All the physical activities that we do, like moving in a vehicle, running, travelling on a bike or a train, we experience the physical quantities of distance, velocity and acceleration. Using the GPS data we can make some qualitative and quantitative analysis of this sense experience as suggested in an earlier section.

7 Implications and Discussion

If we have to keep up to date with the changes that surround us, science and mathematics education cannot ignore the existence of modern devices and technologies. Use of such technologies will enable students to generate their own 'real' world data as has been suggested in NCF 2005 and other literature. What we have tried to emphasize in this article is how a technology like GPS/GIS can enable students to collect their own data, analyze the data, make connections from across the subjects and across the grades. It has been suggested by Monk that graphing must be repeatedly encountered by students as a means of communication and of generating understanding, as the students move across the grades [Monk, 2003]. The activities that have been suggested can be used to make linkages between abstract quantities and real life experiences which would be otherwise difficult to make. Depending upon the grade of the students the activities can be concrete or abstract.This we think will enhance an aspect of *Critical Graphicacy* as suggested by Roth [Roth et al., 2005]. Using such technologies will enable students to learn the concepts involved in a much better way from what they will learn passively in the textbook.

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