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Utilization of GIS for Geometry Analysis in Graphic Science Education

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Abstract. Descriptive geometry was taught with the aim at promoting the understanding of the projection method and the learning of its drawing technique. With the advancement of computer technology, which prompted the introduction of computer-aided graphics processing, *"graphic science"* has prevailed as a term that encompasses various areas of graphics processing, including geometry analysis. Although a number of colleges and universities already have computer graphics in their graphic science curricula, there are few higher education institutions that are teaching geometry analysis. One of the reasons for this trend may be that many colleges and universities teach computer graphics at the expense of traditional descriptive geometry. As a result, they cannot afford to incorporate geometry analysis into their curricula. Another possible reason is that the steps involved in the subject, which consist of measuring angles and lengths of figures, and analyzing these data, are far too complex for students to harvest the fruits commensurate with the time they have spent for learning all these processes.
In the graphic science education of Osaka City University, Geographic Information System for geographical and spatial analyses has been put to use in an attempt to help students learn geometry analysis technique in a short period of time. In this paper, the author will report on the contents of the geometry analysis education and students' class evaluation.

Key Words: Graphic Science, Descriptive Geometry, GIS
MSC 2000: 51N05

1. Introduction

Graphic science, which originated from descriptive geometry formulated by the French mathematician Gaspard Monge, is taught as a part of geometry, one of liberal arts subjects to students belonging to faculty of science and engineering at many universities. Descriptive geometry was taught with the aim of promoting the understanding of the projection method and

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the learning of its drawing technique. The advancement of computer technology in the 1960s prompted the introduction of computer-aided graphics processing. And, while debates are still going on about the significance of introducing the computer in graphic science education (for instance, see [1]), the term "graphic science" has come into wide use to encompass various areas of graphics processing, including descriptive geometry, computer graphics (hereafter referred to as "CG") and geometry analysis.[1]

Although a number of colleges and universities already have computer graphics in their graphic science curricula, there are few higher education institutions that are teaching geometry analysis. One of the reasons for this trend may be that many colleges and universities teach computer graphics at the expense of traditional descriptive geometry. As a result, they cannot afford to incorporate geometry analysis to be incorporated into their curricula. Another possible reason is that the steps involved in the subject, which consist of measuring angles and lengths of figures, and analyzing these data, are believed to be far too complex for students to harvest the fruits commensurate with the time they have spent for learning all these processes.

Osaka City University regards graphic science not only as a class designed to teach students how to draw graphics but also as a field that provides an opportunity for students to obtain skills to communicate with people by using relevant figures, the skills most required in today's highly-information-oriented society (see [3]). In this context, our university has provided lectures and exercises in two classes:

- *Graphic Science I* (which helps students understand the projection method and learn hand drawing) and
- *Graphic Science II* (which teaches students about physical behavior and psychological effects of light and colors and how to use CG for designing).

In addition, from April 2003, the *Geographic Information System* (hereafter referred to as "GIS") was incorporated into computer terminals available to the students to enhance and improve our graphic science education in the belief that developing a sense of geometry analysis is key to obtaining adequate graphic expression skills. What follows are the process of introducing geometry analysis into Graphic Science I and class evaluation results.

2. Outline of the curriculum

2.1. Placement of geometry analysis using GIS

Table 1 shows the outline of the curriculum. As shown in the table, we had only 3 classes (270 minutes) available for teaching GIS and geometry analysis because we also had to allow some time for the projection method and drawing. So there were time constraints. It was not possible to give students the whole information and knowledge about the concept and operation of GIS in such a short time nor was it the goal of this subject. The main objective of the lectures and exercises, therefore, was not to teach GIS to the students. Therefore we identify it as a tool to analyze figures and the classes were designed in the way that students would understand the basic operating method of GIS through lessons of geometry analysis.

[1] In this paper the author uses the word *"geometry analysis"* as the knowledge and technique of evaluating characteristic of figures or shapes based on quantity belong to them (e.g., length, angle, area, number of vertex, etc.) (see [2]).

Table 1: Weekly subjects of *Graphical Science I* in 2003 ("[ex.]" means exercise)

	Title	*Contents*
1st	Introduction	Classification of the projection method [ex.] Drawing of lines taking into account using of thick and thin lines
2nd	Multiviews	Third angle projection, First angle projection, Plan view, Front elevation view, Right elevation view [ex.] Drawing multiviews of figures given by isometric projection
3rd	Geometry Analysis – GIS Introduction	Overview of GIS, Research examples making use of GIS, Differences of vector data and raster data [ex.] Drawing and hiding of overlayed information of residential map, Rescaling of the information, Selecting of displayed area
4th	Geometry Analysis – Complexity of Shape	Evaluation of complexity of shape making use of peripheral length and area of the shape [ex.] Evaluating circularity
5th	Geometry Analysis – Characteristic of Points Distribution and Network	Evaluation of characteristic of points distribution making use of Voronoi diagram, Search of the shortest path [ex.] Evaluating given points distribution and that of points derive from gravity of administrative boundary, Searching the shortest path in radial/circular network, lattice network and existing road network in Osaka city
6th	Single view – Parallel Projection	Axonometric Projection, Oblique Projection [ex.] Drawing isometric of figures given by multiviews
7th	Single view – Perspective 1	Principle of perspective projection, Principle and drawing method of "Direct Drawing Method" [ex.] Drawing perspective of primitive figures given by multiviews
8th	Single view – Perspective 2	Difference of Paraline and Perspective, Viewpoint and visibility [ex.]Drawing perspective of complex figures given by multiviews
9th	Mid-term exam	
10th	Single view – Perspective 3	Principle and drawing method of "Two point Common Method", Comparison between "Two point Common Method" and "Direct Drawing Method" [ex.] Drawing perspective of primitive figures given by multiviews
11th	Single view – Perspective 4	Principle and drawing method of "Multi point Common Method" [ex.] Drawing perspective of complex figures given by multiviews
12th	Single view – Perspective 5	Principle and drawing method of "One point Common Method" [ex.] Drawing perspective of primitive figures given by multiviews
13th	Single view – Perspective 6	Principle and drawing method of "Simple Drawing Method with Grid Cube" [ex.] Drawing perspective of complex figures given by multiviews

2.2. Enrollees

This subject was made a compulsory subject for

1) the first-year students of the Department of Architecture and Building Engineering, Faculty of Engineering,
2) the first-year students of the Department of Environmental Urban Engineering, Faculty of Engineering, and
3) the first-year students of the Department of Housing and Environmental Design, Faculty

of Human Life Science.

It was also made an elective subject as well for

1) the first-year students of the Department of Civil Engineering, Faculty of Engineering,
2) the first-year students of the Department of Applied Physics, Faculty of Engineering, and
3) the second-year students of the Department of Information and Communication Engineering, Faculty of Engineering.

There were 3 classes a week. The number of enrollees from each department in the first semester of 2003 is as follows.

[Faculty of Engineering]	
Dept. of Architecture and Building Engineering:	31
Dept. of Environmental Urban Engineering:	29
Dept. of Civil Engineering:	34
Dept. of Applied Physics:	17
Dept. of Information and Communication Engineering:	19
[Faculty of Human Life Science]	
Dept. of Housing and Environmental Design:	47
[Other]	
Department of Physics, Faculty of Science:	1
Total:	178

2.3. Equipment in the exercise room for graphic science education

Figure 1: Scene of the class

GIS application (SIS Map Modeller Ver6.0, Infomatix Incorporated) was incorporated into 80 DOS/V-compatible notebook computers. A terminal control application (Wingnet, Commuter Wing Co., Ltd.) was also introduced to record student attendance, check the terminals' operation status, transfer graphic data from the teacher's terminal, and distribute and collect learning materials. In all the geometry analysis exercises in Graphic Science I, because of the time constraints, the teacher distributed half-finished materials to the students and collected them at the end of each exercise. Fig. 1 shows a scene of the exercise using the above-mentioned equipment and tools.

3. Contents of lectures and exercises

The three 90-minute geometry analysis subjects using GIS consisted of lectures in the first half of the class and exercises in the last half. During the exercise, the students were given specific tasks to work on. Table 1 shows the outline of the classes. What follows are the detailed contents of each subjects.

3.1. GIS introduction

In order to give the brief outline of GIS to enrollees from different departments, we associate GIS with a spreadsheet.

The students are taught that, while both application softwares are designed for the management and analysis of information, GIS can specifically handle graphic and geographic information as well as numeric and text data. We describe how numeric and text data are associated with graphic and spatial information and explain the concept of property information. Then we show several results of analysis that we have conducted with GIS, explain differences between vector data and raster data, variety of vector data, and conclude the class with an exercise using a residential map. The exercise is designed to help the students learn the basic handling of geographic data with GIS, i.e., how to switch the layer from Display mode to Non-display mode, how to scale the layer and how to change the layer display position.

3.2. Evaluating the complexity of a shape

We use circularity to measure the complexity of the shape. This value can be obtained by dividing peripheral length by the square root of the area.[2] After showing some basic figures and analytically obtaining their relevant values, we move on to the exercise part. Our teaching materials are prepared in the way that, if a certain figure is entered, its indicator values will be displayed on the label. So the students enter divers shapes into the computer to study the relationship between the figure and circularity and the limit of this particular indicator. Next, on the basis of the obtained value, they paint different ranges in different colors (see Fig. 2). They also use the obtained value as a height to draw a thematic map.

The students do the same exercise using administrative boundary of the 24 wards of Osaka City. In the basic figure exercise, the students were provided with half-finished materials prepared by the teachers. In the case of the exercise using administrative boundary, however, they are given unprocessed information and instructed to carry out all by themselves the

[2]Strictly speaking, *circularity* is defined as a value determined first by multiplying the area by 4π and then dividing the obtained value by the square value of peripheral length. In our class, we use the value which is in proportion to reciprocal number of strictly defined circularity.

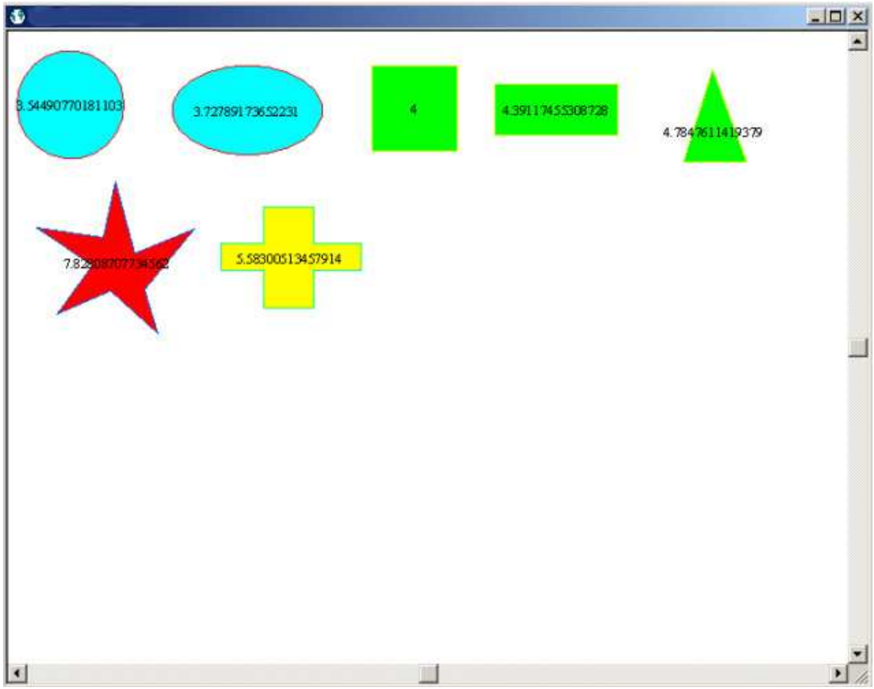

Figure 2: Enter of various figures and indication of circularity

entire series of works, including the registration of circularity as a formula and the drawing of the thematic map that displays property values as label. Finally, they try to locate the wards whose indicator values are higher (i.e., not circular) than the other wards in Osaka City.

3.3. Evaluating the characteristics of point distributions and networks constructed by line segments

To identify the properties of the distribution of points, we make a *Voronoi diagram* on the basis of the points distribution and see the dispersion of the areas of the Voronoi polygons. In addition, we carry out the shortest path search in order to measure network properties by segment. In the lecture, we explain to the students what the Voronoi diagram is all about, why we use this particular diagram, and where one can find the shortest path. During the exercise, the students are provided with the Voronoi diagrams based on three types of point distribution that were prepared by the teachers beforehand. The students then are instructed to display each Voronoi diagram by switching the layer and check out the dispersion of the areas of the Voronoi polygons (see Fig. 3). After that, they receive materials containing administrative boundary of the 24 wards of Osaka City, draw a Voronoi diagram on the assumption that the distribution of gravity points in each ward can be equated with point distribution, and overlap the diagram with actual administrative boundary (see Fig. 4).

With respect to the shortest path search, the students are instructed to do the search concerning radial/circular and lattice networks. As for the radial/circular pattern, they are told to make sure how the path changes according to the positioning of the start point and the end point (see Fig. 5). After that, they also do the same kind of search using the existing road networks in Osaka City.

In these 3 classes, all the enrollees successfully fulfilled prescribed requirements, making it possible for us to collect all the materials (including the products of the exercises) at the end of each class.

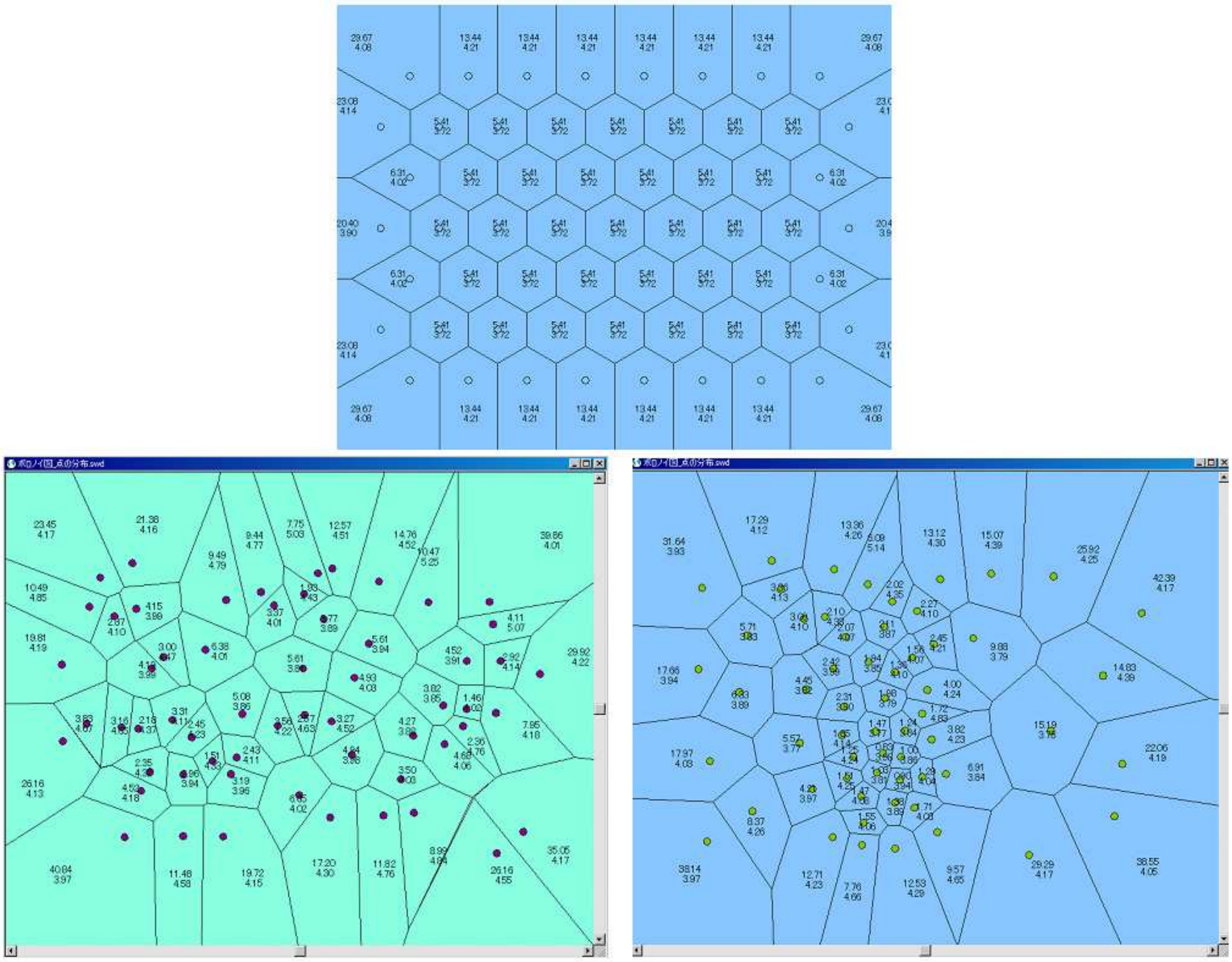

Figure 3: Evaluation of point distribution making use of the Voronoi diagram

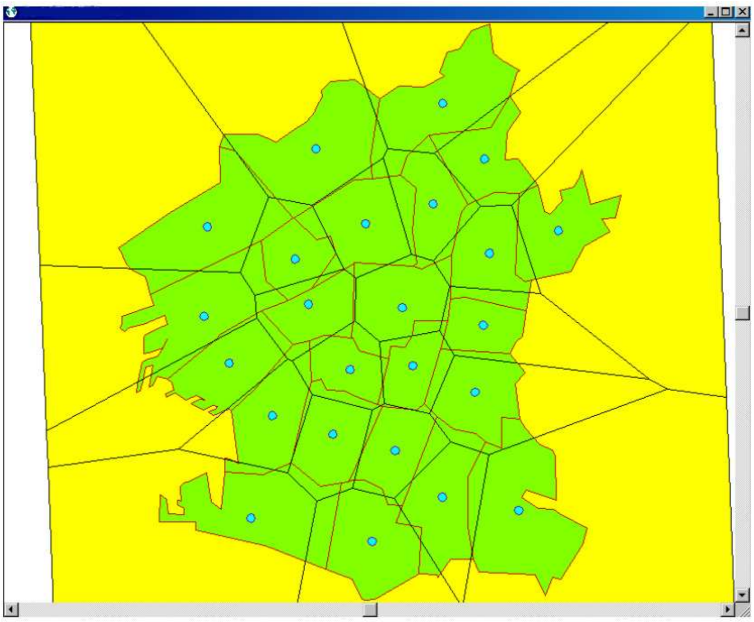

Figure 4: Overlay of the Voronoi diagram and the original administrative boundary

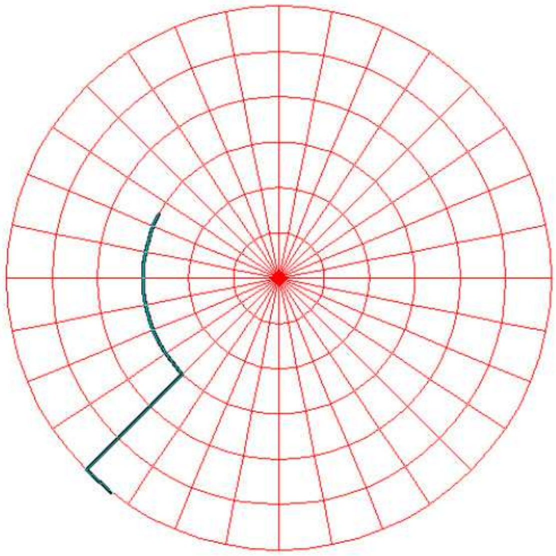

Figure 5: An example of the shortest path search on radial/circular network

4. Results of class evaluation

During the term-end exams of this subject, we conducted a survey on the 12 subjects shown in Table 1. (Class (9) "Mid-term exam" was excluded from the survey.) The survey consists of 4 questions (if the subjects were "Interesting," "Easy to understand," "Helpful," and "Recommendable") with 5 grades (from "Very much so" to "Not at all"). In addition to making these numerical evaluations, the students were asked to write down their comments on the 3 GIS subjects as well as on this subject as a whole.

Fig. 6 shows the average rating given by the students about each subjects (5 points on down in a descending order from "Very much so"). As the figure shows, the 3 subjects using GIS earned lower points than the other 9 subjects in which GIS was not used. The reasons for this low ratings may include that, according to the students' comments, while they found exercises using the computer fairly interesting, the classes went too quickly and too compliant with the teaching manual. As a result, some of the students found the subjects not very exciting or helpful. However, they wrote they were generally happy with the subject as a whole.

In Fig. 7, answers were separated according to the department. The average values of the 3 subjects using GIS and that of the other 9 subjects were determined respectively; and the average value given to the GIS subjects was divided by the average value of the other subjects. Which means that, if the value thus obtained turned out to be over 1, the GIS subjects received positive evaluation. This figure illustrates that students from the Department of Architecture and Building Engineering and from the Department of Housing and Environmental Design gave low evaluations to the GIS subjects while those from the other departments gave almost equal evaluations to the two categories of subjects.

Our future challenges are

1) to adjust our subject schedule so that enrollees can spend more time working at the computer individually,

2) to select the kind of examples related more closely with our daily lives and give clear explanation in the lecture about how useful geometry analysis is in these examples, and

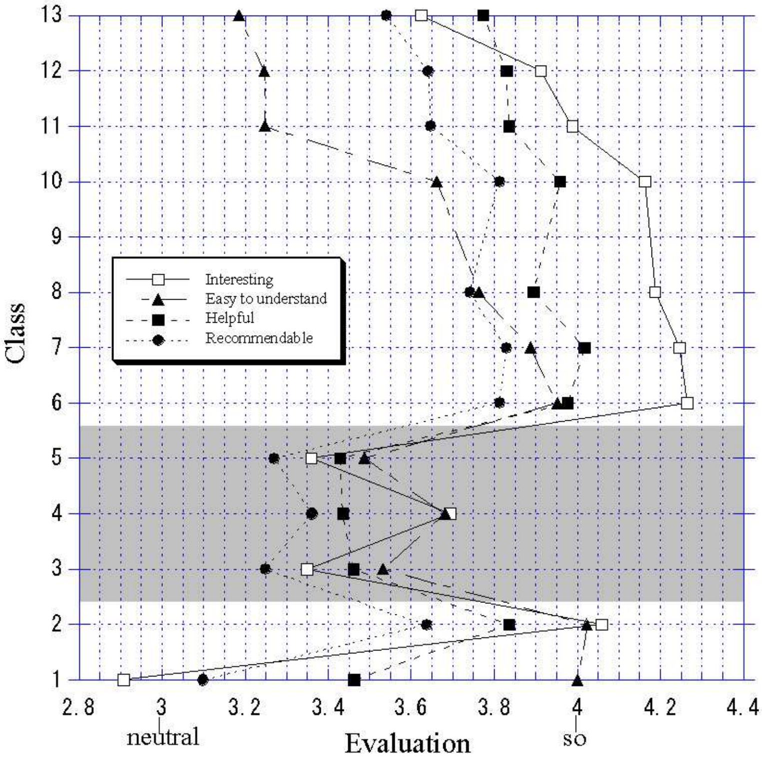

Figure 6: Average rating given by the students

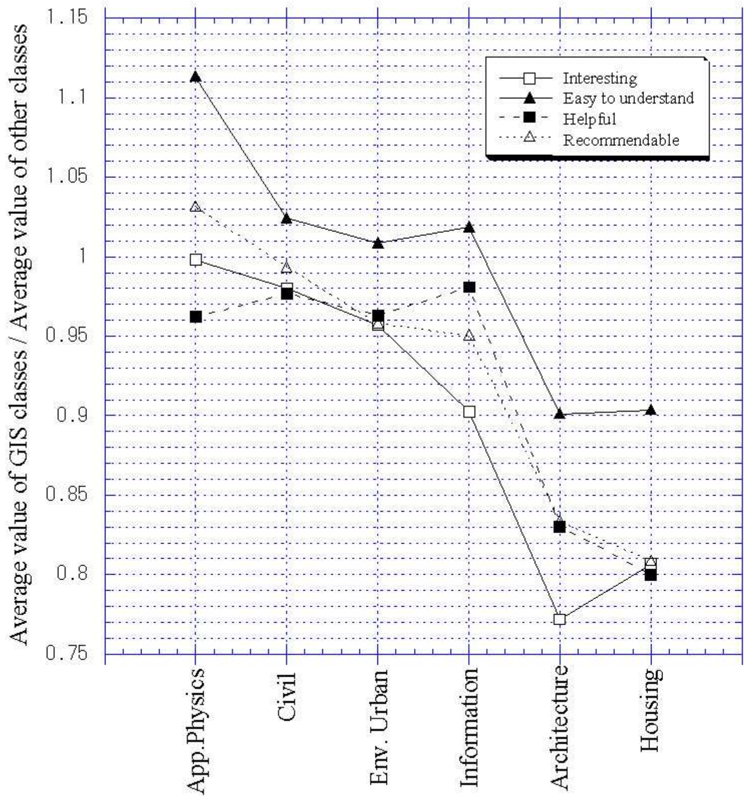

Figure 7: The value obtained by dividing the average value of the GIS subjects by that of the other subjects from the department

3) to scrutinize and modify, if believed necessary, the contents of the examples of application, considering the characteristics of the departments from which the students gave low ratings to the GIS subjects.

Another important task is to work out ways to incorporate into GIS the functions specially designed for those who learn geometry analysis because this subject is not intended for acquiring the operation skills of GIS per se.

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