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Deconstruction of Fractals and its Implications for Cartographic Education

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The research reported here was designed for two reasons: firstly, to involve anyone with an interest in cartographic visualization to participate in eliciting cartographic knowledge and to provide them with the opportunity to contribute their practical knowledge and opinions; and secondly, to inform the design of algorithms for line generalization. In the past, there has been some resistance to such mining and codification of expert knowledge. However, many cartographers now welcome highly interactive computer graphics, computer mapping, and virtual reality systems as providing them with new opportunities for launching cartography into a new creative age. Despite nearly thirty years of research on line generalization algorithms, the available algorithms are somewhat simplistic. This research, undertaken under the auspices of the BCS Design Group, explored the behavioural tendencies of cartographers engaged in line filtering. The results show that a carefully contrived, even if obviously artificial, exercise on the deconstruction of lines into meaningless forms can prompt cartographers to observe, record, and discuss their own cognitive processing.

INTRODUCTION

This research was designed for two reasons: firstly, to involve anyone with an interest in cartographic visualization to participate in eliciting cartographic knowledge and to provide them with the opportunity to contribute their practical knowledge and opinions; and thereby, secondly, to inform the design of algorithms for line generalization. In the past, there has been some resistance to such mining and codification of expert knowledge. However, many cartographers now welcome highly interactive computer graphics, computer mapping, and virtual reality systems as providing them with new opportunities for launching cartography into a new creative age (Collinson, 1997). There is thus a growing willingness to collaborate in projects that could lead to better cartographic software.

Despite nearly thirty years of research on line generalization algorithms, the available algorithms are still somewhat simplistic. This research, undertaken under the auspices of the BCS Design Group, explored the behavioural tendencies of cartographers engaged in line filtering. The results show that a carefully contrived, even if obviously artificial, exercise on the deconstruction of lines into meaningless forms can prompt cartographers to observe, record, and discuss their own cognitive processing. The exercise asked cartographers to provide an abstract representation of a meaningless geometric pattern, corresponding to the first and second generations of the quadric Koch curve. They were asked to select a subset of original points initially. It was hoped that this would help them gauge the degree of generalization required. By relaxing the constraint of having to use a subset of the original points, they were then encouraged to explore their preferred output form corresponding to the same degree of generalization. More importantly, the investigation progressively shifted more and more of the research process onto the participants themselves. The author acted as a facilitator — a) providing guidance and independent interpretations to provoke articulation, and b) assuming responsibility for the dissemination of results — with the hope that this will spark off ideas for similar research by other members of the BCS Design Group.

The exercises undertaken are similar to those conducted by Attneave (1954), Marino (1979), White (1983), and numerous other researchers. Although the visual and mathematical comparison of input and filtered lines has been useful for assessing the performance of line generalization algorithms, Visvalingam and Whyatt (1990) expressed some concern over the conclusions which have been drawn from such surface analysis. Although White's (1983) evidence showed only a forty-five per cent agreement between the output of the Douglas-Peucker algorithm and those of cartographers, it has been widely used to endorse the superiority of this algorithm. There was little discussion of what the other cartographers did, let alone why they did so. Prescriptions for knowledge-based generalization (see papers in Buttenfield and McMaster, 1991) have also tended to focus on the 'what and when' of generalization and reiterate known guidelines. The belief that manual generalization is subjective and intuitive has also impeded the deeper probing of the 'how and why' of individual practice. Deeper analysis of the results of deconstruction of artificial lines shows that inconsistencies in manual generalization need not always be the result of subjective ad hoc decisions; they may reflect justifiable differences in the allocation of priorities.

The paper provides a brief background and the academic motivation for this research. It then briefly describes the nature of the experiment (which is included as Appendix 1) before presenting a classification and discussion of results from an initial attempt. It then presents some results from a second attempt and includes comments made in an open discussion forum some two years later. The paper concludes by noting a) some visible manifestations of cartographic training, b) some potential tensions between preception and perception, c) some preconceptions (possibly induced by current training) which could inhibit creative thinking. Despite repeated probing and the interesting observations, they need to be treated as anecdotal and indicative.

BACKGROUND

Most algorithms for line generalization are based on relatively simple geometric reasoning. The widely used Douglas-Peucker algorithm (Douglas and Peucker, 1973) selects the points, which are furthest from a projected line. More recently, Visvalingam and Whyatt (1993) showed that better results could be achieved through Visvalingam's iterative elimination of triangular geometric features, based on the measured significance of the point at the apex of the triangle. They found that the best measure for 2D lines, such as coastlines, is the area that is lost when a point is dropped. Wang (1996) and Wang and Muller (1998) proposed a more complex geometric process for simplifying bends (i.e. concave or convex sections of lines). This included the context dependent amalgamation of two neighbouring bends, exaggeration of isolated bends and iterative bend elimination using a shape-weighted area tolerance. Visvalingam and Herbert (1998) demonstrated that such complex algorithms do not always produce the intended effect. Indeed, the ArcInfo 7.1.1 implementation produces quite unacceptable results. Moreover, as Wang and Muller noted, bend simplification was designed to operate on simple bends and not on complex curves consisting of features within features. Thus, only cursory reference is made to the results from Wang's bendsimplify algorithm, investigated more fully elsewhere (Visvalingam and Herbert, 1998).

Visvalingam (1998) suggested that it might be useful to view the Douglas-Peucker, Visvalingam, and other geometric algorithms as providing deconstructions, rather than generalizations of lines. Unlike minimal simplification, both generalization and deconstruction produce new geometric patterns — i.e. they seek to deviate from the original source line. This is why Visvalingam and Whyatt (1990) rejected McMaster's (1987) mathematical measures of the performance of line generalization algorithms as misleading and inappropriate, and only appropriate at the level of line approximation. However, deconstruction differs from cartographic generalization: whereas the latter is knowledge-based, deconstruction is an entirely mechanical cognitive process whose sole aim is to discover unexpected patterns and structures in lines and to study the invariant properties of different deconstructors (Visvalingam, 1996).

Visvalingam and Brown (1998) and Visvalingam and Herbert (1998) deconstructed pre-fractals or teragons into decogons. Mandelbrot (1987) coined the terms, pre-fractals and teragons, to refer to specific generations of a fractal curve. Visvalingam (1996) used the word ***decogon*** to refer to deconstructed patterns, which had no intrinsic meaning. The exercises presented here force cartographers to engage in typification and abstraction of the teragons since there is hardly any unnecessary geometric detail present at these low levels of fractal generation for minimal simplification. Visvalingam and Brown's decogons (1998) drew attention to the complex symmetry of the first generation quadric Koch curve, shown in Figure 1, produced by the repeated application of a generator pattern (in bold) to the four edges of a square initiator. Visvalingam and Brown (1998) noted four levels of symmetry, namely:

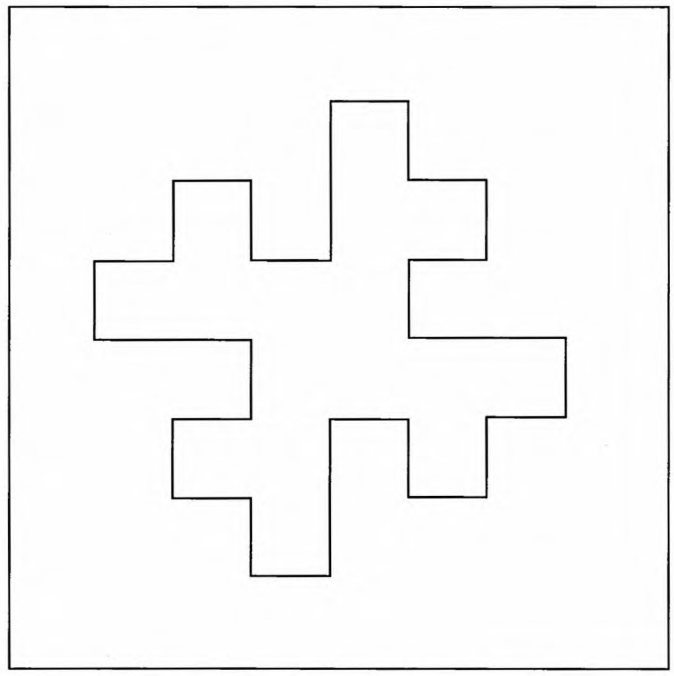

Figure 1. First Generation Teragon of the Quadric Koch Curve

- the four-fold rotational symmetry around the central axis of rotation (*symmetry* two). For example, the four partition planes, which originate from this centre and which pass through the four starting points, divide the curve into its repeating components.
- the two-fold rotational symmetry of the generator around its central point, which is otherwise redundant in defining the generator's shape (*symmetry* two).
- a further two-fold rotational symmetry, creating a Z-pattern, in each half of the generator (*symmetry* three).
- the bilateral mirror symmetry in sections of the curve which give rise to its rectilinear shape (*symmetry* four).

The deconstruction of different generations of taragons indicated the types of symmetries that tend to be preserved by different line generalization algorithms. Visvalingam's algorithm with the area metric appears to best preserve the symmetry of the teragons. Nevertheless, the range of decogons that could be obtained from even simple teragons was quite large and unexpected. The research, reported here, investigated whether cartographers would tend to deconstruct the lines in a more consistent way. Figure 2 classifies the patterns abstracted by algorithms and by people, and provides an index to Figures 3 to 7.

PATTERNS PRODUCED FROM THE LEVEL 1 QUADRIC KOCH CURVE				
By Algorithms	By People			
Figure 3:	Figure 4:	Figure 5:	Figure 6:	Figure 7:
Decogons	Exploratory Sketches	Rectilinear Patterns	Wings and Petals	Spatial Extent

Figure 2. Classification of Patterns Produced by Algorithms and By People

FROM ALGORITHMIC TO HUMAN DECONSTRUCTION OF THE TERAGONS

Different deconstructors impose a different structure on even relatively simple lines. The rows in Figure 3 list the various algorithmic deconstructors and show the series of decogons output by each. To facilitate comparison, all the decogons in a given column have the same number of points. Only a couple of line filtering algorithms was investigated; Fourier and wavelet analyses, which were not included, are likely to produce other patters. Wang's (1996) bendsimplify algorithm only extracted the final square initiator shown in the fourth row from the bottom in Figure 3; it used eleven points for depicting a square (Visvalingam and Herbert, 1998). Although all these decogons are equally plausible, the purpose of the research was to ascertain whether cartographers would tend to agree on particular decogons or whether they would also output quite dissimilar decogons. It was hoped that the artificial exercise of having to generalize a meaningless geometric pattern would a) provide some insights into the cartographer's cognitive processing of these lines, and b) inform further research into digital line segmentation, structuring, and generalization.

THE EXERCISES AND METHOD OF DATA COLLECTION AND ANALYSIS

Appendix 1 provides a listing of the exercises set. Exercise One requires the subject to select twelve out of the thirty-two points defining the teragon. Similarly, in Exercise Two, they were expected to select twenty to forty points from the two hundred and fifty-point curve. The exercise is based on that designed by the psychologist Attneave (1954), which was also used by cartographers, such as Marino (1979), White (1983), and several others since then. In this particular set of experiments, sample numbers were specified to enable the participants to get a feel for the required scale of abstraction. It was hoped that having done so, they would then be able to express what they felt was the appropriate solution for that scale in the second part of each exercise.

The exercise was initially undertaken by participants at the British Cartographic Society's Design Group meeting at the 1996 Annual Symposium in September at Reading. Unfortunately, the aspect ratio of the drawings was distorted by the fax machine. However, this seems to have affected only the output of one respondent. Although there were over twenty-five people at the meeting, only eight cartographers returned the completed exercise. Two other veteran cartographers, who were not at the Symposium, also undertook this exercise in a less time-constrained fashion. Ten results are by no means representative of the cartographic community and were only treated as indicative. In Tables 1 and 2, the set returned by practising cartographers is referred to by the label C. The label S refers to eighteen student returns; David Forrest from Glasgow University kindly persuaded Diploma level cartography students to attempt this exercise. Not all subjects included explanations for their choice of points.

These results were analyzed and interpreted as follows. The first task was to study the figures and tentatively group them into categories. The categories were not pre-defined but were data-driven. The variants within each category were then sub-classed and related, using links in figures and the explanations where possible. Having structured the data, the author tried to deduce the implications of the results. In the meantime, the BCS Design Group members repeated the exercise some eighteen months later at their meeting in April 1998 at Southampton. The author was not present. The author presented her interpretation to three of these participants at the September 1998 BCS Symposium. This prompted them to reveal aspects of their behaviour that they had not recorded at Reading in 1996. On reflection, they felt that some patterns seemed to be better than their original ones. This paper was presented to the BCS Design Group meeting at Glasgow University in November 1998. Visvalingam (1998) provided an interpretation of the original returns made by individuals in 1996. Her paper provided the framework both for assessing the results from the repeat exercise at Southampton and for guiding discussions at Glasgow. The conclusions of this paper take account of these discussions.

SOME INITIAL REACTIONS

Everyone at the meeting attempted the exercise. Some said that they were too embarrassed with the results to hand them in. Some of the comments made by cartographers at Reading are worth noting. Firstly, and most importantly, they felt that the exercise was far too artificial and that it did not relate to how cartographers worked on lines. Some said that they went dizzy parsing the line forwards and backwards, checking the number of points. In comparison to the length of source lines and the number of points to be selected in the exercises undertaken by Marino (1979) and White (1983), Exercise One was not at all onerous. Even so, this suggests that the results presented here (and possibly those presented by other authors) may be partial and that some types of cognitive processing of lines (in the non-returns) are perhaps not being detected.

Several cartographers asked the sort of questions they were trained to ask, namely — why are we doing this? What type of geographic phenomenon does the data refer to? What scale of reduction does the subset represent? Some felt that without such information, the exercise was artificial, meaningless, and a waste of time. Some of those, who returned their output, stated that they hoped that their solution was what I was looking for and said that they were looking forward to hearing what the solution should have been. Again, this reflects some uncertainty and discomfort with performing a deconstruction as opposed to a generalization.

Other cartographers, who were users of mapping software, stated that they found it difficult to project a mental visualization of target shapes since their normal

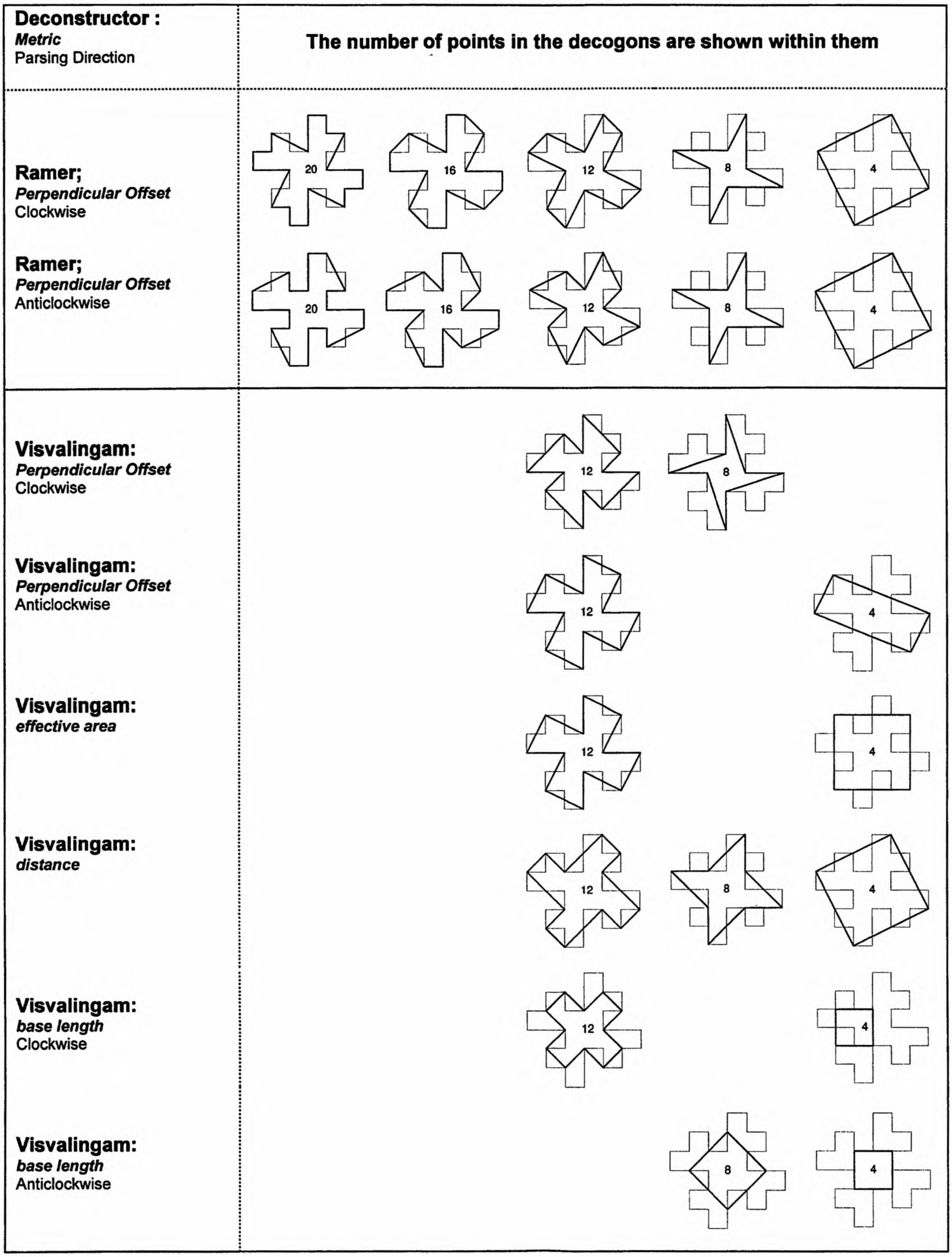

Figure 3. Decogons produced by the Douglas–Peucker and Visvalingam algorithms. Reprinted from Visvalingam and Brown (1999), with permission from Elsevier Science

working practice had made them reliant on the feedback provided by software, which produced curves based on points they input. Without such feedback in a paper exercise, they were unwilling to draw their own curves. These comments are noted here since they provide opportunities for further research into how software may be conditioning cartographic visualization. This paper itself is more focused on the pattern of results in the returns.

Since most of the non-returns were discarded in the room, they were studied later. Although they were not included in the analysis, some anecdotal reference is made to some of the discarded output later. Scribbles, showing steps in exploring progressive abstraction, have influenced the summary of the results presented here.

INITIAL OBSERVATIONS AND COMMENTS ON EXERCISE ONE

The results from Reading are classified and presented in Figures 4 to 7. Some of the figures have been re-drawn by the author where the originals were either too untidy or where the scanned image was not clear. Table 1 shows the number of times a figure of a particular type was produced. In classifying the results, output with mixed patterns have been assigned where justifiable to the class which it most resembled since the aim of the exercise is to study the types of patterns rather than individual patterns *per se.* Not all subjects gave reasons for why they had chosen a particular pattern, so again the reasons suggested in this paper should be treated as anecdotal even if plausible.

All except one person, ***attempted*** to retain the four-fold rotational symmetry. In general, the figure was being perceived as a whole and the original partition planes were largely ignored. In ten out fifty figures, subjects appeared to be attempting to use the four parts to explore different patterns. Figure 4a is a good example of such varied exploration. Figure 4b shows a leaning towards a convex rather than concave shape but there were an equal number of people drawing concave shapes. Figure 4c shows a drift towards wings. Figure 4d shows the exploration of different wing shapes.

Nineteen (of the fifty-six figures) consisted of rectilinear patterns (Figure 5). The only figure to show a deliberate directional bias was Figure 5f — this orientational bias could be due to the distorted aspect ratio on the faxed figures on

Type of Pattern	Sub-type	Number produced as Fig. 1a	as Fig. 1b	Comments KEY S = by students C = by cartographers
Rectangular				Being treated as if it were a road
	Fig. 5a	4S + 8C	1S + 1C	Offset cross
	Fig. 5b	1C		Figure/ground switch
	Fig. 5c		1C	Schematic
	Fig. 5d		1S	For smaller scale — shows extent
	Fig. 5e		1S	For smaller scale — shows extent
	Fig. 5f		1C	Offset road (result may be biased by aspect ratio)
	TOTAL	4S + 9C (13)	3S + 3C (6)	= 19
Wings and Petals				Emphasis on structure
	Fig. 6a	1S	1C	Retains three levels of symmetry
	Fig. 6b–c	1S	2S	Examples of free-form sketches
	Fig. 6d		1S 3C	Fig. 6a rotated to use mid points of edges
	Fig. 6e		1S	Tight fitting curve using mid point
	Fig. 6f	1S	1S 1C	Free form of Fig. 6e
	Fig. 6g		5S	Enclosing curved shape
	Fig. 4c	3S		Drift towards wings
	TOTAL	6S (6)	10S + 5C (15)	= 21
Extent				For display at smaller scale? Emphasis on overall extent and shape rather than on internal structure
	Fig. 7a	1S		Extent using near-redundant points
	Fig. 7b	5S	1S	Convex forms
	Fig. 7c–e	1S	3S 2C	Concave forms
	TOTAL	7S (7)	4S + 2C (6)	= 13
Unclassified				Often used by subjects for exploration
	Fig. 4a	1S	1S	Motley of patterns
	Fig. 4b	4S		Concave and convex (Counted with 7b)
	Fig. 4c	3S		Drift towards wings (Counted with wings)
	Fig. 4d	1S		Different wing shapes (Counted with 6b)
	TOTAL	1S	1S	= 2
Reject		1C		Too many points
TOTAL		18S + 10C (28)	19S + 10C (28)	= 56

Table 1. Frequency of Different Patterns Produced for Exercise One

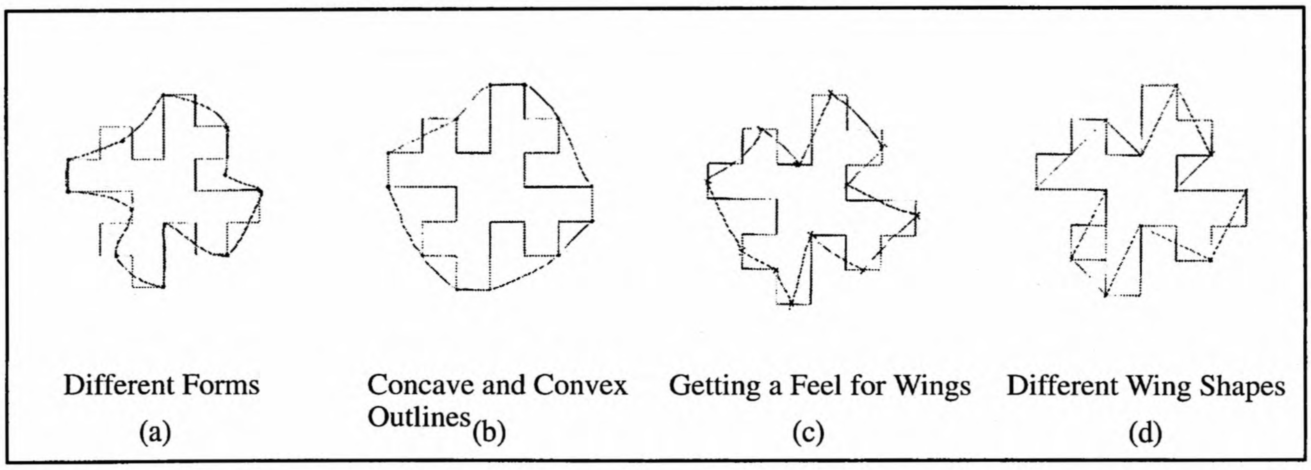

Figure 4. Evidence of Exploration of the Teragon for Possible Patterns

which they were originally drawn. Fourteen of the nineteen figures corresponded to Figure 5a. Nearly all cartographers, who drew this pattern, produced it during the exploratory phase; only one cartographer produced this as the final rendition. The following reasons were presented in its favour:

i) It is a simpler, 'less busy' pattern
ii) It omits the smaller juts
iii) It retains the biggest branches of the figure
iv) It retains the original rectilinear features
v) The original figure resembles a road network

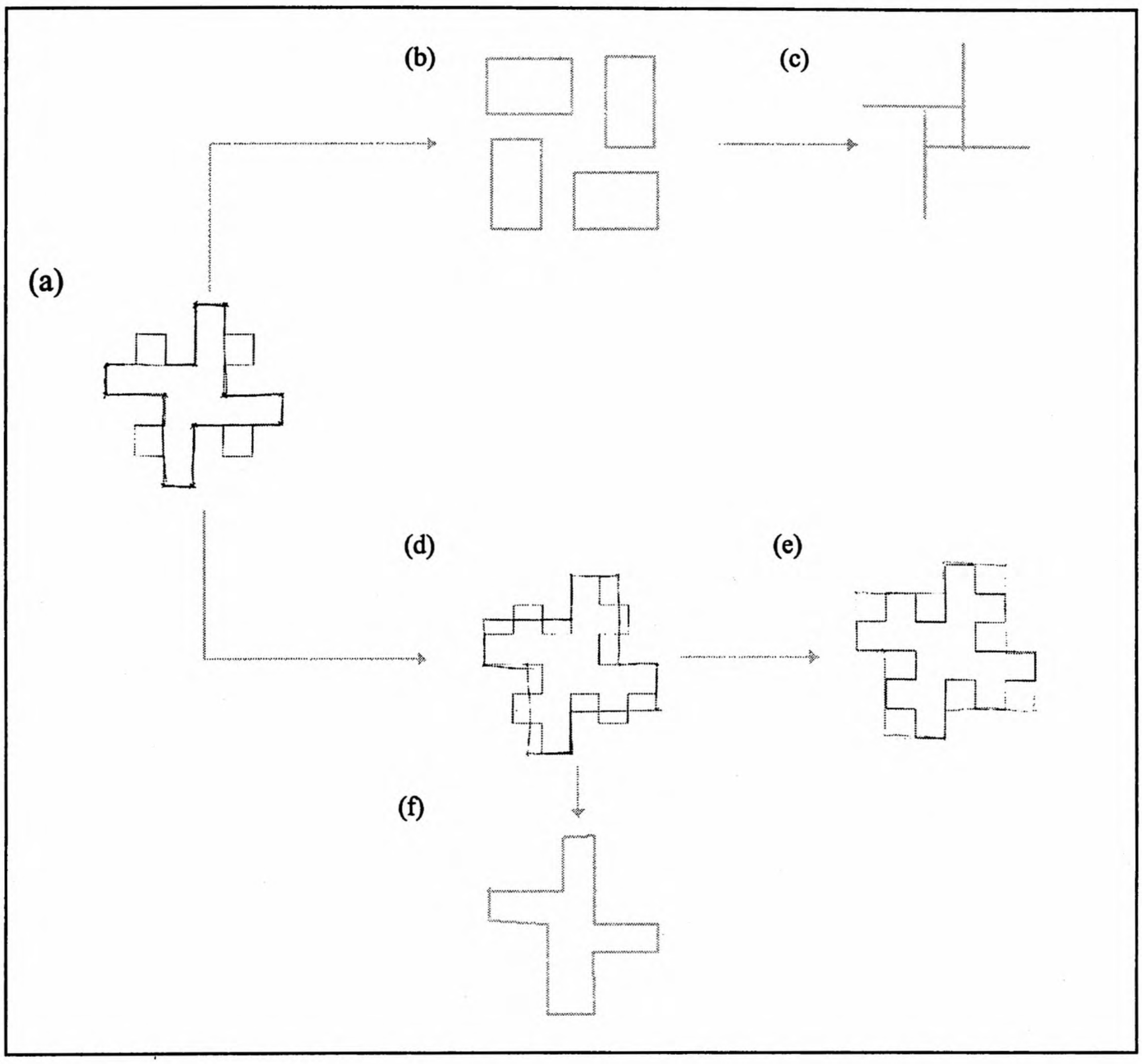

Figure 5. Preservation of four-fold symmetry and rectilinearity

One person included a frame which just fitted the teragon and chose to focus on the background consisting of four disjoint parts which were easier to simplify as shown in Figure 5b (which is the complement of Figure 5a). The same cartographer felt that Figure 5c was the best simplification. There was some discomfort with the somewhat awkward offset cross in Figure 5a. Figures 5d and 5e seek to retain the rectangular pattern while showing the extent of the figure (perhaps for display at reduced scale or to make the offset cross look less awkward). The offset cross is clearly being interpreted as on offset junction in Figure 5f but this visualization may have been induced by the distorted aspect ratio of the faxed figures.

All except one person who started with the offset cross (Figure 5a), then chose the wing and petal shapes shown in Figure 6; twenty-one of the fifty-six figures were of this type. The subjects stated that they deliberately chose to discount the rectangular shape since the winged shapes were more useful for indicating the main and sub-branches in the structure. Cartographers were clearly aware that this structure could be shown using different shaped wings (e.g. exploration of them in Figure 4d as noted earlier). In their final renditions, the cartographers tended to produce straight edged wings, while the students tended to prefer curvy petal-shapes. But twelve of the twenty-one figures used the midpoints on edges, instead of the corner points, in the straight edged and curvy shapes. The cartographers indicated a preference for figures which applied the give and take rule (as in Figures 6a, 6e and 6f). Five students produced the pattern in Figure 6g, which was more concerned with showing the overall shape and extent of the four-petalled shape, perhaps to display at smaller scale.

The shapes in Figure 7 also appear to be more concerned with showing the overall extent of the figure. Here again, opinion was divided between the use of convex and concave forms. Of the fourteen shapes in this class, nine were broadly convex. However, the final preference was for concave figures. One of those who produced the concave form in Figure 7c said that she had attempted to balance the give and take and then adjust the shape as in Figure 7d. Note that Figure 7d could be viewed as a stylized version of the offset cross in Figure 5a, in which the minor branch was omitted. Note also, that many of the patterns in Figure 7 use near-redundant points in preference to information rich points located on curvatures in lines.

In the final analysis, fifteen out of the twenty-eight respondents chose wing and petal shapes for their final rendition. It is interesting that, like the line generalization algorithms, several respondents decided to sacrifice the level four bilateral symmetry in order to preserve the first three levels of symmetry. Some students were also tending to ignore the level two symmetry.

OBSERVATIONS AND COMMENTS ON EXERCISE TWO

People had much more difficulty performing a point-based exercise with the second exercise given the line with two hundred and fifty-six points. They tended to ignore the

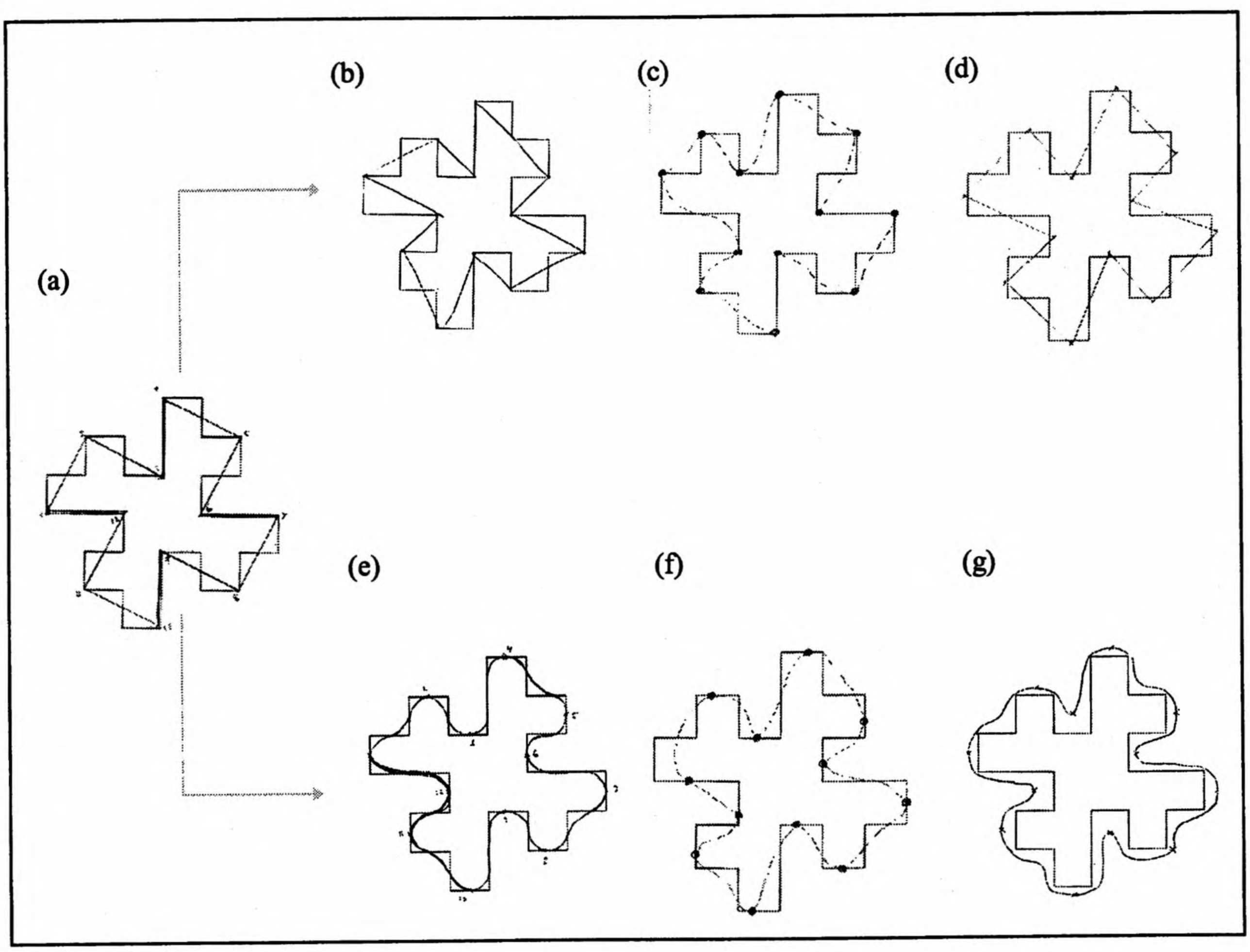

Figure 6. Different Types of Wing and Petal Shapes

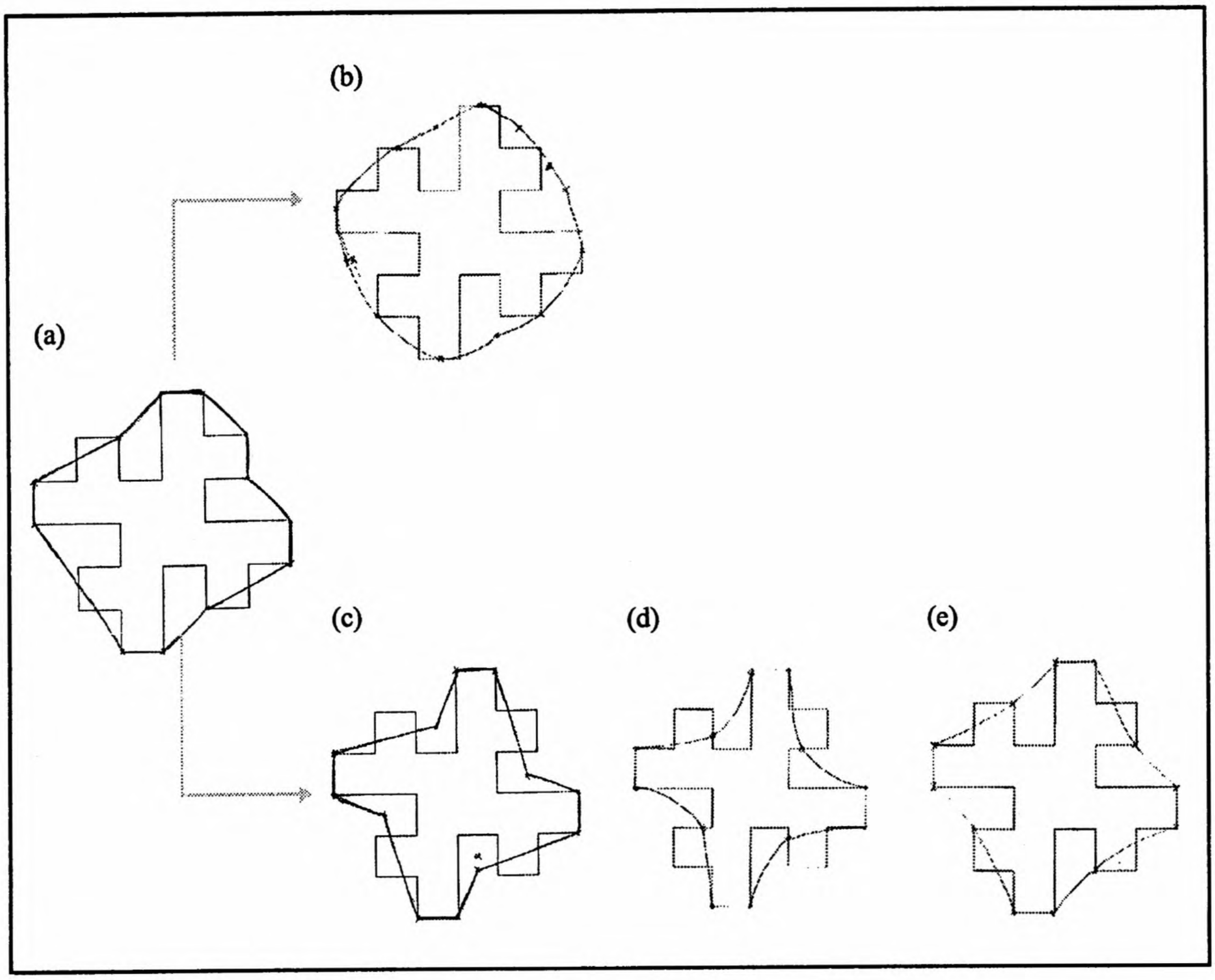

Figure 7. Convex and Concave Figures Showing the Teragon's Extent

Type of Pattern	Sub-type	Number produced as Fig. 2a	Number produced as Fig. 2b	Comments KEY S = by students C = by cartographers
Rectangular				Influenced by knowledge about fractals?
	Fig. 8a	2S 2C	1C	Level 1 teragon
	Fig. 8b	4S	3S 2C	Rotated level 1 teragon
	Fig. 8c		1C	Generalized version of Fig. 8b
	Fig. 8d		1S	Cross as in Fig. 6d
	TOTAL	6S + 2C (8)	4S + 4C (8)	= 16
Wings and Petals				Emphasis on structure and overall shape
	Fig. 8c		1S	Curved version of Fig. 8b
	Fig. 8f	5S 3C	2S 1C	Squarish shape for centre
	Fig. 8g	6S 1C	5S 1C	Tending to U-shape in centre
	Fig. 8h	1S	4S	V-shaped centre
	TOTAL	12S + 4C (16)	12S + 2C (14)	= 30
Free form				
	Fig. 8i	1C		Exploration of structure of figure
	Fig. 8j	1C		Similar to Fig. 7d
	Fig. 8k		2C	Offset cross with centrelines
	TOTAL	3C (3)	2C (2)	= 5
no return		1C	2S 2C	= 5
TOTAL		18S + 10C (28)	18S + 10C (28)	= 56

Table 2. Frequency of Different Patterns Produced for Exercise Two

specified target range of points and focused on the desired shape instead. Again, the first of the pair, used for exploration, showed mixed patterns but there was an overwhelming convergence towards wing and petal shapes in this exercise. Five people, four of whom were students, abstracted the first generation teragon (Figure 8a) during the exploratory stage; ten considered rotating the shape (Figures 8b and 8c). Interestingly, Figure 8b is one of the decogons abstracted by the Douglas-Peucker algorithm (Visvalingam and Brown, 1999). One student produced a generalized winged pattern with just twelve points (Figure 8d), showing a re-use of a pattern already encountered in Exercise One.

There were some variations in the petal shapes but they all have the same orientation as Figures 8b–8d. Figure 8e, produced by the same student who produced Figure 6e, shows a tendency to re-use the same strategy. Note that this student's conscious segmentation of the figure involves a rotation of the partition planes and of the figure, which is implicit in many of the other figures. The emergent central square in Figure 8f, produced by five students, is noteworthy since it shows an attention to form; this figure was then generalized as shown in Figures 8g and 8h, which correspond to Figure 6g. They show that many students and cartographers preferred to include redundant points to pick out a petal shape and ignore the level two symmetry. Two people, one of whom had produced Figures 5a–5c, explored the spatial coverage of the figure (Figures 8j and 8k) and then provided stylized abstractions with centrelines. The drawings, which had been discarded by two cartographers, were a cross between Figures 7d and 8j. One of them told the author that she tended to explore patterns using curves and that she found it difficult to fit curves to the level two teragon. Although the symbolic shapes are distinctly different, they too have segmented the figure as in Figures 8b–8h. The subjects were tending to ignore the low-level rectilinear pattern (which made them think of pixels in remote sensed images) and were focusing more on the overall pattern which has a four-winged shape.

SOME IMPLICATIONS OF THE OBSERVATIONS

The results indicate that the art of line generalization is not entirely intuitive and impenetrable. They suggest some of the types of assumptions and cognitive processes responsible for the variations in output in this case study; for example:

i) Despite reassurances to the contrary, there was an initial assumption that there must be a correct answer and that the exercises had been designed to reveal the level of knowledge and competence of respondents. There has been much more interest in the study now that the participants have grasped the difference between deconstruction and generalization and see the study as probing the various cognitive processes involved in manual generalization.

ii) The majority of participants were tending to see the closed curves, with or without a bounding box, as an object — i.e. the figure as opposed to the background. Only one cartographer also analyzed the figure in terms of spatial coverage, on the one hand, and typifying skeletons at the other. Although cartographic training covers figure-ground relationships and centrelining, the results suggest that most cartographers are selecting a preferred strategy for analysis at the outset. If further tests confirm this, cartographic training should perhaps emphasize different approaches to encourage lateral thinking.

iii) Having 'seen' the pattern as figure, there is a tendency to ignore the original partition planes and orientation of the four-fold symmetry. The spatial coverage of the figure, which was consciously explored in Figure 8i, induced a rotation of the pattern.

iv) There was also a very strong urge among some cartographers and students *to mentally map* the seen figure onto known prototypical forms of objects; i.e. to objectify the figure. Nouns, such as roads, islands, lake, built-up area, woodland, wings, cross, and swastika, were used in written and verbal descriptions; reference was also made to segmented remote sensed images and to roads. Such semantic labelling could have been induced by the normal practice of selecting a generalization that was appropriate for a given object. The psychologist Rubin reported in 1915 that we have a tendency to see objects — not the retinal patterns. We see objects even in clouds and in ink blots. The Rorschach ink blot personality test is based on the assumption that perceptual and personality differences tend to affect what we see. Here previous experience is another factor.

v) The process of recognition appears to involve the *mental projection* of the prototypical object shape onto the figure, leading to a biased view of the latter, especially in Figure 8h.

vi) Equally, the conscious rejection of the rectilinear outline (Figure 8a) in favour of the overall shape of the figure, especially in the case of the level two teragon, indicates a capacity to review the output and try another object or form.

vii) Those who rejected the rectangular pattern in Figure 5a noted that it violated the give and take rule in cartography. They preferred some of the wing shapes in Figure 6 because they articulated this rule. Cartographers appear to be using this rule to track the loss of symmetry.

viii) Curiously, it appears that the tendency to see a known object involves a disregard for certain types of symmetry and this is especially evident in Figure 8. Figure 6g and Figure 8 show a tendency to place much greater emphasis on the shape of the extruding parts rather than on the detail in the centre. This involves a disregard for the level two symmetry that is particularly noticeable in Figures 6g and 8h.

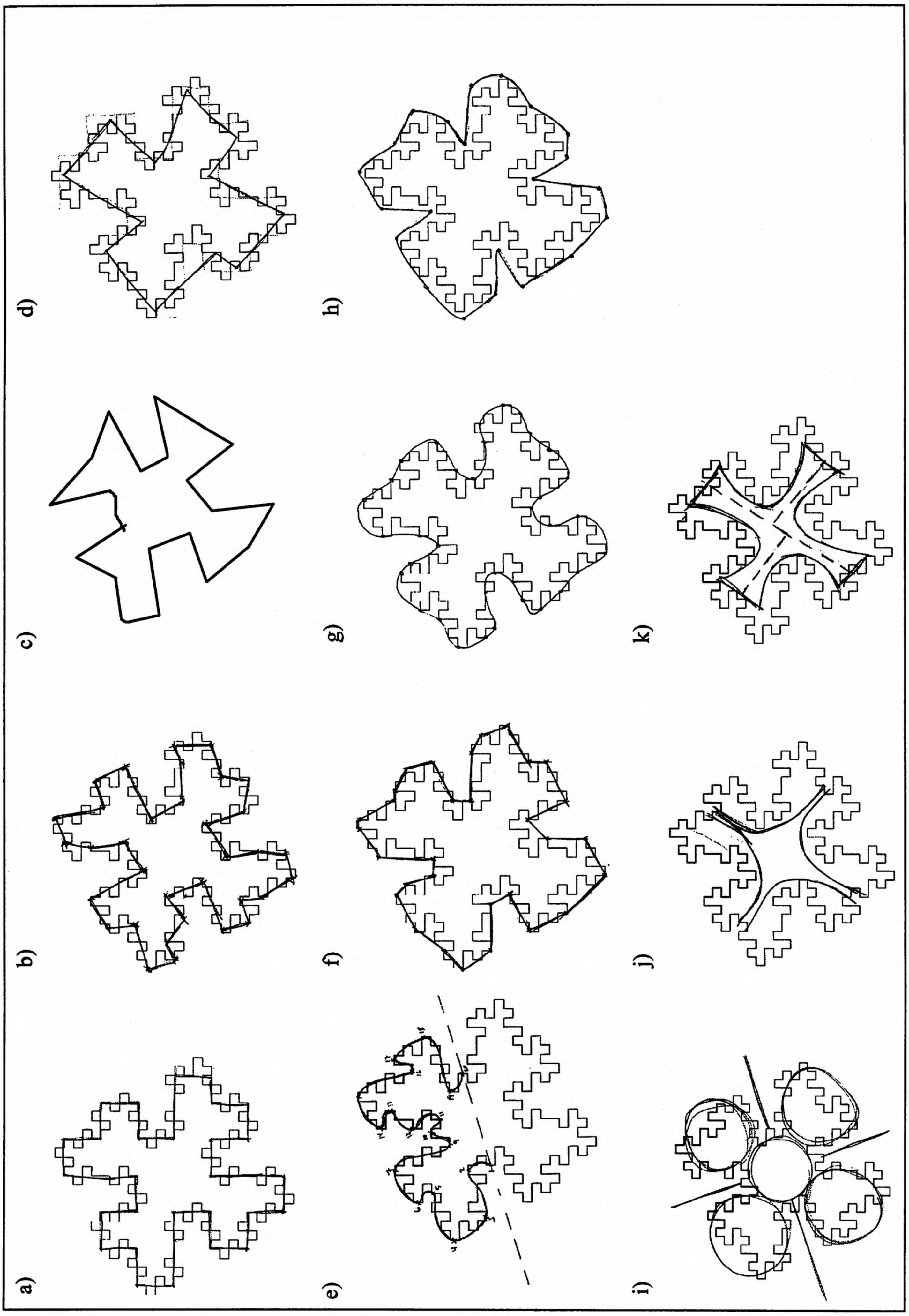

Figure 8. Patterns emerging from Teragon 2 (see Table 2)

ix) Some people were undertaking scale independent generalization while others were thinking in terms of scale-dependent reduction (Figures 5d and 5e, 6g and Figure 7). Both approaches are valid. However, several of those who assumed a scale reduction not only exaggerated the area of the figure but also used many superfluous points in the extruding parts at the expense of the inner parts.

x) This lends weight to the psychological presumption that figures may be segmented at their inner concavities; for example, outlines of a person and of an aeroplane can be segmented into their component parts using this approach. Figures 6g and 8h, for instance, could be segmented at the apex of the central V-shape into four petals. However, the perception of open curves, such as coastlines, may not be biased in favour of identifying the extrusions and needs to be tested. Even here, the line would be segmented differently if the main aim was to show its extent.

xi) The lack of preservation of the two-fold level two rotational symmetry may be due to innate distortions in perception and not necessarily due to the conscious use of recalled prototypical object forms. During the review process two professional cartographers, who thought they had returned Figure 6d, offered new information when shown Figure 4. They stressed that it took repeated meticulous checks and conscious effort to preserve the four-fold symmetry. To their surprise, in their initial attempt at abstracting the four-fold symmetry they had only drawn similar, and not identical, shapes. On closing the curve, they realized that the first and last parts were not identical (as in Figures 4c, 4d, 6c, and 6f). They had thought that they were drawing the same pattern. It was only at the stage of self-review that they had noticed the lack of identity, which prompted them to enforce the symmetry at the edit stage prior to handing in the figure. One person suggested that her output might have been different had she rotated the paper as she worked around the curve but was uncertain as to which specific wing-shape she would have chosen.

There are two factors that may be biasing their perception, namely the orientation of the parts and the involuntary switch of figure and ground. Visvalingam (1996) and Visvalingam and Brown (1999) demonstrated that the triadic Koch curve had its counterpart in the Cesaro curve. It was quite obvious that the orientation of the geometrically identical shapes (e.g. when the paper was rotated) made them appear different. Figure 4d and, to a lesser extent, Figure 6d have orientation dependent shapes. It is interesting that, unlike professional cartographers, students do not appear to have engaged in self-review and edit.

In addition to the orientation-induced perception, there may also be some difficulty in holding a consistent mental image of the figure-ground classification. It is well known that given an ambiguous figure, the brain does not settle for a single interpretation but tends to involuntarily switch between two visual interpretations as it does with the Rubin and Mach figures (Gregory, 1970, p. 16 and p. 38). Here, there are three factors that may be facilitating the switch — the linear symbolism, the repeating pattern, and local focusing. The perception may have been more stable had the 'island' been shaded. In this context, it is noteworthy that several participants at the 1998 Annual Symposium of the British Cartographic Society at Keele said that they found the up-side down maps of Britain (USDMC, 1998) very disconcerting. It was obvious that there was a need to recreate a mental map of the place in much the same way that one has to consciously learn to use a new keyboard with a different layout.

Even impossible pictures showing normal objects, such as those drawn by Hogarth and by Escher, have to be carefully analysed to detect logical inconsistencies since the eye does not immediately perceive these. When working on the line, people were tending to focus on local sections of the line. The output shape is inevitably dependent upon the shape and orientation of the segment of line being processed, which could also be inducing figure-ground reversals. Where the figure had not been consciously partitioned into identical segments, there would be a tendency to output only similar shapes. Trained cartographers rely on holistic vision and systematic comparisons during the 'standing back' stage to adjust their tentative shapes, which may have been only similar, into symmetrically identical ones. The behaviour of learners may be suggesting that such evaluative techniques are acquired rather than innate; equally it may be reflecting the fact that professionals work much faster than students, who may not have had enough time for evaluation of their drawings.

xii) The results also show that students have a distinct preference for curves while some cartographers are happy to render edges connecting points. The reliance on computer software for fitting curves has already been noted.

xiii) Individuals tended to stick with a strategy which proved to be successful in Exercise One. They may have covertly explored other approaches for Exercise One and it is hoped that group discussions will provide more information.

xiv) Although several participants were suspicious that there was perhaps a right answer, which they were missing, the results confirm that there are several equally valid deconstructions of the given line. Not all of these patterns, including Figure 5a, can be derived using existing line deconstruction algorithms. Although the offset cross in Figure 5a was initially rejected by the cartographers at Reading, some two years later, some cartographers felt that it was the best abstraction. It looks as if the rectilinear pattern may have been biasing recognition after all. If the figure had been interpreted as a road, it would make sense to drop the smallest branch. Although there were two equally sized branches, the Gestalt law on continuance may be justifying the elimination of the orthogonal branch. This constitutes a form of bend simplification.

However, neither the *bendsimplify* algorithm (Wang and Muller, 1998) nor its ArcInfo implementation can provide this abstraction (Visvalingam and Herbert, 1998). Also, given teragon two, the bendsimplify algorithm outputs distorted figures that do not resemble any of the manual deconstructions. There is thus a continuing research opportunity for identifying additional line generalization algorithms. As pointed out by Brassel and Weibel (1988), significant advances in the design of generalization algorithms for segmenting and structuring lines.

RESULTS FROM A SECOND ATTEMPT

Some eighteen months after the initial attempt at Reading, members of the BCS Design Group re-did the exercises. Only nine members returned their work. With the exception of one person, a computer specialist, all the others were cartographers by profession.

With Exercise One, five of the respondents chose wing patterns (Figure 6a–d). The wing shapes were still not necessarily identical in the four parts, showing the difficulty that people have in switching between holistic perception and local processing. Four of the five people in this group used mid-points as in Figure 6d. One person switched to Figure 5a, stating that it was a better representation, which used existing points to maintain the shape of the figure. Two others opted for this figure initially but felt that it should be adjusted to that in Figure 5d to balance the give and take and preserve the area of the figure. Another person, who started off with Figure 7b changed to Figure 5e — both of which place emphasis on the extent of the figure.

When it came to Exercise Two, two individuals stated that they could not visualize the degree of generalization required at all and that it was easier to see the form from a distance. The rotated shapes they produced corresponded to Figure 8b. In all, seven people rotated the figure. Four of them then smoothed their patterns with curves as in Figure 8g, saying that point filtering made the figure too angular. One of the figures in this set of seven was particularly interesting since it consisted of a rotation of Figure 8a. None of the figures lost sight of the level two symmetry as Figure 8h did. Two other cartographers reproduced Figure 8a. Mary Spence (written comment) said that she was 'trying to keep the shape, orientation and square character of the feature — area is OK too'. Places where she had re-worked the line indicated conscious application of the give-and-take rule.

PEER DISCUSSION

There were seventeen participants (excluding the author) at the Glasgow meeting; seven of these were professional cartographers and the rest were students. After a presentation of the material above, the questions in Table 3 were used to spur discussion.

The participants were unsure as to whether they consciously manipulated the priorities of cartographic rules during their intuitive generalization and abstained on Q14. Indeed, practising cartographers have questioned the value of rules and guidelines in design (Collinson, 1997). The extracts from individual responses indicate that several considerations were being consciously evaluated and balanced. Although, this experiment was not successful in extracting a statement of priorities, there is clear indication that many cartographers consciously apply the give-and-take rule during the evaluation phase, even if not during the construction phase (Q5 and individual responses). The output of students and their unwillingness to vote on some questions, such as Q5, indicate that the give-and-take approach is not in-born and intuitive but that it is acquired through training and/or experience. The students also abstained from Q9 and did not fully understand what figure/ground switch alluded to, suggesting that this is also learnt. However, they did feel that it would be easier to maintain a stable view of the figure if it has been area-filled. Both cartographers and students tended to re-use proven strategies (Q13).

There was unanimous agreement that there is a tendency to see a closed curve as the figure (Q1) and to objectify it (Q3), even if not everyone felt that the gridded outline should be ignored (Q2). Here, teachers of cartography felt

	There is a tendency to:	Yes	No
Q1.	See closed curves as figures	17	—
Q2.	Ignore its gridded outline and orientation, having seen the figure	13	3
Q3.	Objectify figure — e.g. road, petal	17	—
Q4.	Try different objects and shapes — e.g. island/road ⟶ petal/wing	15	1
Q5.	Make conscious use of give and take rule	7	1
Q6.	Focus on extruding parts of figure	11	6
Q7.	Use redundant points when showing extent rather than structure (see also 6)	3	13
Q8.	Lose sight of the symmetry when working on parts of the line. Why?		
	• Orientational bias	11	—
Q9.	• Tendency to switch between figure and ground	6	—
Q10.	Would area-filling of the interior help?	11	4
Q11.	Have a preference for curves	6	8
Q12.	Rely on software for fitting curves	12	3
Q13.	Re-use previously successful strategies	14	—
Q14.	Assign priorities to cartographic rules. Which?	—	—

Table 3. Votes Taken in November 1998 at Glasgow University

that while non-cartographers may be looking to make a shape, cartographers would (perhaps as a result of training?) distinguish between point, line, and area objects rather than the real world objects, such as woodlands and roads. At the same time, it was pointed out in response to Q11 that the approach adopted would depend upon whether the feature was man-made (angular buildings) or natural features (which would be represented by curves). The evidence to date, however, suggests that both cartographers and students are both inclined to objectify (invoke prior knowledge) before selecting geometric symbolism. The latter are more capable of thinking in terms of abstractions as evident especially on the second attempt (see also Q4). The danger of objectifying was also pointed out using the case of administrative areas where both regions belong to the background. But, to date, only one person consciously explored space usage.

There was strong support for the observation that there is a tendency to focus on extruding parts (Q6), although the evidence and the votes show that experienced cartographers and some students are aware of and watch out for this perceptual bias. There was disapproval of the use of redundant, and especially of new, points (Q7).

The biased introduced by orientation was confirmed (Q8). One cartographer wondered whether people would have made a conscious effort to maintain the elements of symmetry (for example, by rotating the figure) if this had been pointed out at the outset; but, see xi in Some Implications of the Observations, above.

DISCUSSION AND CONCLUSION

In this collaborative research, undertaken by the BCS Design Group, participants were encouraged to deconstruct (produce meaningless forms) which best represented the patterns, represented by the two simulated lines. Line generalization algorithms can generate a wide variety of patterns given the same lines (Visvalingam and Brown, 1999). The initial aim of the research was to discover whether cartographers would produce more consistent deconstructions. The research was open-ended and exploratory and was not hypothesis driven. The results show how the manual deconstruction of lines can be even more variable. Although the semantics associated with natural lines tend to bias consensus towards specific line structuring schemes, the output of different individuals does vary. This suggests that like generalization algorithms, schemes for line structuring may not be universally applicable either and that there would be a requirement for context-dependent techniques.

The results also highlight the type of value added by cartographic training. The observations may be no more than anecdotal since the sample size is limited but they suggest a) a need for establishing a formal framework for teaching self-evaluation, and b) techniques which could be taught to enhance creativity.

The extracts from individual responses indicate that several considerations were being consciously evaluated and balanced. This suggests that different cognitive processes may be engaged during construction and evaluation as in other creative tasks, such as writing and painting. The 'standing back' during the planning and evaluation stages is not being maintained during the enacting stage. Unlike construction, which could be intuitive and right-brained, planning and evaluation tend to be logical left-brain processes. All output patterns of deconstruction may be regarded as equally valid. Although, this experiment was not successful in extracting a statement of priorities, some patterns were regarded as more appropriate than others. For example, there was a rejection of over-generalized figures (8c–8d) and those which included redundant points (especially Figures 7a, 7b and 8h). This was differentiated from the more acceptable fitting of curves to a non-redundant set of points. The loss of symmetry (i.e. structure) in some of these figures also caused concern. It was also felt that the convex forms (Figures 7a and 7b) would be replaced normally by centred symbols, such as circles. It looks as if the above types of variability in students output was being discounted as not adhering to cartographic principles.

Visvalingam and Whyatt (1993) and Wang and Muller (1998) noted that line generalization is characterized by bend elimination. Yet, the need to retain the symmetric structure of the figure was emphasized to the extent that Figure 5a (bend elimination) was abandoned in favour of Figures 6a and 6d. As noted earlier, this shows a tension, caused by an absence of contextual knowledge, between preservation of structure and the overall shape. Those who opted for bend elimination found this difficult in Exercise Two. Equally, many had difficulty in assessing the structure of teragon two. Figures such as 8i–k, like Figures 5b and 5c, show some types of techniques which could be adopted for exploring structures. The output of algorithms (Visvalingam and Brown, 1999; Visvalingam and Herbert, 1998) can also be helpful since a comparison of the options they present can provoke the student's powers of judgement and creative response.

Many cartographers and students were able to abstract Figures 8a, 8b, 8f, and 8g without explicit analysis of the structure by relying instead on other techniques, involving extreme points or the give-and-take rule during evaluation, even if not during construction. Figures 8a and 8b may be regarded as the basic decogons from which the other stylized versions may be derived by further filtering, fitting of curves, and skewing the symmetry. Both these patterns have a similar shape but they differ in orientation. Figure 8b and derivatives emphasize coverage — they retain the extreme points on the extruding and intruding parts. Indeed, this forms the basis of the Douglas-Peucker algorithm which produces a rotated four point pattern in Figure 3. It also outputs a version corresponding to Figure 8b as one of twenty-four decogons for Teragon two (Visvalingam and Brown, 1999). Visvalingam and Whyatt (1990) noted how the retention of extreme points can distort shape. Figure 8b and the output by this algorithm (in Visvalingam and Brown, 1999) do not balance give-and-take, nor retain the angular corners or the similarity of bends. Yet, this was a popular choice even if it looks as if curves have been fitted to mask such distortions (Figures 8g and 8h).

Figure 8a, like Figure 6a, could be arrived at by application of give-and-take. However, the give-and-take idea, has been applied quite differently by different people.

For example, it can be applied to Figure 5a to derive either 5d or 7d. It is difficult to define algorithms for such creative applications of give-and-take. Also, unlike holistic, top-down structure-based deconstruction, it can be applied locally to dissimilar sections of the line, resulting in unbalanced and clumsy shapes. Such inconsistencies may be regarded by some as falling within the realms of drafting, which is increasingly being replaced by software. However, this requires schemes for partitioning lines. It looks as if the use of curves, even when trucating features, has masked the need to explicitly study this problem in manual cartography.

Algorithms developed within Artificial Intelligence, for segmenting curves at their concavities (Hoffman and Richards, 1984), tend to suggest different segmentations for figure and ground. Plazanet (1995) and Wang and Muller (1998) draw on this work. While the basic analysis of a line into convex and concave sections may be correct, the complex Bendsimplification system seems to be flawed (Visvalingam and Herbert, 1998). It was hoped that people would see teragons more consistently and that this would inform the further development of algorithms. The evidence is that there is even greater variation in the cartographers' deconstruction of fractals.

If we ignore the variations introduced by a) inattention to detail during drafting, and b) lack of adherence to cartographic principles, variations in deconstruction initially appear to depend upon perceived tensions between the preservation of structure versus shape. However, where the structure is not grasped, there appears to be a reliance on geometric heuristics, such as give-and-take, which ignores the semantics of the line, or on coverage and extreme points (which offer scope for mental projection of pertinent objects, often exaggerating the figure).

These observations suggest the following tentative conclusions (the text in parenthesis provides the type of information on which specific conjectures are based).

1. Cartographic Training Appears to be Fostering:

- *A tendency to assume semantic meanings and engage in semantic labelling* (written comments). This tendency *to map* occurs because the practice of generalization is knowledge-based. This facilitates recognition and exploits the psychological tendency to re-use (mentally project) previously successful solutions when facing new problems.
- *An awareness of the compromises arising from the application of different cartographic guidelines and the need to make choices*, e.g. preservation of the orientation and rectilinearity versus the need to give and take; or, emphasis on structure versus shape and/or coverage (written comments).
- *The awareness of distortions in subconscious perception*, for example, figure-ground reversal — see below (review of output with individuals).
- *Active self-monitoring, review and editing of output, including semantic re-labelling* (review of output with individuals).

2. Potential Distortions Arising From a Perceptual Tendency:

- *To focus on extruding parts and to morph the shape to fit the mentally projected form* (output).
- *To see shapes differently on close scrutiny and on taking a holistic view when standing back* (personal discussion). This could be due partly to orientation and partly to figure-ground reversals; the holistic view takes the island to be the figure, but this classification need not be maintained during local processing.
- *To emphasize the features that continue rather than change direction.* This is well known but was not explicitly stated by respondents.
- *To initially reject figures to which there is an adverse muscular reaction impressing itself as a negative feeling* (personal communication). The offset cross was said to be disconcerting.

3. Some Potential Inhibitions to Creative Cartographic Visualization:

- *An assumption that there must be a preferred singular solution especially among students* (general verbal articulation). This may have been induced by training.
- *A psychological predisposition to see a closed curve as figure and not ground* (output).
- *A tendency to re-use solutions (forms).* The re-used forms suggest that there is a tendency to re-use (mentally project) known patterns, not necessarily known objects. This may be indicating a re-use of successful strategies without attempting to explore other strategies to discover new possibilities.
- *Over-reliance on software and work-related* (verbal articulation by non-respondents conditioned to fitting curves).
- *Lack of experience in analysing and evaluating potential structures potential structures and outcomes* (output). Such observational skills could be developed using different algorithms to generate output from contrived lines.

When these results were shown to participants some two years later, they were surprised a) at their initial subconscious behaviour and subsequent change of mind, and b) at the need to monitor subconscious perception-induced behaviour and consciously apply visual logic based on common sense and cartographic precepts. This shows the value of adopting a variety of techniques for knowledge elicitation, such as introspection and thinking aloud on paper, individual retrospection, peer review and dialogues on the psychological and 'cultural' origins of their overt behaviour. These individuals were also interested in the way some of the others had approached the exercises and amazed at just how much even this small set of results revealed about their own inner cognition. This experiment shows that the art of generalization is not entirely intuitive and inscrutable.

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