

An Experimental Approach to the Design of Cartographic Symbols

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SUMMARY

Graphic designers and an experimental psychologist worked together to improve the design of two map symbols which are frequently confused: the symbols for cuttings and embankments on topographic maps. The problem was analysed in terms of the function of the symbols and their likely cognitive representations. Tests were developed to evaluate alternative designs, including an intervisibility task which required users to visualize the landform from the symbols viewed in the context of a map. Tests were given to schoolchildren and to experienced map users in order to compare the standard symbols with five alternative designs. Children's performance was strongly affected by the symbols they used, but experienced users were much less affected. After some refinement of the symbols a further experiment demonstrated the superiority of a number of alternative designs over the existing symbols on a range of tests: scores were almost double on the intervisibility task. The paper makes recommendations to cartographers and argues for greater consideration of the inexperienced map user in the design process.

This paper describes a research project to improve the design of two symbols which frequently cause confusion on maps. Several graphic designers and an experimental psychologist worked together on the project, and we argue that more was achieved cooperatively than either discipline could have achieved working alone.

There are a number of difficulties in successfully conveying meaning through symbols. Unlike language, there are not many well-defined conventions, and understanding rests on a plethora of learned associations which may vary with age and culture.

The design of symbols for maps must take account of a number of factors: they need to be understood internationally, they must be discriminable from each other, they need to achieve the correct impression of prominence, and they must occupy only a small space on a crowded map. Although there is a small literature which considers map design in terms of map reading performance (Phillips, 1979), this approach is not usual in revising cartographic symbols.

THE PROBLEM

Informal enquiries suggested that a number of map readers have difficulty in distinguishing cutting and embankment symbols on Ordnance Survey (OS) topographic

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maps. A *cutting* is where a road or railway passes through an excavation, taking it below the level of the surrounding ground. The opposite of this is an *embankment*, which raises the road or railway above the level of the surrounding land.

To confirm the confusion between the symbols, Figure 1 was shown to 102 university undergraduates studying a wide range of subjects. They were asked to say which symbol represented a cutting and which an embankment. Seventy-two per cent were correct and 28 per cent incorrect. Some of those who were incorrect may have chosen at random, and it follows that a roughly equal number should be correct by chance. Therefore we can say that somewhere between 28 and 56 per cent of undergraduates are unable to correctly distinguish the symbols. Undergraduates who had passed the A-level geography examination were only slightly better than those who had not: 78 per cent were correct on the test.

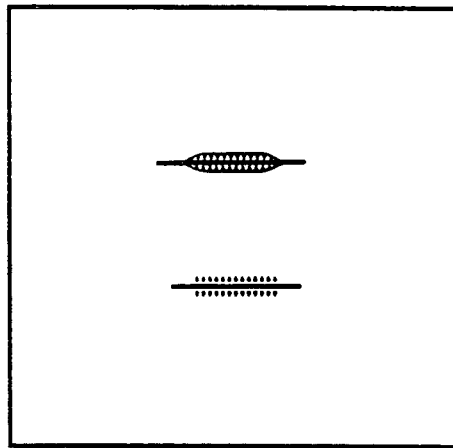


Figure 1. The ^{lower} symbol represents a railway embankment and the ^{upper} symbol shows a railway cutting as they are depicted on Ordnance Survey 1:50,000 maps.

The symbols misled undergraduates, and it is probable they mislead people in general. If we had shown the symbols in the context of a map, rather than in isolation, performance would no doubt be a little better, as all sorts of contextual clues are provided by a map, but because the map reader cannot rely on the presence of contextual clues, the symbols seem to be in need of improvement.

An examination of a large number of topographic maps from different parts of the world suggests that the symbols shown in Figure 1 are in wide use with only small variations in drawing style from country to country. The symbols are composed of a number of *hachures*. The hachure is a wedge-shaped symbol normally placed so that the narrow end of the wedge points downhill. Hachures developed as a means of depicting relief on maps engraved on metal plates, and were the most popular method of showing the shape of the landform in the nineteenth century.

NEW SYMBOLS

Our task was to devise new pairs of symbols which we hoped might be an improvement on the existing symbols, and to carefully test these using realistic map-reading tasks. It is frequently said that good design is the business of producing something which is well matched to its purpose. This is a difficult principle to apply in designing maps

because the cost of map production often means that the same map must be used by many different users and for many different purposes. Despite this difficulty our primary consideration was to match design to function.

Our first approach to designing new symbols was to consider the likely cognitive representations. In visual or spatial terms a cutting is something which goes down, which is shadowy and inconspicuous. In contrast, an embankment goes up and is conspicuous to a distant observer. From the point of view of a railway passenger a cutting blocks visibility of the surrounding landscape, whereas an embankment improves it. The representation may optionally be linked to the verbal labels 'cutting' and 'embankment', although of course it is quite possible for someone to recognize and visualize the features without knowing their names.

A number of approaches to symbol design were discussed. The main problem with the existing symbols is that they are confused with each other, but it was clear that in putting this right there was a danger of making the symbols inefficient in other ways, for example by increasing their confusability with other symbols on the map. Perhaps the most salient difference between a cutting and an embankment is that the former dips into the ground whilst the latter rises above it, and so we began by considering which monocular depth cues could be exploited to show this difference.

Despite the number of depth cues catalogued by psychologists (e.g. Gibson, 1950), these are only rarely incorporated in map symbols which portray relief. For example, one of the most effective general methods of depicting relief is layer tinting (see Phillips, De Lucia and Skelton, 1975) where height is shown by a progression of coloured tints, but this employs no recognized depth cue. Contour lines also have no basis in depth cues, although it is possible that misapplied depth cues could explain some of the difficulties in interpreting them (Griffin and Lock, 1979, Underwood, 1980).

We too found depth cues of only limited value in devising symbols; and so we explored alternative ways of portraying 'up' and 'down'. There are a number of possibilities including the use of simple pictures and an exploitation of the figure-ground relationships produced through graphics.

Following prolonged discussions we devised more than 30 pairs of symbols based on depth cues, pictorial representations and other approaches. With careful selection

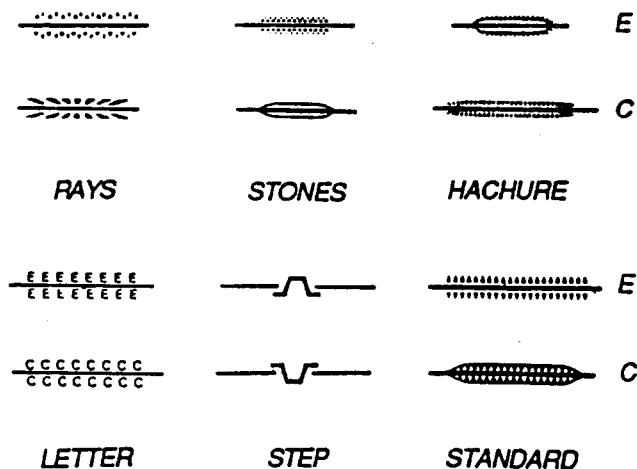


Figure 2. The six pairs of symbols tested in Experiments 1 and 2.

we narrowed our choice to five pairs of alternative symbols, which are illustrated in Figure 2 together with the *standard* symbols.

EXPERIMENT 1

Tests

A number of tests based on realistic map-reading tasks were developed. We considered it was important to try to avoid tasks that depended on knowledge of the words 'cutting' and 'embankment', and to ensure that some tasks tested the symbols in the context of a map. An intervisibility task (question 3 below) came closest to meeting these requirements, although this was only one of a range of tasks employed.

Subjects and design

The subjects were 99 girls aged between 11 and 13 attending a London school. Approximately equal numbers were assigned at random to each of the six pairs of symbols which they used on all questions, except for the last question which tested all six pairs.

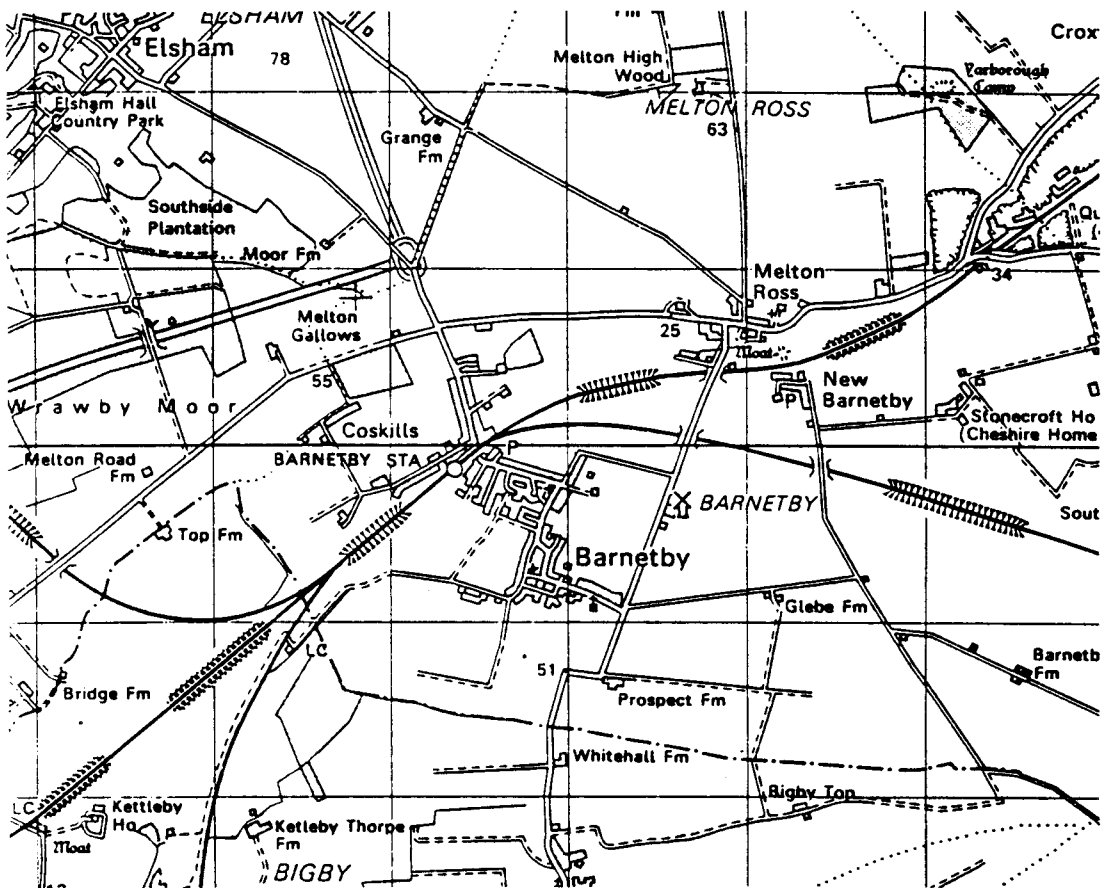


Figure 3. Part of one of the maps used in the experiments. This example shows the *light cutting* symbols tested in experiment 3. (Based on a 1:50,000 OS map. Crown Copyright © 1975.)

Maps

An area measuring 153 by 214 mm was adapted from the outline edition on a 1:50,000 OS second series map. This depicts a rural area in England. The map is printed in black only and does not include contour lines. Some extra railway lines were added so that the map shows six railway cuttings and six embankments. These were all placed where there was no clue from other map symbols as to which was which. A separate version of the map was prepared to a high graphical standard for each of the six pairs of symbols (see Figure 3).

Procedure

The girls were tested in the four groups normally used for geography teaching. The purpose of the tests was carefully explained and the need to work quickly and accurately was emphasized.

Question 1

Question 1 used a page similar to that shown in Figure 4. The words 'cutting' and 'embankment' were explained with the aid of the pictures. The girls were told that the symbols shown below the pictures were new map symbols which they would not have seen before. They were given one minute to guess which was which, and label the

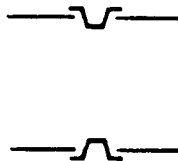
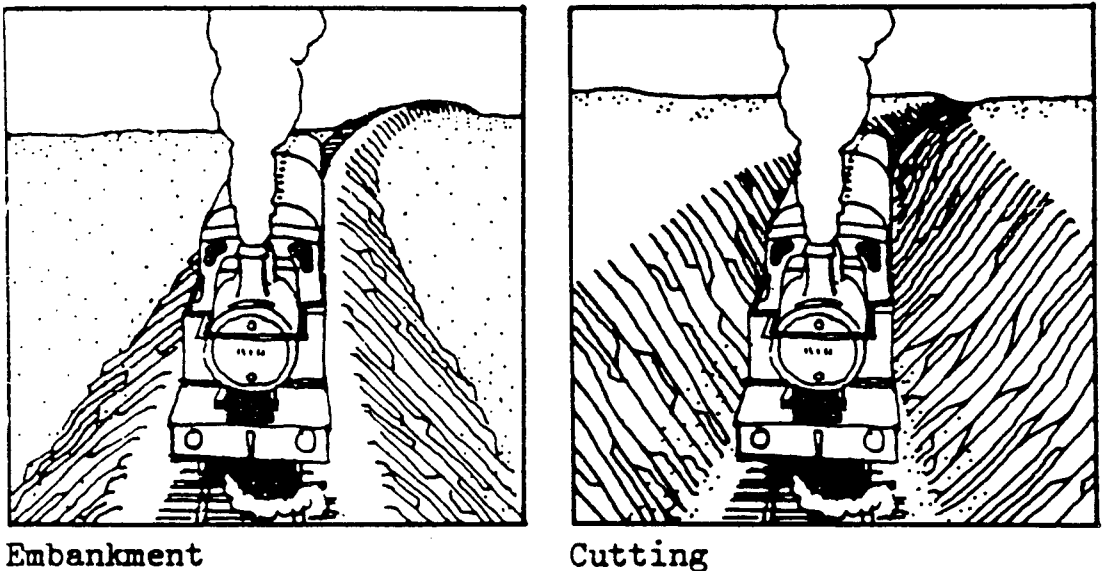


Figure 4. An example of a page used for question 1. In this example *step* symbols are shown.

symbols 'C' and 'E'. On half the sheets the correct cutting symbol was in the upper position, and on the other half the positions were reversed.

Sheets for question 1 were exchanged for booklets and the girls were told to look at the first page. This was similar to the previous sheet except that the symbols were clearly labelled 'Cutting' and 'Embankment'. They were given half a minute to look at these and try to remember them.

Question 2

Question 2 was a series of short questions to be answered with the map. The locations *A* to *E* were clearly marked on the map with green letters and crosses. The questions were:

1. What is the total number of railway cuttings and embankments shown on this map? ___ cuttings and embankments.

For the remaining questions imagine you are on a train travelling from *A* to *E*.

2. How many cuttings would you pass through on your journey?
3. How many embankments would you pass over on your journey?
4. After you leave *A* do you first come to a cutting or an embankment?
5. Would you get a better view from *B* or from *C*?
6. A man is standing at *D*. Would you be able to see him as the train passes by?
7. Just before you arrive at *E* do you pass through a cutting or an embankment?

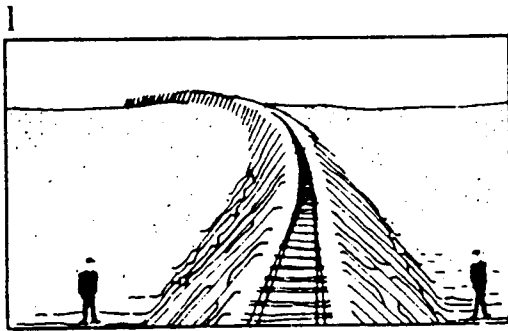
A minute and a half was allowed to answer as much as possible. The question was scored by counting the number of correct answers: this method of scoring, which is also used in question 3, follows a suggestion by Poulton (1965) for increasing sensitivity by combining the effects of subjects' speed and accuracy into a single measure of performance.

Question 2 is a cocktail, testing a mixture of skills including visual search. It is dependent upon an understanding of the words 'cutting' and 'embankment'.

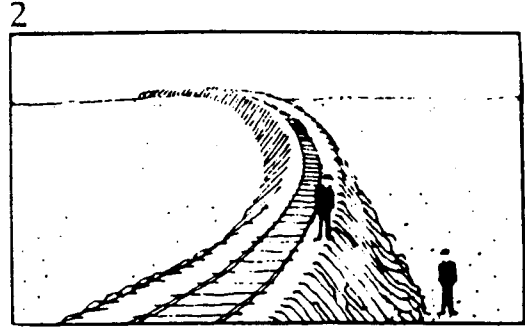
Question 3

Using the four pictures shown in Figure 5 the girls were asked to imagine that the railway is being repaired by a team of railway men working in pairs at different places along the track. They were asked to decide, for each pair of workmen, whether or not the men would be able to see each other from where they are standing. Each man is either standing on the railway or some way from it. They were then told that they would have to work along the map from the letter *A* to *L*. Next to each letter was a pair of crosses representing the position of the workmen. They were told to decide whether or not each pair could see each other, and to write either 'Yes' or 'No' in the space provided. The twelve items (*A* to *L*) represented the four situations shown in Figure 5 three times each. The letters and crosses were overprinted on the map in green. The time limit was 90 seconds and the score was the number of correct responses minus the number incorrect.

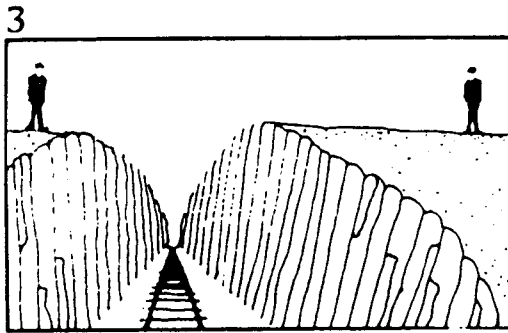
This intervisibility question tests a narrower range of skills than question 2. To



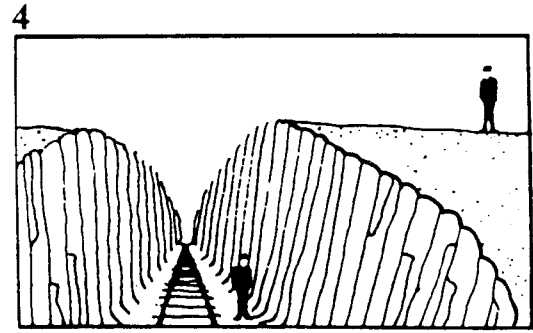
They cannot see each other.



They can see each other.



They can see each other.



They cannot see each other.

Figure 5. These pictures were used to explain the four situations to be identified in the intervisibility task (question 3).

answer it, it is necessary to visualize the situation from the symbols, but knowledge of the words is not needed. For a discussion of the validity of the concept of mental imagery in map reading see Eley (1983).

Question 4

Next the girls spent 3 minutes doing some pencil mazes before proceeding to question 4. This was identical to question 1 and was included to check whether, after the change of activity, they could still remember which symbol was which. The page was similar to Figure 4, but with the position of the two symbols reversed.

Question 5

Finally they turned the page to question 5. All 12 symbols were shown in one of two random orders, and the children were asked to guess whether each symbol was supposed to represent a cutting or an embankment, marking it 'C' or 'E'. Sufficient time was allowed for everyone to finish this question. This last question was intended to provide a rough indication of how well each symbol worked individually, rather than as one of a pair.

Results

Table 1 shows the means for each pair of symbols on each question. Apart from question 5, each mean is from an average of 16 subjects. Means for question 5 come

Table 1. Mean scores from Experiment 1 (and in parenthesis from Experiment 2)

Question	Type of symbols						Maximum
	Rays	Stones	Hachure	Letter	Step	Standard	
Q1*	71% (100%)	31% (78%)	81% (89%)	79% (100%)	82% (100%)	50% (100%)	100%
Q2	2.7 (3.4)	3.4 (4.2)	2.9 (3.8)	2.2 (4.4)	2.1 (4.7)	2.8 (3.2)	7
Q3*	4.2 (8.8)	0.5 (7.0)	1.8 (9.6)	5.8 (7.6)	6.2 (9.1)	3.2 (7.1)	12
Q4	78%	69%	71%	100%	71%	54%	100%
Q5 Cuts.	72% (73%)	44% (84%)	70% (88%)	85% (94%)	74% (96%)	55% (92%)	100%
Embs.	65% (92%)	63% (88%)	52% (90%)	87% (100%)	71% (96%)	70% (85%)	100%

* $p < .05$.

from all 99 subjects. One-way analyses of variance were carried out on questions 2 and 3, but only question 3 was significant ($F(5,93) = 2.5, p < .05$). For the binary data from questions 1 and 4, chi-squared tests were used. Only question 1 was significant (chi-squared (5) = 14.9, $p < .05$).

On question 3 a Duncan's Multiple Range test showed that the lowest mean differs significantly ($p < .05$) from all the others, and the highest mean also differs significantly from the second lowest.

Discussion

In question 1 the two symbols were seen in isolation and subjects had to say which was which. Subjects were at chance level on the *standard* symbols and this confirms the difficulty found previously with these symbols. Four of the experimental pairs of symbols produced a performance above chance level, even though these were symbols which they had never seen before. But the *stones* symbols were below chance level, suggesting a tendency for subjects to interpret the symbols in the opposite way to that intended.

Question 4 repeated the procedure in question 1 unexpectedly, after a distraction task. All the experimental symbols produced a performance above chance level with almost perfect discrimination of the *letter* symbols. The *standard* symbols remained at chance level.

The results of questions 1 and 4 are not conclusive but they suggest that four of the experimental pairs may be discriminated more correctly than the existing symbols.

Question 3 tests the ability to make intervisibility judgements using the symbols in the context of a map. Three of the experimental pairs produced superior performance to the standard symbols but two were inferior. On a range test only the poorest-

performing pair differs significantly from the *standard* symbols. The *step* symbols produced the best performance with a mean almost double that for the *standard* symbols.

Question 2 was a mixture of short verbal questions. Although this is non-significant it is interesting to speculate why the *stones* symbols have the best mean on this question but the worst on questions 3 and 1. A possible explanation is in the first item of question 2, which involves visual search. This item was more difficult than expected and may have had a strong influence on the score. It required subjects to count the total number of symbols on the map and only 43 per cent did this correctly, although there were only 12 symbols to count. While the *stones* pair are hard to discriminate correctly, they may be the easiest pair to locate quickly on the map. This is supported by an analysis of the first item on question 2 which is statistically significant (chi-squared (5) = 22.0, $p < .001$) and shows the highest mean with the *stones* pair.

Search and location tasks require the use of peripheral vision to a greater extent than identification tasks, and so it is not surprising that different symbols should be optimal. Christner and Ray (1961) report a similar effect.

Question 5 is a crude attempt to see how difficult the symbols were to interpret in isolation. A pair of symbols may fail because just one of the pair is difficult to interpret: this may be happening with the cutting symbol of the *stones* pair and the embankment symbol of the *hachure* pair.

This first experiment is not conclusive, but it does provide valuable data to take the design process forward.

EXPERIMENT 2

Experiment 2 repeated the tests used in Experiment 1 on a much more experienced group of map users.

The experiment was conducted at a cartography conference. A single group of 50 was tested. These included representatives of national cartographic organizations, cartographers, surveyors, map librarians, and university geographers. The material and procedure was the same as for Experiment 1 except that the time limits for questions 2 and 3 were reduced to 1 minute. Question 4 and the maze problems were omitted.

The means are shown in Table 1; they appear in parentheses below the corresponding mean for Experiment 1. The same statistical tests used in Experiment 1 were applied, but none of these reached the level of significance.

The experienced map readers were predictably better at the tests than the children, but differences in map design had no detectable effect on performance. On the intervisibility task (question 3), the experienced map readers are well below the ceiling, but their means show considerably less variation than the schoolchildren's. The difference between the highest and lowest mean for the experienced users is 31 per cent of their mean, but for the children the difference is 170 per cent. The same effect is evident in the other questions, although a ceiling effect could be operating for the experienced map readers in questions 1 and 5.

Although our symbols were unfamiliar, and differed considerably both in their appearance and in the cognitive principles on which they were based, the experienced map readers used them with almost equal fluency. What seems to distinguish the

experienced and inexperienced users is not just better performance, but also a greater versatility in coping with alternative designs.

This greater versatility of experienced map readers is echoed in the finding of Gilhooly, Wood, Kinnear and Green (1988) about memory for maps. As well as demonstrating better memory for contour maps, the skilled map readers showed evidence of more specialist schemata in their verbal protocols.

DESIGN REVISION

With the data from both experiments available, we met again as a group to consider how to use the information to refine the symbols. The main conclusions we drew from the experiments were:

1. Our target user should be the inexperienced map reader. Experienced map users are capable of considerable flexibility in using alternative symbols and can look after themselves.
2. Ease of discrimination and ease of location are different factors. The *stones* symbols seemed to be the easiest to find but the hardest to discriminate correctly.
3. Although not conclusive, the results suggest that the *letter*, *step* and *rays* pairs may be easier to discriminate correctly than the *standard* symbols.
4. To convincingly demonstrate the superiority of new symbols, another experiment is needed with a rather larger number of subjects.

It appeared that several of the alternatives might be an improvement on the standard symbols. We went on to consider a number of factors which were not evaluated in the experiments. The *letter* symbols have an obvious disadvantage as they depend on knowledge of the English words. Both the *letter* and *step* symbols will almost certainly confuse users when a map is turned upside-down. They also fail to portray the length of a cutting or embankment. The *rays* cutting symbol may be good functionally, but it is so different from the existing symbol that it is almost certain to meet considerable resistance from the cartographic community: the most acceptable symbols would probably be those that were closest in appearance to the existing ones.

These additional considerations led us to consider a new pair of symbols based loosely on the *hachure* cutting symbol and the *stones* embankment symbol. As part of a pair, neither of these symbols performed well in the experiments, but the data from question 5, where the symbols were viewed singly, encouraged us to try to improve them by redrawing. After considerable discussion and graphic experiment we decided to test the five alternatives in Figure 6.

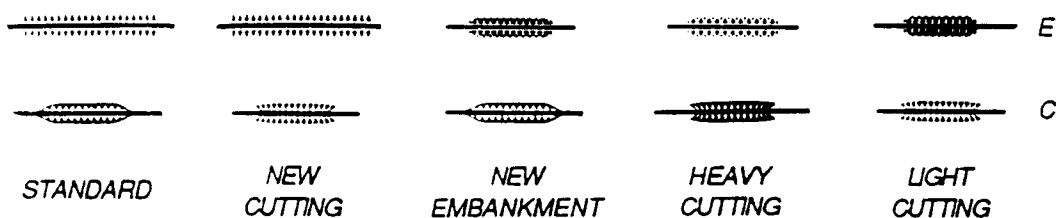


Figure 6. The five pairs of symbols tested in Experiment 3.

On the principle that cartographers are most likely to accept symbols that are close to the existing ones, we created a pair of symbols by combining the existing embankment symbol with our cutting new symbol to create the pair called *new cutting*. We also did the opposite combination to make *new embankment*.

We also tried two versions of our new pair of symbols. The *heavy cutting* and *light cutting* pairs differ just in their relative lightness and darkness. This arose from an issue we could not resolve without doing an experiment.

Which should appear lighter on the map—the cutting or the embankment symbol? As a kind of hole in the ground, we may think of cuttings as dark and shadowy, and so perhaps they should have the darker symbol. However, embankments are the more prominent feature in the landscape and so perhaps they deserve the more prominent symbol. Against the white paper of the map, the darker of the pair appears more prominent. We could see no way to resolve these arguments except by experiment.

EXPERIMENT 3

Method

The method was similar to that used in Experiment 1. Maps of the same type were specially prepared with the five pairs of symbols. The *standard* symbols were drawn slightly larger for this experiment to match more closely those currently being used in 1:50,000 OS maps.

The subjects were 103 boys and 98 girls aged between 13 and 15 years. They were all from the same year of a London comprehensive school and were tested in two groups. Approximately equal numbers were assigned at random to each of the five pairs of symbols. Each pupil used the same pair of symbols on all questions.

Questions 1, 2 and 3 from Experiment 1 were repeated using a similar procedure. Questions 4 and 5 were not used.

Question 2 was split into two parts. In the first part (question 2a) subjects viewed one of the maps with no overprinting. They were given 1/2 minute to count the number of cuttings and embankments and write down these numbers. Unlike the previous experiments, they were asked to count the two types of symbol separately. The score was the number of correct responses—a maximum of two. Question 2b used the six remaining questions presented in the same way as before, with the same time limit of 90 seconds. It was hoped that 2a would crudely test the ease of locating the symbols, whereas 2b would test subjects' ability to discriminate and understand them in questions that used words.

In all other respects the procedure was identical to experiment 1.

Results

Table 2 shows the means for each pair of symbols on each question. Each mean is from an average of 40 subjects. A chi-squared test on the binary data from question 1 is significant (chi-squared (4) = 10.7, $p < .05$). One-way analyses of variance were carried out on the remaining questions, which are all significant. For question 2a, $F(4,170) = 2.9, p < .05$. For question 2b, $F(4,196) = 2.8, p < .05$. For question 3, $F(4,195) = 4.1, p < .01$.

For question 2a, a Duncan's Multiple Range test shows that the highest mean differs

Table 2. Means from Experiment 3

Question	Type of symbols					Maximum
	Standard	New cutting	New embankment	Heavy cutting	Light cutting	
Q1*	44%	65%	66%	71%	76%	100%
Q2a*	0.9	1.0	1.1	1.4	1.2	2
Q2b*	4.1	4.1	4.5	4.3	5.0	6
Q3**	4.2	4.3	7.5	7.0	8.0	12

* $p < .05$; ** $p < .01$.

significantly (adopting $p < .05$) from the two lowest. For question 2b, the highest mean differs significantly from the three lowest. For question 3 the three highest means all differ significantly from the two lowest.

Discussion

Three out of four test questions show a loosely consistent rank ordering—*light cutting*, *new embankment*, *heavy cutting*, *new cutting*, *standard*—listed from best to worst performance. The slightly different pattern on question 2a may reflect the visual search component in this question.

The tests demonstrate the superiority of the *light cutting* symbols over the existing *standard* symbols on a range of map-reading tasks.

Although there is no significant difference the results suggest that, to aid identification, the embankment symbol should appear darker than the cutting symbol. The reverse is true in the *standard* symbols and in some of the others tested. The darkness of symbols seems to convey the message of prominence, rather than be seen as a shadowy hole in the ground.

GENERAL DISCUSSION

The understanding of symbolic information is much more than the learning of an association between a symbol and what it represents. What appears to distinguish expert from novice map readers is not only a greater speed and accuracy in using maps, but also a much greater flexibility in working with different types of symbol, especially when symbols are met for the first time. But schoolchildren do not have this flexibility, and so variations in symbol design have a much greater effect on their performance.

We chose to investigate in detail the cartographic representation of cuttings and embankments. The same symbols for these features are used throughout the world and they cause considerable confusion to both schoolchildren and university students. We began a systematic search for alternative designs for these symbols and evaluated these by performance tests conducted on novice and expert map readers.

The *light cutting* pair of symbols produced superior performance to the existing *standard* symbols on a range of tests and these are recommended as an alternative. Other symbol pairs also produced superior performance and these may be worth consideration also.

Our evidence comes from English map readers and it is possible that different results would be produced by map readers in other countries. Other map reading tasks might also generate different results. However, in the absence of other evidence, the size of the effects produced (scores almost doubled on the intervisibility task) demands that the new symbols deserve serious consideration.

The *standard* symbols have evolved from the hachure symbol. They appear logical to the tiny minority of map readers who understand hachures, in much the same way that peculiarities of English spelling sometimes appear logical to those who understand their roots in classical languages.

Map design decisions are made largely by professional cartographers influenced by pressure groups consisting of experienced map readers. If our results are representative, the choice of symbols for experienced map readers has little effect on their performance at reading maps, and so is largely aesthetic. In contrast, differences in map symbols do affect performance of less experienced map readers, but their interests are often ignored.

ACKNOWLEDGEMENTS

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