DETOUR EXPERIMENTS WITH STICKLEBACKS (*GASTEROSTEUS ACULEATUS* L.)

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(With Two Text-figures.)

The work of Köhler (1927) has demonstrated the great value of simple detour experiments in testing the intelligence and learning capacity of certain higher vertebrates; the aim of the work here to be described was to apply this general method of experimentation to a vertebrate much lower in the scale. In a typical detour experiment the direct way to a visually attractive object is blocked, and a roundabout way left open. The object should remain visible and the indirect way should be easily surveyed. The problem should be one adapted to the normal movements and behaviour of the animal. These conditions were fulfilled with the stickleback by the simple device of offering it food in the bottom of a small glass jar.

PRELIMINARY OBSERVATIONS.

Two sticklebacks of a stock originating from the River Gade at Waterend, Herts., and reared in a small garden pond at Radlett, were transferred to a small aquarium on October 27th, 1929, and kept under observation. It was soon noticed that they depended very largely upon eyesight for finding food, and this was tested in the following simple way. They were normally fed upon short pieces of small earthworms, which they seized with avidity and shook as a terrier shakes a rat. A piece of worm was offered in a thin-walled glass tube full of water; this was attacked vigorously from outside. Even a completely motionless piece, killed by hot water, was snapped at when presented in the tube. It is clear that the sense of smell played no part in this response.

Further experiments showed that this approaching and biting response could be elicited by other objects as well, so that it is not necessary to assume that the fish recognised the worm pieces as such. Thus a crude imitation of a piece of worm modelled in putty and presented inside the tube was attacked, though it was much whiter than a real worm fragment. It was also found that the end of a wooden needle mount drawn through the water would be followed and attacked. The sticklebacks would also follow, and often snap at, the needle mount when drawn along outside the glass wall of their aquarium, and they would follow other objects as well, such as the vulcanite mouthpiece of a pipe and the end of a red penholder. They may often be seen to pick up oddments from the bottom or floating in the

water which have obviously no nutritive value whatsoever. The stickleback is therefore primarily a visual type; it lives and feeds by sight mainly. The fact is important in relation to the experiments which follow.

Experiment 1.

The fish were transferred from their original aquarium to a rectangular glass tank, 31 × 14·5 × 11 cm., with a depth of water of 7 cm., and kept there for 5 days to get accustomed to surroundings. The fish were about 4·5 and 4 cm. long, the larger (*A*) being a male and more vigorous than the other (*B*).

For each experiment two sections of a small earthworm were placed in a 1 oz. wide-mouthed bottle, height 6·2 cm., width at bottom 4 cm. (both external), width of mouth 2·5 cm. (internal). The bottle was filled with water and placed in the aquarium *on its side*, lying up against the long wall of the aquarium next to the observer, half way along it, and with the mouth of the bottle always facing to the right. The worm pieces remained at the bottom of the bottle, *i.e.* to the left. The bottle was removed immediately after each experiment. This was the case in all the series of experiments described in this paper. The fish were observed from a distance of about 18 inches, the observer taking great care to avoid any abrupt movement which might frighten, or divert the attention of, the fish.

Table I gives the times taken to enter the bottle and seize a piece of worm.

Table I. *Exp.* 1. *Fishes* A *and* B.

Serial No.	Date 1930	Hour	Time taken to enter bottle		Position
			Fish *A*	Fish *B*	
1	23. iii.	11.38	20 min.	15 min.	
2	26. iii.	12.18	4 min.	—	
3	26. iii.	14.46	2 min.	19 min. 30 sec.	
4	28. iii.	7.48	32 sec.	—	
5	28. iii.	7.54	—	25 sec.	
6	30. iii.	9.38	2 min.	2 min. 2 sec.	
7	30. iii.	9.45	20 sec.	Not in 5 min. 12 sec.	
8	31. iii.	9.00	8 min. 40 sec.	11 sec.	L. (*A*) R. (*B*)
9	2. iv.	18.20	10 sec.	9 sec.	R.
10	4. iv.	9.00	8 sec.	3 sec.	R.
11	5. iv.	13.50	58 sec.	—	L.
12	5. iv.	13.55	40 sec.	—	L.
13	5. iv.	14.08	—	4 min. 25 sec.	L.
14	6. iv.	9.30	38 sec.	—	L.
15	7. iv.	8.55	1 min. 50 sec.	2 min. 10 sec.	L.
16	8. iv.	8.55	39 sec.	—	L. (*A*) R. (*B*)
17	9. iv.	8.55	2 min. 32 sec.	—	L.
18	10. iv.	9.00	Not in 2 min. 15 sec.	52 sec.	L.
19	11. iv.	8.55	3 min. 54 sec.	3 min. 56 sec.	L.
20	12. iv.	9.50	45 sec.	25 sec.	L. (*A*) R. (*B*)

In this table R. signifies that the fish were to the right of the bottle when it was introduced, L. to the left. A blank record (—) does not signify failure, but merely that the experiment was terminated before the second fish entered. As a rule, when one fish emerged with a worm piece the other chased it, disregarding the bottle, which was then removed.

The usual behaviour of the fish was to go straight for the pieces, biting at them as visible through the bottom of the bottle; later the sides of the bottle would be attacked, especially from above. There was at first no systematic search for an entrance; the way in was found in the earlier experiments apparently by chance. As a rule the fish entered without hesitation as soon as it came into a position from which it could see the pieces through the mouth of the bottle; as a rule it came out quickly, either head foremost or tail foremost. The difficulty of the problem lay not so much in finding the entrance as in inhibiting the immediate attack at the bottom of the bottle where the worm pieces lay. These strongly attracted the fish, and they would return again and again to the attack. After the first week it became evident that the time taken to enter depended to a considerable extent upon the position of the fish relative to the bottle on its introduction. If they were to the right of the bottle, it was easy for them to enter at once—see, for instance, tests 9 and 10—but if they were at the left they were immediately attracted to the bottom of the bottle and wasted time in vain attacks. This was very noticeably the case in No. 8 *A*. From test 11 onwards, the fish were attracted or driven to the left of the bottle before it was put in. Fish *B* had a habit of lurking in the right hand corner of the tank, from which it could not be moved in Nos. 16 and 20.

The exact interpretation of the results is a matter of some difficulty. The very high figures found in *A*'s first test and in *B*'s first and second successful tests were never approached in later trials—*some* change in the fishes' behaviour is then apparent after these one or two trials. There is, however, no regular and consistent decrease in the time taken, if we consider the tests from No. 11 onward. *A*'s good performances in Nos. 11, 12 and 14 are followed by less successful efforts in 15, 17 and 19, though good scores are made in 16 and 20. *A*'s average time in the first four trials of this series is 61·5 sec., and in the last four trials 117·5 sec. *B*'s performances are likewise irregular.

A certain change in the behaviour of *A*, however, became apparent from No. 14 onwards. In that test, *A* attacked first at bottom, then at upper side, moved to right and entered at 38 sec. In test 15, *A* attacked at bottom for only a few seconds, then moved to upper side and to right and swooped down from right, hitting the bottle too far to the left and thus missing the entrance. Similar behaviour was noted in No. 17, but *A* returned a second time to the bottom of the bottle. No. 16 was a replica of 14 so far as *A* was concerned, and so was 20. In No. 18 *A* was not successful in resisting the immediate attraction, and in 19 also the bottom of the bottle was attacked repeatedly. Out of nine trials, from No. 11 onwards, *A* (approaching from the left) solved its problem rapidly and successfully in five, and showed stupid behaviour in three cases only; in the remaining case (No. 15) the behaviour was on the right lines but success was delayed. Though definite numerical proof cannot be adduced, there is little doubt that *A* was beginning to seek out the necessary detour.

Owing to *A*'s superior vigour and success, *B* did not have so much chance of learning, and its performances were irregular. *B*'s appetite was never so keen as *A*'s, and it was sometimes chased and bitten by *A*.

Of the nature of the learning one can say that it did not consist in the acquirement of a definite motor habit, but in the partial elimination of useless movements—not a mere dropping out of useless movements but an active inhibition of them. This inhibition was, however, still uncertain after eighteen tests extending over 3 weeks.

It is clear that an association was formed between the presence of the bottle and food, for on two occasions when the bottle was presented without food, it aroused interest, and *A* entered. The particulars are as follows.

On the morning of 5. iv. 30 (13 days from the beginning of the experiment), the bottle, having been well washed and stood in running water, was placed in the tank without a worm. Both fish paid attention to it, approaching the mouth of the bottle. *A* entered about three-quarters of its length, at 88, 105 and 122 sec., inspected the entrance again half a minute later, and went right in at 4 min. 3 sec.

On 12. iv. 30, the empty bottle was placed in the tank in the presence of *A*, who investigated it, and entered it at 50 sec., and five times more in the course of 3 min., when the bottle was removed.

A complete record was kept of the behaviour of the fish in each of the twenty tests, but need not be reproduced here, with the exception of the notes on test 3: after entering at 2 min., and relinquishing the worm, *A* went in and out twenty times in the next 17 min., and finally came out without the worm. During this time *B* attacked the bottom and the upper side of the bottle, sometimes approaching the entrance; though *A* entered several times while *B* was "standing by," there was no sign of imitation on *B*'s part.

Experiment 2.

In order to eliminate the complication arising from the position of the fish relative to the bottle, a new series was started, with the food lying in the bottom of a small glass jar placed ***upright*** in the middle of the tank. The food always lay along the side of the jar. The jar was 6·3 cm. high, 4·4 cm. wide at bottom (external), with a somewhat constricted neck, the mouth being 3·2 cm. in internal measurement. There was 2·6 cm. depth of water above the rim of the jar. Fish *A* only was used in this series.

In order to test the response of the fish to the jar without food, it was placed in the tank at 11·45 on 12. iv. 30. The fish examined it thoroughly, nosing round the bottom, and also at the sides and neck, but not entering. Its interest persisted for about three-quarters of an hour, though diminishing, and when the jar was removed after an hour the fish had ceased to give it any attention. The fish had, of course, a lengthy experience of the not dissimilar glass bottle used in Exp. 1.

Regular training started on April 22nd, and continued with 1 day's intermission for a period of nearly 4 weeks; from No. 7 onwards, with one exception, the tests were made in pairs, one immediately following the other; on the last day two pairs of tests were carried out.

If we consider first the time taken to get out of the jar, we find evidence here of very rapid learning. In the first test the problem was not solved in 1 hour; in the second the fish got out some time between 10 and 25 min., in the third in just

Table II. *Exp.* 2.

Serial No.	Date 1930	Hour	Time taken to get in	Time taken to get out
1	13. iv.	14.15	2 min. 15 sec.	Not in 1 hr.
2	16. iv.	18.30	7 min. 45 sec.	10–25 min.
3	18. iv.	9.35	3 min. 30 sec.	Just over 4 min.
4	19. iv.	10.00	2 min.	35 sec.
5	22. iv.	9.52	2 min. 5 sec.	21 min.
6	23. iv.	10.15	1 min. 5 sec.	2 min. 45 sec.
7	24. iv.	9.25	2 min. 10 sec.	4 min. 30 sec.
8	24. iv.	9.36	1 min. 3 sec.	15 sec.
9	25. iv.	14.08	3 min. 12 sec.	20 sec.
10	25. iv.	14.16	55 sec.	10 sec.
11	26. iv.	16.04	3 min. 5 sec.	5 sec.
12	26. iv.	16.13	48 sec.	7 sec.
13	27. iv.	14.51	20 sec.	10 sec.
14	27. iv.	14.53	38 sec.	7 sec.
15	28. iv.	18.58	45 sec.	13 sec.
16	28. iv.	19.02	2 min. 43 sec.	5 sec.
17	29. iv.	19.00	39 sec.	6 sec.
18	29. iv.	19.02	20 sec.	20 sec.
19	30. iv.	8.49	2 min. 3 sec.	5 sec.
20	30. iv.	8.55	16 sec.	5 sec.
21	1. v.	9.00	2 min. 50 sec.	20 sec.
22	1. v.	9.04	47 sec.	5 sec.
23	2. v.	8.55	21 sec.	9 sec.
24	2. v.	8.58	1 min. 10 sec.	15 sec.
25	3. v.	9.59	1 min.	7 sec.
26	3. v.	10.02	37 sec.	3 sec.
27	4. v.	10.26	30 sec.	5 sec.
28	4. v.	10.31	22 sec.	6 sec.
29	5. v.	8.25	1 min. 10 sec.	3 sec.
30	5. v.	8.30	13 sec.	3 sec.
31	6. v.	8.52	25 sec.	5 sec.
32	6. v.	8.55	28 sec.	4 sec.
33	8. v.	9.03	20 sec.	21 sec.
34	8. v.	18.58	20 sec.	68 sec.
35	9. v.	19.01	2 min. 30 sec.	5 sec.
36	9. v.	19.06	1 min. 45 sec.	5 sec.
37	10. v.	18.06	12 sec.	8 sec.
38	10. v.	18.10	31 sec.	6 sec.
39	11. v.	18.05	32 sec.	7 sec.
40	11. v.	18.07	50 sec.	5 sec.
41	12. v.	8.57	1 min. 52 sec.	8 sec.
42	12. v.	9.01	39 sec.	6 sec.
43	13. v.	18.57	1 min. 45 sec.	5 sec.
44	13. v.	19.01	12 sec.	8 sec.
45	14. v.	18.33	48 sec.	12 sec.
46	14. v.	18.38	40 sec.	3 sec.
47	15. v.	19.01	29 sec.	5 sec.
48	15. v.	19.03	1 min. 28 sec.	2 sec.
49	16. v.	18.58	27 sec.	3 sec.
50	16. v.	19.01	19 sec.	3 sec.
51	17. v.	18.17	32 sec.	6 sec.
52	17. v.	18.20	35 sec.	5 sec.
53	18. v.	9.35	42 sec.	5 sec.
54	18. v.	9.39	14 sec.	7 sec.
55	18. v.	18.59	21 sec.	8 sec.
56	18. v.	19.01	20 sec.	5 sec.

over 4 min. In the fourth test the solution was hit upon at once. The difficulty of the problem lay in the fact that the fish was a little longer than the internal diameter of the jar, so that when it had entered and eaten its bit of worm, it found

itself in a slightly cramped position, with its head lower than its tail. When it attempted to swim forwards and up, it was impeded by the shoulder of the jar, and found great difficulty in getting its head past this obstruction, though there was no real mechanical impediment; it would go round and round inside, biting vigorously at the walls. The simplest solution of the problem was, of course, to back out tail first, and this solution was discovered in the fourth test. Two days elapsed before the fifth trial, and by this time the solution had apparently been forgotten, the fish taking 21 min. to get out. In tests 6 and 7 the times were greatly reduced, but the fish still experienced trouble. In test 8, however, the solution was again hit upon at once, and thereafter the fish always emerged with the greatest ease and celerity; in only one test (34) was the time more than a few seconds, and on this occasion the fish deliberately remained inside the jar looking for more food. It appears, therefore, that the proper method of getting out was not learned by degrees, but suddenly, and the solution was retained. One cannot, of course, assume that the fish showed "insight" into the problem; the solution was probably found by chance; but the remarkable thing is that when the trick was discovered (for the second time) it was repeated in all subsequent tests.

We may consider now the times taken to enter the jar. If we group the tests from No. 7 onwards in tens, and take the average "time in," we get the following:

Nos.	Sec.
7–16	93·9
17–26	60·3
27–36	48·3
37–46	48·1
47–56	32·7

The average time in the first six tests, which were, however, not carried out on consecutive days, was 186·7 sec. We see, then, that the time taken to enter was very materially reduced during the experimental period, and that the improvement took place gradually, though not uniformly. The time in the first period of intensive training was almost exactly one-half of the time during the six preliminary tests; in the second period the time was reduced by about one-third. A smaller improvement was shown in the third period, none in the fourth, and a big drop (about one-third) in the last period. There is therefore very definite evidence of progressive improvement as a slow and more or less continuous process.

The behaviour of the fish gradually changed as the experiment proceeded. At first the fish attacked persistently at the bottom of the jar, biting at the worm fragment as it showed through the glass. Already in test 3 and more definitely in 4 it alternated this direct attack with swimming up towards the rim, and in all subsequent tests this upward swimming was observable; sometimes the fish went in at its first rise, but more often not. Even towards the end of the experiment, however, the first response to the jar was the direct attack; only on a few occasions (Nos. 18, 29, 30, 55 and 56) was there no biting at the worm, but the number of attacks from about test 23 onwards was as a rule limited to one or two. A very characteristic form of behaviour developed on many occasions in the later tests—after a

tentative bite at the bottom of the jar the fish would move up and down, up and down, looking alternately at the worm and at the rim of the jar, the very picture of hesitation. Often when it had neared the rim and was about to dart into the jar, it seemed drawn down irresistibly by the sight of the worm and renewed its fruitless attack from the outside. Though it never learned to resist completely the direct attraction of the worm, there was clear evidence from its behaviour that it sought the way in and that it became more adept in taking the "long way round." Direct evidence that it knew the way in and was delayed only by the attraction exercised by the worm is afforded by the results of some tests in which the jar was presented without a piece of worm. The details are as follows:

Table III.

Serial No.	Date	Hour	Time taken to get in	Time taken to get out
11 *A*	26. iv.	16.02	22 sec.	6 sec.
13 *A*	27. iv.	14.48	12 sec.	6 sec.
15 *A*	28. iv.	18.53	60 sec.	3 sec.
17 *A*	29. iv.	18.56	23 sec.	4 sec.
37 *A*	10. v.	18.03	12 sec.	51 sec.
39 *A*	11. v.	18.01	32 sec.	3 sec.
53 *A*	18. v.	9.27	22 sec.	55 sec.
55 *A*	18. v.	18.55	10 sec.	3 sec.

These tests were carried out just before the normal daily trials on the dates specified. It will be seen that, with one exception (15 *A*), when the fish searched round the bottom of the jar before entering, the time taken to enter was very short, much shorter than the average times at these periods when the jar was offered containing food. In all these tests without food the fish went in and out several times in the course of the 2 minutes during which the jar was left in the tank. Also in the normal trials (with food) the fish often entered a second or third time after it had eaten its food, no doubt looking for more.

It is probable that learning would have been much more rapid if the tests had been made at more frequent intervals; as it was, the fish was normally given two consecutive trials every 24 hours. It is noticeable that its performance in the second trial of each pair was as a rule distinctly better than in the first trial of the day, the average times being 44·7 sec. and 71·7 sec. respectively.

The experiment had to be brought to an end on May 18th owing to my departure abroad, but it seems likely that further improvement would have been shown by the fish. I had intended to resume the experiment a fortnight later, but in the meantime the fish unfortunately met an untimely end.

Experiment 3.

A rather obvious objection to Experiment 2 was that the fish had already been trained to solve a somewhat similar problem, and that what Koffka (1928, p. 187) calls "transfer of training" may very well have facilitated the solution of the upright jar problem. Exp. 2 was therefore repeated later in the year with a new fish of dif-

ferent origin which had received no preliminary training. This fish (*C*) came from a small brook near Radlett, and was kept in the experimental tank for 11 days before training began. *C* was about 4·5 cm. in length, a vigorous but deliberate fish. The conditions of this experiment were the same as in Exp. 2.

A week before the experiment started the jar without worm was placed in the tank. It was casually inspected by the fish twice in 15 min., but evidently aroused no interest.

The record of times is given in Table IV.

Table IV. *Exp.* 3. *Fish* C.

Serial No.	Date 1930	Hour	Time taken to get in	Time taken to get out
1	22. xi.	9.18	Not in 2 hr.	—
2	23. xi.	9.38	Not in 1½ hr.	—
3	23. xi.	15.16	35 min.	44 min.
4	23. xi.	20.24	61 min. 45 sec.	2 min. 30 sec.
5	24. xi.	20.05	55 min. 30 sec.	2 min. 15 sec.
6	26. xi.	20.34	60 min.	1 min.
7	27. xi.	20.25	4 min. 30 sec.	32 sec.
8	27. xi.	20.34	5 min.	5 sec.
9	28. xi.	20.14	2 min. 28 sec.	3 min. 13 sec.
10	28. xi.	20.23	2 min. 7 sec.	34 sec.
11	29. xi.	11.47	1 min. 40 sec.	8 min.
12	29. xi.	12.05	2 min. 10 sec.	20 sec.
13	30. xi.	10.45	1 min. 45 sec.	4 min. 3 sec.
14	30. xi.	10.54	1 min. 4 sec.	14 sec.
15	1. xii.	20.32	1 min. 9 sec.	13 sec.
16	1. xii.	20.37	1 min. 4 sec.	13 sec.
17	4. xii.	20.58	45 sec.	18 sec.
18	4. xii.	21.01	35 sec.	11 sec.
19	5. xii.	20.44	2 min. 27 sec.	9 min. 40 sec.
20	5. xii.	20.59	19 sec.	41 sec.
21	14. xii.	14.04	(2 min. 25 sec.) 4 min. 25 sec.	9 min. 40 sec.
22	14. xii.	14.23	22 sec.	38 sec.
23	28. xii.	10.02	46 sec.	19 sec.
24	28. xii.	10.07	36 sec.	3 min. 46 sec.
	(1931)			
25	18. i.	9.55	1 min. 7 sec.	Not in 15 min.
26	18. i.	10.17	2 min. 5 sec.	Not in 15 min.
27	15. ii.	11.17	5 min. 58 sec.	Not in 15 min.
28	15. ii.	11.42	1 min. 40 sec.	12 sec.
29	15. iii.	10.18	5 min. 24 sec.	Not in 5 min.
30	15. iii.	10.31	1 min. 6 sec.	Not in 15 min.

The first series comprised twenty trials extending over 14 days; the subsequent tests were devised to discover how long the solution would be retained, and will be considered later (pp. 14–15 below). Taking the first series, we notice that, just as in Exp. 2, the problem of getting out was solved suddenly, the time falling from 44 min. in the third test to 2 min. 30 sec. in the fourth, and 1 min. in the sixth, thereafter remaining at very low figures with four striking exceptions. It is noteworthy that the type of solution was different from that adopted by *A*—fish *C* always came out head first. While the solution was rapidly discovered, its retention was a little uncertain. Thus on 3 consecutive days in the middle of the experiment

C took several minutes to get out in the first test of each day, making a rapid exit in the second daily test.

The same phenomenon of a marked and sudden reduction is shown also by the "times in," and is illustrated graphically in Fig. 1.

In the first two trials no solution was arrived at in the times allowed—2 hr. and 1½ hr. In both the fish attacked vigorously at first; in the second the attacks were frequently renewed. In the third trial the fish passed over the mouth of the jar, saw the worm and immediately went in. In the fourth trial, which took place in artificial light, attacks were very frequent, and it was noticed that the fish paid more attention

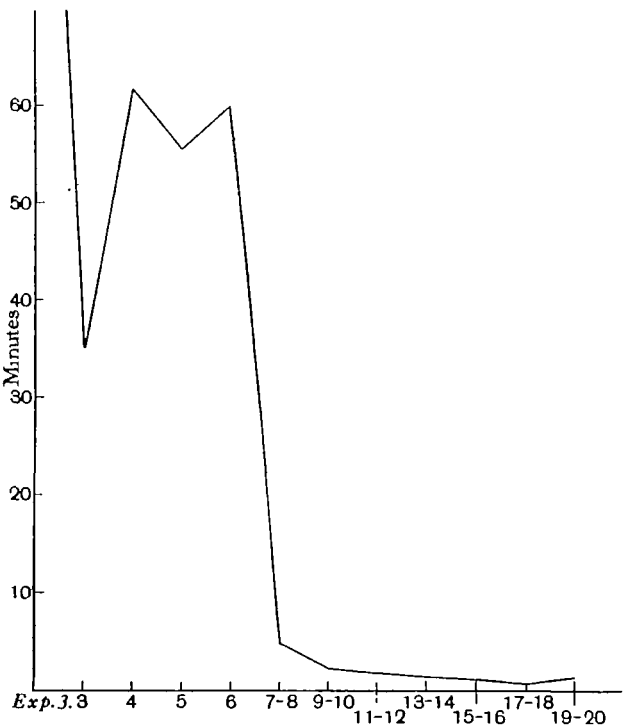

Fig. 1.

to the jar and rose to the rim more often—certainly five times before the final rise and entry. It nearly solved the problem at 24 min., when it passed over the mouth and hung about close by for a minute or so. On its eventual entry it seemed slow and deliberate. Several rises were observed in the fifth trial. It looked in over the rim at 47 min. before finally entering at 55½ min. In the sixth test it rose several times but not as high as the rim, and spent much time examining the jar; it crossed over the mouth once a few minutes before eventual entry. The rapid success in the seventh test came on the second rise near the rim; there was some hesitation before entry. In the eighth trial, after a few direct attacks it went up to the rim and down to inspect several times, giving the definite impression that it was seeking the way in, but being diverted by the direct visual attraction. After getting out it went in

again and out twelve times in the next 7 min. 20 sec. In the ninth trial it attacked only once before investigating the jar and finding the way in. In the next three trials it attacked vigorously at first, then went up and down several times, then up and in. In tests 12 and 13 it went in at the first rise. In the remainder of the tests the behaviour was similar, and entry was gained either on first rise or, more usually, after several alternating rises and descents. In general its behaviour was similar to that of *A*, but rather more deliberate and slow.

It seems clear that the way in was found, in trial 3, by chance pure and simple. It is hard to say whether there was definite seeking for the entrance in trial 4, but the fish certainly rose towards the rim several times, and this was so also in trials 5 and 6. An early rise was successful in 7, and in 8 there was certainly a definite seeking for the mouth. Some light is thrown upon the question by the results of two tests with the jar alone, without the worm. Given the empty jar at 8.57 on 25. xi. 30, between tests 5 and 6, the fish showed no apparent interest in it during 5 min. The same test repeated at 8.56 on 28. xi. 30, 12 hours after the successful test 7, gave positive results. The fish examined the bottom of the jar for food, rose and cruised round the rim and lower down the jar, entering in just over 3 min. It came out in 20 sec., and 20 sec. later entered the jar again for a short inspection. The jar had clearly acquired a "significance" which it lacked 3 days before. It is impossible to say with certainty that the fish sought the way in till the seventh or eighth trial.

It will be noticed that many of the trials in this series took place under conditions of artificial light, not, as in Exps. 1 and 2, in daylight. No definite difference in behaviour was observable, provided the fish had been allowed a few minutes to recover from the "flight reaction" which invariably follows the sudden turning on of a light (see note, on p. 407 below).

Experiment 4 A.

As the results of Exp. 3 were of considerable theoretical importance it was thought desirable to repeat them with another fish (*D*). This was a fish of the same origin as *C* but a trifle larger. The results were disappointing. Though tested every day from December 6th to the 11th—six tests in all of either 1½ or 2 hr. duration—it completely failed to enter the jar. Only on a few occasions did it even approach the rim; it seemed sluggish and timid and swam low. All it seemed to learn in any trial was to reduce the vigour of its direct attack—to inspect the piece of worm rather than attempt to bite it through the glass. An intercalary test (between 3 and 4) without the worm gave negative results during 5 min.

Experiment 4 B.

Thinking that a training in the simpler problem with the jar lying on its side might help it to achieve success in the more difficult one, I put *D* through a replica of Exp. 1, using, however, the jar instead of the bottle, with the following results.

The fish was to the left of the jar on introduction in all tests except No. 8. In test 1 it paid no attention to the jar for 25 min., and thereafter attacked only four times in all. In tests 2 and 3 the way in was found by chance; in 4 and 5 the fish

went up and over the jar, biting at it, which may perhaps be regarded as the beginning of an attempt at solution. In 6 the same behaviour was observed, and direct biting at the worm was inhibited. In tests 7 to 9 the fish made no direct attack but approached the side of the jar and moved along to the mouth—the solution was rapid and complete. Rather unexpectedly the last two tests gave poor results. The times taken to get out are not important, as exit offered no particular difficulty.

Table V. *Exp.* 4 B. *Fish* D.

Serial No.	Date 1930	Hour	Time taken to get in	Time taken to get out
1	14. xii.	14.31	Not in 1 hr.	—
2	23. xii.	10.54	8 min. 25 sec.	27 sec.
3	23. xii.	11.17	9 min. 35 sec.	3 min.
4	24. xii.	11.21	8 min. 58 sec.	32 sec.
5	24. xii.	11.40	2 min. 40 sec.	35 sec.
6	25. xii.	10.25	2 min. 3 sec.	11 sec.
7	25. xii.	10.34	23 sec.	19 sec.
8	26. xii.	10.17	27 sec.	39 sec.
9	26. xii.	10.21	22 sec.	16 sec.
10	27. xii.	14.01	2 min. 53 sec.	19 sec.
11	27. xii.	14.08	1 min. 17 sec.	9 sec.

Experiment 4 C.

After this training on the easy problem, *D* was again tested with the jar upright. Three tests were carried out on consecutive days at the end of December. In the first the fish carried out numerous direct attacks and showed great interest in the jar; it once passed over the mouth but did not see the worm, and failed to enter in 50 min. Next day its interest in the jar still persisted, and it spent much time investigating the jar high up; it just failed twice to go over the rim, and was unsuccessful in effecting an entry in 1 hr. and 50 min. In the third test its behaviour was less persistent and effectively directed than in the previous two, and as it had apparently "lost interest" in the problem its training was not continued further.

Experiments 5 *and* 6.

The upright jar experiment was restarted with a new fish, *E*, of the same origin as *C* and *D*. This was a lively fish, with a habit of swimming high. The results obtained are shown in Tables VI and VII.

The "times in" are shown graphically in Fig. 2.

In the first test the fish moved actively about the tank, occasionally attacking, but on the whole paying little attention to the worm. Although it had spent 24 hr. in the tank before the experiment, its behaviour indicated that it had not completely settled down. In the second trial, after a few attacks and inspections the fish approached the rim and went slowly in at 8 min. 50 sec. It came out head first after many struggles in 6 min. 30 sec. In the third trial it carried out many attacks, and went up towards the rim at 3 min. 45 sec. On second approach to the rim, at 7 min. 15 sec., it went in a few seconds later. In the fourth trial, rising towards the rim was more frequent, four ascents being noted before the successful one at 4 min.

In the fifth trial there were no attacks, but immediate inspection and a rise to the rim, the fish entering immediately after the second rise; there was undoubtedly in this case a direct seeking for the way in. The same remark applies to tests 6 and 7. In trial 6 the fish went just in and out again twice before the final entry at 1 min. 15 sec. In trial 7, entry was effected at the first rise. This fish definitely learnt the way out, head first, after two trials.

Table VI. *Exp.* 5. *Fish* E.

Serial No.	Date	Hour	Time taken to get in	Time taken to get out
	1930			
1	31. xii.	11.27	Not in 1 hr.	—
	1931			
2	1. i.	14.07	8 min. 50 sec.	6 min. 30 sec.
3	2. i.	9.37	7 min. 30 sec.	2 min. 30 sec.
4	3. i.	9.47	4 min. 5 sec.	20 sec.
5	3. i.	9.57	(1 min. 22 sec.) 1 min. 35 sec.	15 sec.
6	4. i.	10.19	(51 sec.) 1 min. 15 sec.	15 sec.
7	4. i.	10.24	42 sec.	18 sec.
8	5. i.	20.39	3 min. 48 sec.	20 sec.
9	5. i.	20.47	1 min.	18 sec.

Table VII. *Exp.* 6. *Fish* E. *Opaque jar.*

Serial No.	Date 1931	Hour	Time taken to get in	Time taken to get out
1	7. i.	20.34	1 min. 30 sec.	2 min. 55 sec.
2	7. i.	20.41	1 min. 20 sec.	38 sec.
3	8. i.	21.50	45 sec.	23 sec.
4	9. i.	20.26	48 sec.	17 sec.
5	10. i.	18.18	53 sec.	19 sec.
6	11. i.	12.18	1 min. 15 sec.	15 sec.

Several tests were made with the jar alone, not containing food. The first took place immediately before trial 3. The fish examined the jar after 1 min., moved up to the rim and went in at 1 min. 25 sec. This may have been a chance solution, but the jar had evidently acquired significance. The same test was repeated just before trial 4. The jar was examined at once, five ascents towards the rim were made and entry effected after the fifth, at 4 min. 25 sec. In the third trial without the worm, just before trial 6 of Exp. 5, the fish rose several times before entering at 1 min. 31 sec.

In trial 8 of the main series, carried out in the evening, success was considerably delayed, the fish alternately attacking and rising and not achieving entry till 3 min. 48 sec. The second trial (9) on the same evening gave, however, a rapid solution *without preliminary attacks.*

Exp. 6 may in practice be treated as a continuation of Exp. 5, although the conditions were altered. With a view to the tests carried out as Exp. 7, the jar was

coated with opaque white paint so that the worm could not be seen through its walls. Notwithstanding the change in appearance the fish solved the problem easily from the beginning, approaching the top of the jar directly and deliberately in test 1. In test 2 it first inspected the bottom of the jar before rising, but went straight to the rim in the three subsequent trials. In the last, it went first to the rim, then down to the bottom before rising again to enter. It is clear that there was transfer of training from the experiments with the transparent to those with the opaque jar.

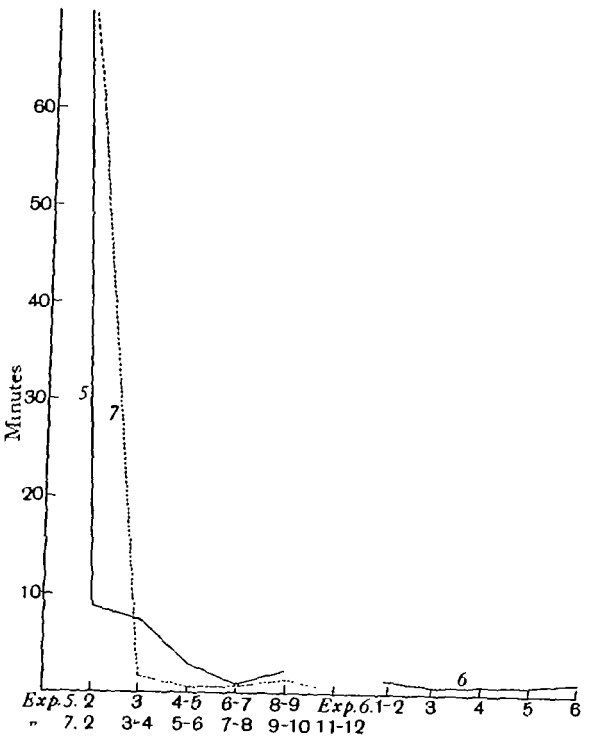

Fig. 2.

Experiment 7.

This was designed to cover the formation of an association between the jar and food without the disturbing element of the direct attraction of the food. For this reason the opaque jar was employed. A new fish, of the same origin as *C*, *D*, and *E*, was used, about 4 cm. in length, a trifle longer than *E*.

The results of the tests are given in Table VIII.

In the first test the fish paid immediate attention to the jar, which was, of course, much more conspicuous than in its unpainted state, and occasionally nosed at it. It nearly got in at 3 min. 30 sec. when it passed over the rim. Some 20 min. later it again visited the rim, but paid little further attention till near the time of its entry, when, after hovering at the rim, it suddenly went in and ate the worm. It came out after much difficulty some 13 min. later, head first. In the second trial it showed no

sustained interest in the jar, but occasionally examined it both at the bottom and at the rim. The solution was delayed till 1 hr. 50 min., when it crossed over the rim and went rapidly in. In these two trials the solution was undoubtedly found by chance. In trial 3 a change in behaviour was manifest; it rose almost immediately to the rim, and after two further visits to the rim it got in at 2 min. 55 sec. It was clearly seeking, albeit in a vague way, for the entrance. In the trial immediately following, the solution was direct and immediate, the fish moving straight to the rim and in at 20 sec. Next day the two tests had the same results—rapid and direct entry in well under a minute. Good results were obtained also in the next pair of tests (7 and 8). In the ninth test, in daylight, the fish went round and round the jar before entry, which was delayed till 2 min. 33 sec. The three subsequent tests were completely successful, the way in being found in 20–25 sec. Getting out was not too easy for this rather large fish, but the way was learnt rapidly, and presented no difficulty after the first three trials.

Table VIII. *Exp.* 7. *Fish* F.

Serial No.	Date 1931	Hour	Time taken to get in	Time taken to get out
1	17. i.	9.47	1 hr. 39½ min.	13 min. 15 sec.
2	18. i.	10.49	1 hr. 50 sec.	4 min. 5 sec.
3	20. i.	10.03	2 min. 55 sec.	1 min. 35 sec.
4	20. i.	10.14	20 sec.	48 sec.
5	21. i	21.00	43 sec.	13 sec.
6	21. i.	21.06	19 sec.	12 sec.
7	22. i.	20.32	38 sec.	10 sec.
8	22. i.	20.36	26 sec.	6 sec.
9	24. i.	14.24	2 min. 33 sec.	27 sec.
10	24. i.	14.32	25 sec.	10 sec.
11	25. i.	10.10	25 sec.	12 sec.
12	25. i.	10.13	20 sec.	10 sec.

Two additional tests were made, with the empty jar, one immediately after test 4, when after examining the bottom the fish entered at 52 sec. and emerged in 18 sec. The second took place just before test 11, when entry was made at 1 min. 28 sec., and exit in 30 sec.

The time curve for Exp. 7 is given in Fig. 2.

RETENTION OF EFFECT OF TRAINING.

(Exp. 3, tests 21–30.)

After a period of intensive training, lasting over 14 days and comprising twenty tests, during which it learned the way in and the way out thoroughly, fish *C* was tested at intervals up to 14 weeks after the end of the original period of training. During these weeks it was kept in a large aquarium tank, and occasionally fed, being transferred to the experimental tank some hours, usually about 24, before the tests took place. In test 21, 9 days after training, entry was effected at 4 min. 25 sec., after a partial entry at 2 min. 25 sec.; the way out was not found till 9 min. 40 sec. The second trial on the same day was very successful in both respects. Good times were scored in the next two trials, 14 days later, except that some difficulty was

experienced in getting out in the second of these. In tests 25 and 26, 6 weeks after the original training, the way in was found in fair time, corresponding to those about half-way through the original period of training, but the way out seemed to have been forgotten. In a test without worm, immediately before test 25, the fish entered in 30 sec., but did not manage to escape in 15 min. Four weeks later, the time of entry went up to nearly 6 min., but typical hesitation-behaviour was observable from the second minute onwards, the fish moving up and down, up and down, and nearly getting in several times before final entry. In the second trial on this occasion the same behaviour was shown, the fish getting in at 1 min. 40 sec. In this case exit was immediate, and the fish then went in and out three times in the next minute.

In the last retention tests, 29 and 30, the behaviour was similar to that observed in 27 and 28, 4 weeks previously. Exit was effected in 24 sec. in test 29, presumably by chance; the fish re-entered the jar at once, and on this occasion failed to get out in 5 min. The way out seemed to have been forgotten, for in test 30 the fish tried vainly for 15 min. and was then released.

Immediately before test 29 the fish was given a trial with the empty jar. It approached at once and examined the bottom of the jar persistently; at 30 sec. it moved up towards the rim, and thereafter went up and down alternately in the typical manner, going in at 2 min. 47 sec. Clearly the jar had retained its meaning. Exit was not effected in 5 min.

NOTE ON RESPONSE TO SUDDEN ILLUMINATION.

Sticklebacks observed at night a few seconds after a strong light has been turned on appear to be "asleep"; they sit motionless on the bottom. If, however, they are observed *at the moment* of turning on the light, they are found to be afloat, carrying on their typical fanning fin-motion, just as in the day time. Immediately on perceiving the light they shoot to the bottom, generally moving slowly backwards thereon, but soon coming to rest, with the pectoral fins widespread and motionless, and the spines erected. In this state they are rather irresponsive to stimulus. After 2 or 3 minutes they being to move again and behave in general as in daylight, responding to the usual visual stimuli in a normal manner. Turning off the light does not appear to act as a stimulus during this phase. The sticklebacks appear to become habituated to the turning on of the light, as the response does not appear if a second stimulus is given shortly after the fish has recovered from the first. This point, however, requires further study.

This characteristic response to sudden illumination can be elicited also by frightening the fish, and it is accordingly to be regarded as a flight or protective reaction. Sticklebacks *A* and *B*, which were kept for 6 months under observation, gradually became more tame, so that they would take food from the hand or a pair of forceps. The general flight response—darting away and zig-zagging through the tank—gradually disappeared in the course of time, but could be elicited by the sudden movement of some large visual object, such as a towel or a sheet of newspaper, or by a rapid movement of the observer. The fish would then dash about,

showing "flash," then settle on the bottom, as in the light response, with spines stiffly erected, generally turning pale. If removed to close quarters, such as a finger bowl, they dash about, and take up the same "scare" or protective attitude, just as in the response to sudden illumination, turning pale, and sometimes disgorging their food if they have recently eaten. There is little doubt, then, that this typical and unmistakable response is indicative of "fear." In nature, sticklebacks respond rapidly to the approach of an observer and dart under the shelter of the water plants. I have not observed in the course of my experiments any marked difference between the behaviour of the fish in daylight and under conditions of bright artificial illumination—two 60-watt lamps about 1 yard and 2 yards away, the tank being between them.

DISCUSSION.

The experimental results appear to justify the following statements. (1) The way in is at first found by chance, that is to say in the course of "random" movements, not directed towards finding the entrance. (2) The fish definitely try to get out, but the solution is discovered at first (unless it is extremely easy) also by chance. (3) After a very few entrances the behaviour becomes directed towards finding the entrance, vaguely at first, with increasing definiteness as the tests succeed one another; the behaviour, in other words, acquires the objective signs of conative action. (4) The change from undirected to directed behaviour is signalised by an abrupt drop in the time curve. (5) At about the same time the jar or bottle is attended to, *i.e.* acquires meaning or significance; there is, therefore, a certain organisation of the sensory field. (6) In the attempts to get out, the general striving is replaced after a very few trials by a directed effort to repeat the successful solution discovered by chance; this change in behaviour is shown in the time curve by a sudden drop. (7) In a long series of tests, the "times in," after directed behaviour has been established, show on the average a slow but regular decrease. (8) Learning the way in is delayed by the direct attraction of the food in the case of the transparent jar, and the habit is learned with greater precision and ease when an opaque jar is used.

That the solution is in the first few successful tests found by chance is shown by the description of behaviour in Exps. 3, 5, and 7. It is, therefore, no genuine solution; it does not imply "insight" in Köhler's sense; the fish does not survey the situation and suddenly decide what to do. (Even in Köhler's experiments with apes chance discoveries sometimes play a part in the solution; witness Sultan's first discovery that one bamboo rod can be fitted into another.) The change in behaviour from vigorous direct attacks varied by random swimming around, in the course of which the entrance is fortuitously discovered, is described in the records above (see particularly pp. 6–7, 9–10). The fish begins to alternate with the direct attacks a definite rising towards the rim. This definite seeking action becomes more pronounced as the tests proceed, and in some cases the direct attack may be omitted and the fish

swim at once to the entrance; this is, of course, clearest in Exp. 7, where the direct attraction is eliminated.

These observational results, which find expression in the striking drop in the time curves, show that the learning is *not* a more or less mechanical dropping out of "useless" movements, that is, movements not followed by "satisfaction," as Thorndike (1911) would have us believe. There is an active inhibition of the direct attack, and also an active seeking for the way in previously discovered—a seeking or trying or conative action which develops rather rapidly after a comparatively small number of successes. The phenomenon, shown in Exp. 2, of a slow diminution in average time after the solution has been learned may possibly be due to "habit-learning" in Thorndike's sense.

Other points of interest which deserve mention are the transfer of the effects of training from one experiment to a slightly different one (Exps. 1 and 2, 5 and 6), and the length of time (14 weeks) over which the solution may be retained.

There appears to be little previous work of a similar character. Thorndike (1898, 1911) reports, but without numerical details, the results of training *Fundulus* to swim from one end of a tank to the other through holes in a series of screens placed across the tank. The fish soon learned to avoid butting against the screens and to swim direct for the holes; the times taken very markedly decreased. Quite similar experiments were carried out with goldfish by Churchill (1916). His time curves show the same phenomenon of a marked drop after the first two or three trials as has been noted in the present experiments. He notes that the fish "gradually learned to explore more and more closely about the opening and thus the time was reduced. Toward the last they swam fairly accurately to the opening and passed through with very little nosing about" (p. 251)—behaviour had become "directed," in the sense in which we have used the word. He noted, as we have done, marked differences in capacity between different fish—cf. the stupid behaviour of fish *D.* Somewhat similar tests have been made with *Gobius* by Marie Goldsmith (1905, 1915), but I have not seen the original papers, and have available only the short accounts in Piéron (1910) and Goldsmith (1927), from which it appears that the fish, shut off from its nest by a glass partition containing a gap, quickly learned to find the way back.

Piéron (1910) also relates some experiments with the goldfish, to which a parallel may be found in the experiments described in this paper. He offered the fish earthworms inside glass tubes, and found that in time the fish gave up attacking them. One fish, for instance, attacked 117 times in half an hour in its first trial, but some days later only three times in a quarter of an hour. In our stickleback experiments it was often noticed that the vigour of the direct attacks soon waned and the fish contented itself with a close inspection. This appears to be a case of learning by experience, but the effects were transitory.

SUMMARY.

The six individuals of *Gasterosteus aculeatus* tested learned to find their way into a small jar or bottle for food, and also learned how to come out. One failed in the standard test, with the jar upright. The solution was found at first by chance, but after a few trials the behaviour became definitely directed towards finding the solution. This change was accompanied by a sudden drop in the time taken; the jar also acquired significance, ceasing to be an indifferent object. The mode of solution was retained for over 3 months. The bearing of these results on the theory of learning is briefly discussed.

The flight reaction shown by sticklebacks on sudden illumination is described.

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