



SPECIAL ARTICLE

No simple fix for fixation errors: cognitive processes and their clinical applications

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Summary

Fixation errors occur when the practitioner concentrates solely upon a single aspect of a case to the detriment of other more relevant aspects. These are well recognised in anaesthetic practice and can contribute significantly to morbidity and mortality. Improvement in patient safety may be assisted by development and application of countermeasures to fixation errors. Cognitive psychologists use 'insight problems' in a laboratory setting, both to induce fixation and to explore strategies to escape from fixation. We present some results from a series of experiments on one such insight problem and consider applications that may have relevance to anaesthetic practice.

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*We dance round in a ring and suppose,
But the Secret sits in the middle and knows.*

Robert Frost [The Secret Sits, in 'A Witness Tree' (1942)]

In 2008 Martin Bromiley, an airline pilot, described his late wife's case, essentially a failure to recognise a 'can't intubate, can't ventilate' situation [1]. The team involved in Elaine Bromiley's care was competent to deal with the case, yet failed to respond appropriately when faced with a problematic airway. The case painfully demonstrates a fixation error. Fixation occurs when anaesthetists concentrate on a single aspect of the case to the detriment of other more relevant aspects [2, 3]. Ironically, these are relatively easy to detect only in hindsight.

Examples of fixation error abound in everyday anaesthetic practice and another fatal outcome was reported previously, after the anaesthetic team fixated on the patient – a young boy – and his failure to respond to treatment of bronchospasm, instead of checking the equipment, where in fact the problem was located [4].

In the Elaine Bromiley case, the expert anaesthetists did not immediately recognise the 'can't intubate, can't ventilate' situation and persevered with attempts to intubate and ventilate when they should have changed

to another strategy, such as performing a surgical airway (or asking the ENT surgeon who was present to do so). Understanding what caused this type of impasse could illuminate anaesthetists' cognitive processes during challenging cases. To handle non-routine situations, expert anaesthetists must be able both to recognise the demand for a new approach to the problem and to produce a solution that works. The process by which anaesthetists reach an insight into a clinical event as it unfolds resembles the process by which new ideas are produced when problem solving is studied in laboratory experiments by cognitive psychologists, using simplistic, puzzle-like problems ('insight problems') to induce fixation in naïve participants and to observe the kinds of strategies that people use to escape from their fixation. Insight problems are easy to state, yet notoriously difficult to solve. In the insight problem solving literature, fixation refers to the unhelpful reliance on past experience to the detriment of the current situation [5]. Our past experience directs us towards a dead-end and we need to find a new way of approaching the problem at hand – we need to employ 'lateral thinking' [6].

We present some results from a series of experiments on an archetypical insight problem, the cheap necklace problem [6–8] (Fig. 1), focusing specifically on the

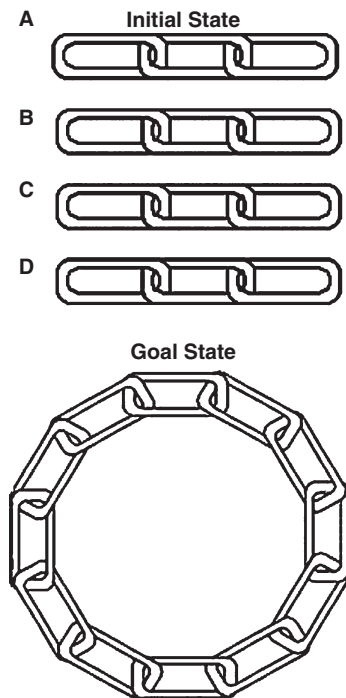


Figure 1 Application 1: the cheap necklace problem. The task is to connect all four chains so as to form a complete closed necklace at a cost of no more than 15 cents (it costs 2 cents to open a link and 3 cents to close it again).

relevant lessons we can learn from each experiment that may help us better understand anaesthetists' problem solving. These research findings are illustrative of people's failure to solve a novel problem that requires no specialised knowledge. The problem is easy to state, requires the use of familiar resources and behaviours, yet it remains a difficult problem to solve. Our purpose is to demonstrate, in the following eight applications of the cheap necklace problem, the ease of human failure in the laboratory where the consequences and time pressures are minimal. This provides some insight into how people fail in healthcare, where the stakes are higher, time pressure is greater, and several goals may need to be reached as opposed to the cheap necklace problem where there is only one goal. Anaesthetists' problem solving resembles that exhibited in the cheap necklace problem: fixation is a natural by-product of the heuristics, or rules of thumb, used to cope with complexity and/or uncertainty.

The research reported here was conducted as part of the PhD thesis by the first author and adhered to the British Psychological Society Code of Conduct Ethical Principles and Considerations, with the ethical approval of the Psychology Department at Lancaster University. Methods and results of each application are described in brief in the context of each application; where experiments have been

published in more detail elsewhere appropriate references are given. Where different conditions are described, the participants were randomly assigned to them. All statistical tests reported here were performed with Statistical Package for the Social Sciences (spss, Chicago, IL, USA) 16.0, using Fisher's exact test or the chi-squared test as appropriate, with $p < 0.05$ denoting statistical significance.

Application 1: a roundabout approach may provide a more effective solution

The cheap necklace problem is as follows. There are four chains, each consisting of three links (Fig. 1). It costs 2 cents to open a link and 3 cents to close it again. One's goal is to connect all four chains so as to form a complete closed necklace at a cost of no more than 15 cents.

The solution to this problem requires a detour: in order to make the bigger chain, one of the smaller chains must be broken. Thus, one should open the three links of one chain, e.g. A, at a cost of 6 cents in total and then use these three links to connect the remaining three chains, B–C, C–D and D–B, at a cost of 9 cents in total. Putting these together, 6 cents to open the three links plus 9 cents to close these links, costs 15 cents exactly.

The majority of people (97% [9]) fail to solve the cheap necklace problem as given. This is because their attempts concentrate on joining the chains together in the aim of coming closer to the goal of forming a necklace. The first moves that participants make are highly regular, and consistent with a strategy of trying to make progress towards the goal (a necklace) while avoiding moves that seem to lead backwards from the goal (breaking up a chain) – i.e. a 'hill-climbing' heuristic [10]. Hill-climbing is a heuristic in which, at each step, the problem solver selects moves that reduce the distance between the current state and the goal state of the problem as much as possible.

Implication

The cheap necklace problem itself provides us with our first lesson: a roundabout approach may be better – conversely, the obvious path may lead to fixation. For example, consider the intractable bronchospasm problem [4]: what may appear to be bronchospasm might be caused by problems with the tracheal tube or the breathing system, and checking these before going down a bronchospasm treatment pathway may provide an effective solution.

Application 2: the information is likely to be in the environment

First, colour hints were given in the initial state of the cheap necklace problem that were designed to encourage

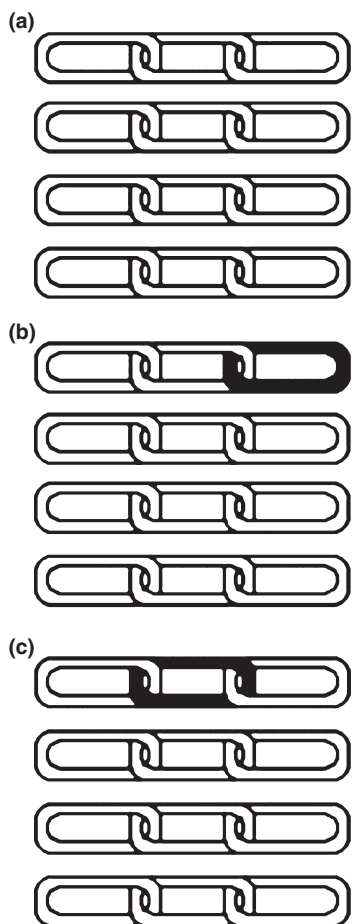


Figure 2 Application 2(i): (a) the initial cheap necklace state, (b) the ‘right link’ state condition, and (c) the ‘middle link’ state condition. The colours act as a hint to break the top chain as the solution requires.

participants to decompose one chain as the solution requires. Three conditions were thus contrasted: the original cheap necklace vs the ‘right link’ condition, which consisted of a black coloured right link of the top chain, vs the ‘middle link’ condition, which consisted of a black coloured middle link of the top chain (Fig. 2).

Methods (i)

Fifty-five second year undergraduates at Lancaster University acted as participants. Nineteen served in the original cheap necklace condition, 18 in the ‘right link’ condition and 18 in the ‘middle link’ condition. They were allowed 10 min to work on the problem. The experiment was conducted as part of a lecture class on problem solving.

Results (i)

Performance in the original cheap necklace condition remained at floor (0/19 solved), whereas only 3/18 participants (17%) solved the problem in the other two

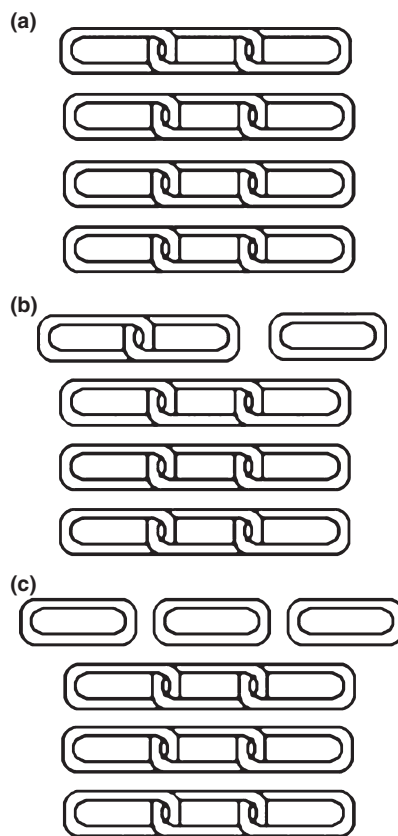


Figure 3 Application 2(ii): (a) the initial cheap necklace state, (b) the ‘two-link chain + single link’ state condition, and (c) the ‘three separate links’ state condition. The separate links act as a hint to break the top chain as the solution requires.

conditions (NS). Drawing attention to one of the chains in this implicit way had no effect on performance, nor did it made any difference which link was coloured. Even when prompted to open the middle link, 94% of people ignored this and opened either the right or left link of that chain (as if protesting against the hint). The application of a hill-climbing heuristic determined performance: participants kept joining the chains together to reach their goal, to its detriment.

Next, the configuration of the initial state of the problem was manipulated, having one of the chains as a two-link chain with a single link next to it in one condition, and having separate links in place of one chain in another condition (Fig. 3).

Methods (ii)

Sixty-two second year undergraduates at Lancaster University acted as participants. Twenty served in the original cheap necklace condition, 21 in the ‘two-link chain + single link’ condition, and 21 in the ‘three separate links’ condition. They were allowed 10 min to

work on the problem. The experiment was conducted as part of a lecture class on problem solving.

Results (ii)

Only one participant out of 20 (5%) solved the problem in the original cheap necklace condition, and 1/21 (5%) in the ‘two-link chain + single link’ condition, whereas 12/21 participants (57%) solved the problem in the ‘three separate links’ condition ($p < 0.0001$), suggesting that only the latter condition was helpful.

Implication

These two experiments provide us with our second lesson: the information leading to the solution may be in the environment but the problem solver needs to become aware of it. As the information becomes more and more obvious, from colour hints to actual chain decomposition, people are more likely to make use of it and provide an effective solution.

In anaesthesia training, how do we make learners more aware of this? How do we help them reflect on their environment? Key information may be available from other members of the theatre team. For example, in the Bromiley case, one nurse not only realised the severity of the situation, but also anticipated the consequences by booking a bed in the Intensive Care Unit. Another nurse even provided a clear solution to the problem, by making a tracheotomy set available. Yet, both attempts to make the rest of the team aware of the situation failed [1]. The theatre auxiliary nurses are often the longest serving members of a theatre team and may have witnessed problems similar to that currently presenting. Asking them to recall some of the events may provide the information necessary to kick-start a solution.

Application 3: theory without praxis is not enough

For experiment 3, the problem was presented with a conceptual hint to the nature of the solution: ‘*Sometimes it is necessary to destroy in order to create. In order to solve this problem, you need to go backwards before you can go forwards*’.

Methods

Forty-three members of the general public attending a Lancaster University Open Day took part in the experiment. Twenty-one served in the original cheap necklace problem, and 22 served in the ‘hint’ condition. They were allowed 5 min to work on the problem.

Results

Two out of 21 (9%) participants solved the problem in the original cheap necklace condition and only 1/22 (4%)

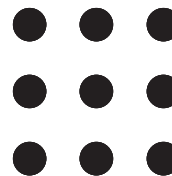


Figure 4 The nine dot problem. The task is to connect the dots by drawing four connected straight lines, without either lifting the pencil from the page or retracing a line. The solution can be found at the end of this article.

solved it in the ‘hint’ condition (NS), suggesting that the use of hints in prompting a change in the problem solver’s internal cognitive state seems futile. Similar findings emerge when applied to the famous nine dot problem [11] (Fig. 4): a hint stating ‘*go outside the box*’ is not useful as it is difficult to implement. However, a hint that relates directly to the drawing of lines (i.e., giving the first line) is more useful. Thus, the hint provided for the cheap necklace problem, ‘*you have to destroy in order to create*’, is not useful as it also fails to provide a way of implementing it. Overall, it appears that hints that relate directly to the solution’s implementation – hints that help the participants perform an action – are more helpful than hints that merely direct attention to the conceptual nature of the solution.

Implication

This offers a third lesson: ‘knowing what’ is different from ‘knowing how’ and therein lies the difficulty for novice anaesthetists, who may have mastered some theoretical knowledge (knowing what) but have not yet had sufficient experience to use this knowledge in a practical setting (knowing how) [12]. Acknowledging this fundamental difference and being aware of one’s own limitations (whether in knowing what or knowing how) is of paramount importance.

The suggestion is that one has to engage with the problem in a practical way – i.e. it is not enough just to learn the underlying theory – and one has to work with the scenarios. For example, when learning a failed intubation drill, one has to engage with it by simulating its use – whether by table-top scenarios or simple manikin based scenarios – to be able to use the drill as an effective solution.

Application 4: even simple problems can have complexity

In experiment 4, the problem was simplified by removing the money constraint and instructing participants only that they need to open and close three links to make the necklace.

Methods

Thirty-two undergraduates and postgraduates at Lancaster University took part in this experiment. Sixteen served in the original cheap necklace condition and 16 in the ‘no money constraints’ condition. They were allowed 10 min to work on the problem. Each participant was tested individually.

Results

Five out of 16 participants (31%) solved the problem in the original cheap necklace condition and 6/16 (37%) solved it in the ‘no money constraints’ condition (NS); i.e. the removal of the money constraints did not improve performance and participants remained fixated.

Implication

So the fourth lesson is that in our attempts to simplifying things, despite our best intentions, the problem either remains or a different one emerges. Thus, when trying to find ways of explaining things, whether one is the trainer or a trainee, we need to be aware that by simplifying one aspect of the problem, we do not always simplify the problem itself. For example, if a patient experienced an episode of pulseless ventricular tachycardia intra-operatively then defibrillation would be part of a solution to that problem. However, if the anaesthetist were not considering potential underlying causes (usually some combination of the four ‘H’s and four ‘T’s [13]) then a longer lasting solution may not come about. Attempts to simplify the problem by focussing solely on the abnormal rhythm rather than the patient as a whole will not address the complexity of this problem. Indeed, if not addressed then the learner may become fixated on the ‘VF/pulseless VT’ algorithm at the expense of a more complete solution.

Application 5: the relevant cues may be very subtle but detectable

In the fifth experiment, we manipulated the initial configuration of the problem to limit the availability of moves that lead to the ‘wrong sort of progress’ (i.e. moves that appear to make progress but lie off the solution path). In one condition, the chains were presented in the form of a square, and in another, in the form of a triangle with the remaining one on the side (Fig. 5).

Methods

Fifty-one undergraduates and postgraduates at Lancaster University took part in this experiment. Seventeen served in the original cheap necklace condition, 17 in the ‘square’ condition and 17 in the ‘triangle + chain on the side’ condition. They were allowed 10 min to

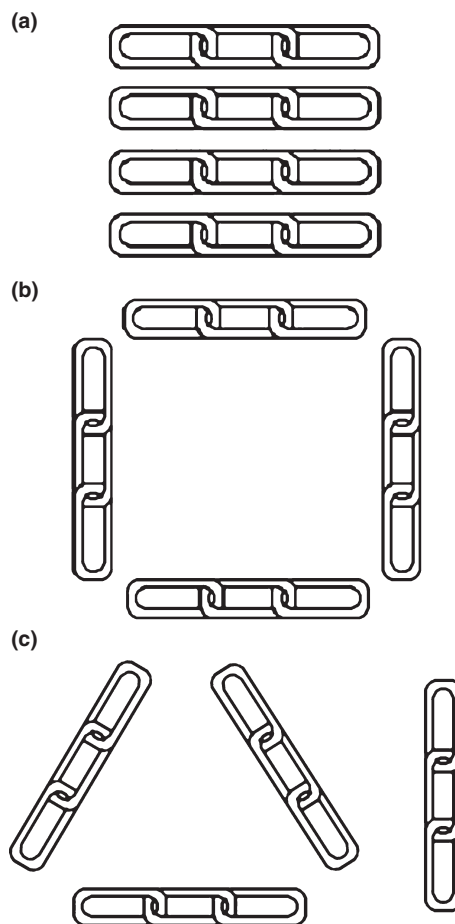


Figure 5 Application 5: (a) the initial cheap necklace state, (b) the ‘square’ state condition, and (c) the ‘triangle + chain on the side’ state condition. The new configurations act as a hint to avoid moves that lead to the wrong sort of progress.

work on the problem. Each participant was tested individually.

Results

Six out of 17 participants (35%) solved the problem in the original cheap necklace condition, 4/17 (23%) solved it in the ‘square’ condition, and 3/17 (18%) solved it in the ‘triangle + chain on the side’ condition (NS). Furthermore, participants’ moves showed their fixation on the hill-climbing heuristic: they kept trying to join two three-link chains in order to move closer to the goal. More surprisingly, even when acknowledging the futility of this naïve solution, they persevered with it in an attempt to act for the sake of acting (though with no escape from fixation).

Implication

The fifth lesson is that sometimes, the answer to our problem is staring us in the face and we need to detect the

subtle salient cues in our environment. Anaesthetists are often aware of subtle differences in features such as background noise. This is illustrated by an anecdote in which a consultant anaesthetist, when walking along an operating theatre suite, was struck by the noise coming from one of the theatres – the expiratory phase of the minute volume divider ventilator was shorter than normal. This sound was characteristic of disconnection and so served as a useful warning in the days before capnography, pulse oximetry and minimum monitoring standards. He entered the theatre and reconnected the ventilator hose to the common gas outlet before the trainee anaesthetist in that theatre had even become aware of a problem (K Myerson, personal communication). We can help promote an awareness of subtle differences by drawing the attention of trainees to drops in tone of the pulse oximeter and other such features.

Application 6: explore your environment

In the sixth experiment [9], attempts were again made to manipulate the availability of wrong moves to participants by attaching different costs of opening and closing links, and presenting a variation of the initial state.

Methods

Thirty-two undergraduates and postgraduates at Lancaster University were recruited. Sixteen served in the ‘late failure’ condition and 16 in the ‘early failure’ condition.

The initial state of the problem consisted of the original cheap necklace condition with the top chain A composed of two already opened links on either side of a closed link (Fig. 6). The solution again required the breaking of that chain by simply opening the middle link and then using the now three opened links of the chain to join the remaining three chains. However, in one condition, the ‘early failure’ condition, the costs changed to 5 cents for opening a link and 0 cents for closing one, and making 5 cents the maximum cost for the solution. Thus, following moves under hill-climbing, failure would occur early on (specifically at move two): after having closed the two already opened links (total cost of 0 cents), then opening a new link would cost 5 cents which is the total cost allowed for the solution.

For the ‘late failure’ condition, the costs changed to 0 cents for opening a link and 5 cents for closing one, with the maximum cost allowed 19 cents (the solution requires only 15 cents). Thus, under the assumption of hill-climbing moves, failure would occur later on (specifically at move five): after closing the two already opened links (at a total cost of 10 cents), opening a new one (0 cents) and closing it again (another 5 cents added, to a total of 15 cents so far), then having to open another

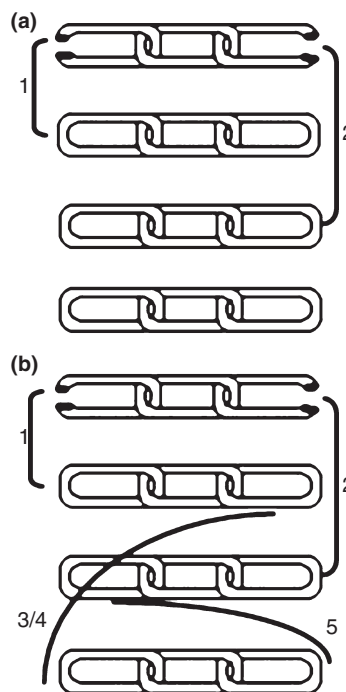


Figure 6 Application 6: (a) the ‘early failure’ vs (b) the ‘late failure’ conditions. The new configurations and their new associated costs act as a hint to avoid moves that lead to the wrong sort of progress. The numbered lines show the sequence of moves typically made in the naïve (‘hill-climbing’) approach.

one (0 cents) and close it back up again would exceed the 19 cents allowed for the solution.

Participants were allowed 10 min to work on the problem and were tested individually.

Results

Eleven out of 16 (69%) participants in the ‘early failure’ condition and 10/16 (62%) in the ‘late failure’ condition solved the problem (NS). Most importantly, the way the participants solved the problem varied. Serendipitously, while participants were manipulating the actual links of chain A – with the two already opened links – they happened to capitalise on the fact that one or both of these links fell from chain A. Trial and error was demonstrated by participants’ trying out different combinations, without explicitly putting aside a three-link chain.

Implication

The sixth lesson is that opportunities that arise in our environment should be exploited to our advantage, and sometimes mere trial and error can be an effective strategy, so long as we learn from those trials and errors. One of the components of fixation is that the protagonist does not learn and repeats the same action (for example continues to try to intubate rather than state ‘I have tried

intubation, I have varied several parameters – different position, different blades, use of cricoid force – and I continue to be unable to intubate, so I shall now abandon attempts at intubation and attempt to ventilate via the facemask'). The latter is an example of someone learning from error – intubation in this patient will be very difficult or impossible. It is not the persistent failure from each attempt but the additional information that one gains from action-oriented problem solving that may lead to a solution [3].

Application 7: recall of successful solutions to previous problems may interfere with the solution of new problems

The aim of this experiment was to examine the extent to which participants remembered the principle behind the cheap necklace problem solution and whether they could apply it to a new variant, the 4-4-2-2 variant (referring to the number of links in each of the four chains of the new problem; Fig. 7). The 4-4-2-2 variant requires the decomposition of one two-link chain into two separate links (to connect two chains) and then merely the connection of the newly formed chain with the remaining one.

Methods

This experiment was an extension of the experiment in Application 3, above. After completing the experiment described above, the participants were given the solution to the problem in written form as a sequence of link breaks and joins. They were then engaged in an unrelated 'filler' task for 4 min. After that, they were given 5 min to solve the 4-4-2-2 variant. All participants were finally asked to re-solve the original cheap necklace problem at the end of the testing session.

Results

Four out of 21 participants (19%) solved the 4-4-2-2 variant having previously served in the original cheap necklace condition and 6/22 (27%) solved it having

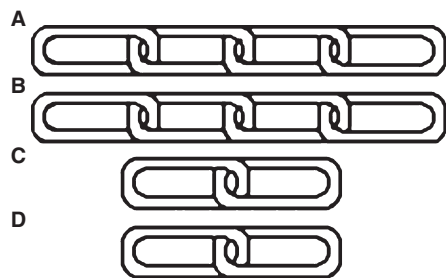


Figure 7 The 4-4-2-2 variant of the cheap necklace problem. The task is to connect all four chains so as to form a complete closed necklace as before.

previously served in the hint condition. Although solution rates overall were significantly higher for the 4-4-2-2 variant (10/43; 23%) than for the cheap necklace problem (3/43; 7%; $p = 0.016$), suggesting a positive transfer from one problem to the next, seeing the solution to the cheap necklace problem was not a sufficient condition for producing the solution to the 4-4-2-2 variant. Even though they once again needed to open three links only, the majority tried to connect chains together, without breaking any chain. The possibility that participants forgot the solution to the original cheap necklace problem can be ruled out, for all 43 participants were able to re-solve it within 2 min.

The failure to reproduce easily a solution to the cheap necklace problem in a perceptually and conceptually related problem leads to the conclusion that participants fail to generalise this procedure to an analogous problem, which is evidence of a procedural encoding of the solution and a lack of conceptual recoding. There was further evidence that a procedural recoding was in operation for failed solutions to the analogous problems, as some participants did break three links but not the correct ones that would lead them to solution. Maybe participants remembered the procedure of breaking three links, but could not apply this procedure to the current problem. One question that this result raises is whether individuals spontaneously encode the conceptual insight (of breaking up a whole chain) when shown the solution to the standard problem. It may be that participants simply encode the procedure without attending to, or considering, reasons why a solution worked for the problem.

The question of order of the above insights impinges on our results. Could it be that those who have the procedural insight but not the related conceptual insight are unable to transfer to a variation of the cheap necklace problem, whereas only those who have the conceptual insight are likely to transfer? We cannot ignore the possibility that procedural knowledge is required first, so that people can then extrapolate the necessary conceptual knowledge in order to transfer. This raises the question of whether a conceptual insight can lead to an appropriate procedure.

Implication

This experiment provides us with our seventh lesson: we need to acknowledge the tension between prior knowledge and goal-directed behaviour. Sometimes, the current situation or our past experience leads us astray: when the current situation is incongruent with our past experience, we still persevere with what we already know to the detriment of trying something new [14]. Procedural insight may precede the conceptual insight and may be necessary for conceptual insight to occur. As

with Application 3, it may be helpful to explore the limitations of existing knowledge by using table top exercises to think about new solutions. In such circumstances the learner does not have the deterioration in cognitive function that occurs in the real world, when patients' lives and wellbeing are at stake, and so may be able to explore the limitations of existing procedures and by so doing, better understand the underlying concepts.

Application 8: being shown the solution does not equate with solving the problem

What is the difference in re-solution and transfer between those who solved the cheap necklace problem and those who were shown the solution to the cheap necklace problem? Previous research [15] suggests that only those participants who had constructed the solution would re-solve the problem, and not those who had simply read the solution. In the transfer experiment in Application 7, most participants were able to reproduce the solution to the problem after a 2-week delay. The only difficulty was in transferring their acquired knowledge from the original cheap necklace problem to its variant, the 4-4-2-2. Along this line of thinking, we propose that a procedural recoding of the solution can be achieved by mere exposure, that is, being shown or having read it, whereas the conceptual recoding, associated with insight, can only be achieved by elaboration after the solution attempt.

Implication

Thus experiment 7 also provides us with our eighth and final lesson: whether one solves a problem by oneself or is shown the solution by another, it is still possible to solve the exact same problem again later on. However, being shown the solution is not adequate for transferring knowledge to another analogous problem. An in depth understanding of solutions to problems (i.e. what is the solution and WHY, and how can one reach it) is of paramount importance. Again, this has major implications in terms of the transfer of knowledge and so education of anaesthetists.

By their very nature, professionals work in a world in which solutions that were successful in previous presentations of problems may not be successful in future presentations of those same problems. Professionals have to develop a practical wisdom (phronesis), referred to by Della Fish [16] in several of her books, that helps them apply existing solutions or create new solutions.

Conclusion

There is no simple fix for fixation. The countermeasures for fixation errors in anaesthesia require us to understand

how the cognitive processes described above relate to anaesthesia, especially when risk and time pressures are added to the mix. By describing the above applications, we hope to provide some approaches to creating and developing countermeasures to fixation. Awareness has been proposed as a general strategy to improve problem solving in anaesthetic practice [3]. By enhancing awareness of problem solving patterns, such as fixation, practitioners can assess their own tendencies toward fixation and thus develop appropriate measures against it.

One possible measure against fixation can be derived from the Bromiley case. The anaesthetists involved in the repeatedly unsuccessful treatment were oblivious to their fixation, but the attending nurses recognised the problem. Practitioners could thus be advised to use other people as a source of insight. Of course, other people are not always conducive to avoiding fixation, but can actually exacerbate the problem. The conditions under which fixation can be avoided or reinforced due to other people could be empirically tested in the future.

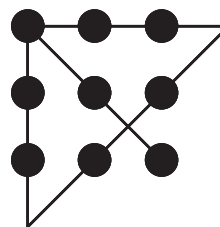
Training can be enhanced by our initial recognition of these faulty problem solving patterns. Simulations that increase awareness of the potential problems with routine, as well as non-routine, cases could accelerate practitioners' pace at which learning evolves and increase speed of recognition of a problem.

As our experiments here suggest, recognising that something is not working is not sufficient: one must produce the correct alternative. Alternatives are constrained by the nature of the task: in our laboratory controlled setting, the alternatives for the cheap necklace are limited (i.e. participants either produce the naïve solution or they actually solve the problem). In anaesthetic problem solving, though, the alternatives are constrained further by the patient, the other members of the operating theatre team, and the environment itself. Creating conditions in a safe educational setting where practitioners can explore their fixations, become aware of the conditions that harvest these fixations, and explore their own ways of eliminating them, might lead to better anaesthetic problem solving and consequently to a sustained improvement in patient safety.

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Solution to Figure 4.