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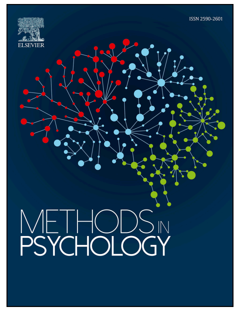

Kinenoetic Analysis: Unveiling the Material Traces of Insight

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PII: S2590-2601(21)00026-6

DOI: https://doi.org/10.1016/j.metip.2021.100069

Reference: METIP 100069

To appear in: *Methods in Psychology*

Received Date: 16 October 2020

Revised Date: 28 June 2021

Accepted Date: 23 July 2021

Please cite this article as: Ross, W., Vallée-Tourangeau, Fréé., Kinenoetic Analysis: Unveiling the Material Traces of Insight, *Methods in Psychology* (2021), doi: https://doi.org/10.1016/j.metip.2021.100069.

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Kinenoetic Analysis:

Unveiling the Material Traces of Insight

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Abstract

Research on insight problem solving sets itself a challenging goal: How to explain the origin of a new idea. It compounds the difficulty of this challenge by traditionally seeking to explain the phenomenon in strictly mental terms. Rather, we suggest that thoughts and actions are bound to objects, inviting a granular description of the world within which thinking proceeds. As the reasoner transforms the world, the physical traces of these changes can be mapped in space and time. Not only can the reasoner see these changes, and act upon them, the researcher can develop new inscription devices that captures the trajectory of the creative arc along spatial and temporal coordinates. Kinenoetic is a term we employ to capture the idea that knowledge comes from the movement of objects and that this knowledge is both at the level of the problem-solver and at the level of the researcher. This form of knowledge can only be constructed in problem solving environments where reasoners can manipulate physical elements. A kinenoetic analysis tracks and maps the changes to the object-qua-models of proto solutions, and in the process unveils the physical genesis of new ideas and creativity. Our aim here is to lay out a method for using the objects commonly employed in interactive problem-solving research, tracing the process of thought to elucidate underlying cognitive mechanisms. Thus, the focus turns from the effects of objects on thoughts, to tracing object-thought mutualities as they are enacted and made visible.

Kinenoetic Analysis: Unveiling the Material Traces of Insight

Problem solving is manifest whenever a living creature navigates an uncertain world. The problems it faces can be mundane and demonstrably rooted in the resolution of uncomfortable physical states– how to get enough food to eat to remove the physical feeling of hunger – or far more abstract yet still uncomfortable states – think of philosophers wrestling with problems such as the nature of derived content. Simply put, problem solving in all its forms is an essential part of lived experience; the resolution of ignorance, is foundational to understanding how people gain knowledge (Arfini, 2019).

Problem solving in its more abstract form is also an example of the kind of effortful thinking considered as a form of so-called ‘higher’ cognition. The cognitivist research tradition favours studies of a quantitative nature (Ball & Ormerod, 2017; Bickhard, 1992; Kuiken et al., 1992; Smythe, 1992). The problem for such a research programme is to uncover invisible or unconscious thought processes. This it typically does through experiments which assume that problem solving proceeds through a rational and generalisable manner. Other methods employed are eye tracking which aims to uncover thought as expressed through attention or brain scans which track thought in terms of brain activity. The work presented in this paper aims to strengthen our understanding of problem solving and thought by suggesting an additional method of tracking cognition which complements existing research programmes. We present a kinenoetic analysis of cognition, a method which is observational in nature and draws from work on the extended mind (e.g., Wilson & Clark, 2009), cognitive archaeology (e.g., Malafouris, 2020) and science studies (e.g., Latour & Woolgar, 1986) to support the notion that thinking is reflected and even, more strongly, constituted by actions in the world.

Kinenoetic is a term we employ to capture the idea that knowledge comes from the movement of objects. It is thus both a form of knowledge and a methodology for tracking that knowledge: this form of cognition is only evidenced in environments where problem solvers can interact with objects and these interactions with objects leave measurable material traces. The gulf between epistemology and ontology is collapsed since what the reasoner knows and what is in the world are co-constructed (they "co-respond" as Latour [2013, p. 86] puts it). These material traces become an experimental artifact and an object of interest. A kinenoetic analysis tracks and maps the changes to the object-qua-models of proto solutions, and in the process unveils the physical genesis of new ideas and creativity.

Kinenoetic analysis is predicated on two inter-related methodological practices. The first reverses the traditional direction of competence and performance. Kinenoetic analysis foregrounds action on a material object as the antecedent of knowledge or meaning, not as its consequent: "Competence follows performance rather than preceding it" (Latour, 2013, p. 230). The second is a granular description of changes in the object that hamstrings the traditional reflex of endowing intentionality to the agent, intentionality that begs an explanation rather than providing one; postulating intent requires explaining the nature and origin of intent, deflecting theoretical attention away from the world in favour of the agent, and more specifically what is in her head. Objects are made to do something (or in French *faire faire*), and it is the performance of the object that provide hints and cues to new knowledge.

Insight Problem Solving

Research in problem solving commonly focuses on two sorts of problems: Analytical problems and insight problems. Analytical problems are those which can be solved in a step-by-step manner (such as mental arithmetic), while insight problems require a leap that crosses discontinuities between an incorrect problem representation to a more fruitful one. Take for example the classic insight task: the 17 animals problem. The problem invites participants to solve the following riddle: how to distribute 17 animals in four enclosures such that there is an odd number of animals in each enclosure. The problem masquerades as a simple arithmetic one, and naïve participants labour fruitlessly in their attempts to identify which combination of 4 odd numbers can add to 17, an impossibility with whole numbers (indeed some participants sometimes suggest that carving up animals is the only possible solution). The hypothesised moment of insight comes when the participants realises that a potential solution involves overlapping pens which allow some animals to be enclosed in more than one pen.

The challenge or the "puzzle of creative cognition" (Ohlsson, 2018, p. 12) is how to develop a model of the origin of a novel thought from a closed system that does not contain that thought. Insight research, on this view, is fundamentally concerned with the cognitive capacity to conjure something from nothing or indeed, if this capacity even exists. Whereas analytical problems lend themselves to computational modelling which relies on culturally predetermined model of normative problem solving (although see Lave, 1988; Nunes et al., 1993 for suggestions that this normative approach is not always followed), the underlying tension in insight problem solving is that the process by which a new thought is generated is unclear to the researcher or indeed the participants under scrutiny. Despite some bold attempts, this type of problem solving generally struggles when investigated or measured using typical methods from cognitive psychology which are dependent on normative and algorithmic assumptions. Simply put, insight is idiosyncratic and hard to reliably elicit (Batchelder & Alexander, 2012; Chu & MacGregor, 2011).

The disciplinary conceptual framework of the cognitive psychologist naturally orients her focus on content and mental processes, away from the broader physical and social context in which discovery happen. To crank up data fast in a cost-efficient manner, creative cognition laboratory workers need their fruit flies and naïve participants cannot be presented with very complex problems. Rather, university undergraduates are presented with batteries of simple riddles and word associate problems, each presented for a few minutes (or seconds) and participants' performance is aggregated in terms of solution rates or mean latency to solution. Problems vary in their numerical, logical or visuo-spatial aspects; they are made easier or harder to solve (by adding irrelevant and misleading premises); the phenomenology of discovering the answer is sometimes measured, to capture the qualia of 'aha' moments. Sometimes participants are immobilized in a scanner, and the neural correlates of insightful solutions are imaged in coloured areas of brain activity.

In an attempt to develop abstract computational models of how mental representations are transformed to yield new ideas and solutions, laboratory research on insight often glosses over key features of creative problem solving as recounted by scientists, artists and engineers (Glăveanu et al., 2013; Vallée- Tourangeau & March, 2020). From these we learn that the development of knowledge, the genesis of new ideas, the production of a work of art, proceeds on the basis of gradual transformations of physical objects along a contingent arc. What is transformed are objects, be they sentences, experimental apparatus, canvases, lumps of clay. Each change in the object triggers new perceptions and new actions that enact change in the object in an iterative loop. Accepting this interdependence of thought and object requires a different methodology. It is no longer enough to assume that a disconnected thought is the same as an embedded one. The traditional quantitative methods of cognitive psychology may not be able to fully investigate problem solving that unfolds in this way. To do such work justice we need to step outside disciplinary allegiances and look to work in more embedded research fields which adopt a more descriptive and inductive approach to understanding interaction in the world.

Interactivity

Experimental cognitive psychology has not been immune to the need to include things outside of the head in its models of how we think. In the main, this area of work is dominated by embodied cognition but here we are less interested in the extension of the mind into the body than the development of object-thought mutualities. That is, we are interested in the thinking that arises when objects and thoughts are bound together through actions so that understanding of one is dependent on the other. Until now, much of the research on this mind-world coupling has comes from the area of interactivity. Interactivity describes the coupling of the agent with her environment. It commonly proceeds by allowing an experimental participant access to malleable physical problem representations and assesses whether this leads to improved performance. It has both a computational basis, items from the external world are often "recruited" and an ecological one—it is a form of "sense saturated coordination that contributes to human action" (Steffensen, 2017, p. 86). The agent is both active and yet constituted by those same actions and it is thus better seen as a systemic rather than agent-centred approach to cognition. A systemic approach suggests that cognitive processes are fundamentally changed when in interaction with the environment and so requires an experimental procedure that reflects that.

Experimental research in interactivity traditionally contrasts low interactivity environments with high interactivity ones. Participants are presented problems which invite and allow an interaction with the environment typically in the form of movable external representation such as numbered tokens (e.g., to solve arithmetic problems; Ross et al., 2020; Vallée-Tourangeau, 2013) or letter tiles (e.g., in a word production task; Maglio et al., 1999; Ross & Vallée-Tourangeau, 2021). However, people can also be invited to interact with more complex physical objects such as string and thumb tacks (Chuderski et al., 2020) or even jars and water (Vallée-Tourangeau et al., 2011). These artefacts can be actual objects (e.g., Fioratou & Cowley, 2009) or digital representations which can be moved on a tablet (e.g., Vallée-Tourangeau et al., 2020). The only constraint is that they must be able to be moved and transformed. Necessarily, these are 'first order' problems (Vallée- Tourangeau & March, 2020), that is problems which invite the participants to solve them through and with the environment rather than problems which take the form of riddles or other similarly abstracted mental tasks (and hence engages what we term 'second order' thinking; what Clark [2010, p. 23] refers to as 'off-line reasoning').

In a high interactivity condition, the participants are invited to move the artefacts as they choose. In the low interactivity condition, their movements are limited or constrained. The exact nature of the low interactivity condition and the movement constraints vary across studies: participants are sometimes given pencil and paper (Chuderski et al., 2020), or they are allowed to move freely without rearranging artefacts (Ross & Vallée-Tourangeau, 2021) or their movements are restrained, with hands laid flat on the table (Vallée-Tourangeau et al., 2016). What is constant across these operationalizations is the static nature of the initial problem presentation: it cannot be physically transformed or modified.

The research programme into interactivity thus far aimed to demonstrate the augmentative effect of cognitive extension. An experiment has 'worked' if it establishes that performance is better in the high interactivity condition. Indeed, the empirical data from the research in interactivity strongly supports that engaging with external, movable representations changes performance and, by implication, underlying processes whether for Bayesian reasoning (G. Vallée-Tourangeau et al., 2015), insight problem-solving (Vallée-Tourangeau et al., 2016) or mental arithmetic (Ross et al., 2020). This suggests that embedding participants in a materially rich environment will improve human performance which has important implications beyond the laboratory (Vallée-Tourangeau & Vallée-Tourangeau, 2020). However, the evidence reported is inconclusive at times: interactivity does not result in improved reasoning performance in all circumstances and across all levels of individual differences or tasks (Chuderski et al., 2020; Maglio et al., 1999; Ross & Vallée-Tourangeau, 2021).

Object-thought Mutualities. Until recently, while embracing an externalist and complex view of cognition, the interactivity research programme was by and large solidly anchored in a quantitative research tradition. Our aim here is to outline a method for using the objects commonly employed in interactive problem-solving research not as an experimental manipulation but rather as an instrumentalized procedure to trace the process of thought. Thus, the focus turns from the effects of objects on thoughts, to tracing object-thought mutualities as they are enacted and made visible. Our critical reflections are geared to explore more fully the promissory note that any interactive task environment offers to researchers willing to adopt a more qualitative approach. An interactivist perspective on insight invites a shift in methodology, a shift that has been resisted in past research efforts on the role of interactivity in cognition (with some notable exceptions, e.g., Steffensen et al., 2016). Laboratory research on creativity that crafts task environments where participants can interact with a physical object invites the careful description of the agent-world coupling. As an agent transforms the world, the physical traces of these changes can be mapped in space and time. Not only can the reasoner see these changes, and act upon them, the researcher can develop new inscription devices that captures the trajectory of the creative arc along spatial and temporal coordinates. A shift to a more qualitative capture of the genesis of new ideas is the logical development afforded by the four elements of an interactive problem-solving task environment: (i) actions, (ii) objects, (iii) space and (iv) time.

Objects and artifacts have been the focus of qualitative research, of course (for a review, see Chamberlain & Lyons, 2017). Objects, their creators, users and collectors, can be interrogated; the role of objects as actants in configuring systems and networks within which distributed agency emerges has been well documented (e.g., Latour, 1999). Humphries and

Smith (2014) outline different object-centered programmes of research in terms of their biography, materiality, and practice. Kinenoetic analysis focuses on their *movement* and *transformation* along a creative arc that can span different time scales (viz., the condensed time scale of the cognitive psychologist who explores problem solving in a short time interval, to the ethnographer of a work of art that traces its evolution and transformation over weeks or months). It focuses on the observable and verifiable actions on objects. The researcher's knowledge in these cases comes from the movement of object-thoughts in the world rather than from a contemplation either of cognitive process abstracted from the world or self-constructed life worlds. The data here are not generated by text-based analysis but by observations of behaviours and actions. These observations come from a mapping of the physical nature of these transformations of and actions on objects in space and time.

Kinenoetic analysis focuses on tracking changes in the world, changes in objects, rather than the conjectured changes in the creator's mental representation of these objects. The form of kinenoetic analysis described here is made possible by the detailed scrutiny of video data and the instrumentalization of the problem task so that it becomes both measure and instrument. Qualitative work sometimes addresses the creative process through the understanding of the participant (Lahlou, 2011) but this is not the aim here and indeed the qualitative nature of the data should be dissociated from a qualitative epistemological position; this connection is not a logical or necessary one. There is a tendency for methods to be subsumed under the philosophical position and the contents of the methods less important than the research philosophy which underpins them (Niglas, 2010). Bryman (2007) reports that mixed methods researchers struggled to integrate research from both traditions because they view the two areas of research as distinct paradigms with distinct epistemological allegiances. We argue that this is not necessarily the case and the link between a constructivist epistemology and qualitative data risks sequestering methods into rival camps at the expense of the research question. The work here proceeds from a pragmatist position which suggests that researchers should recruit the methods which most suit the research question (Cornish & Gillespie, 2009; Engel et al., 2013). Kinenoetic analysis combines three levels of investigation of the problem with different epistemological underpinnings to shed light on complex processes.

Qualitative Approaches in Creative Problem-solving Research

A so-called pure insight sequence, the sequence that has exercised problem solving researchers since Köhler (1925) can be characterized in terms of the following stages: a reasoner labours a solution but efforts are motivated by an incorrect interpretation of the problem. In theory, an impasse inevitably ensues, leading to a period of despondency and inactivity; the aha moment is the sudden breakthrough, the new felicitous interpretation of the problem that re-energizes the reasoner to think more productively about the problem and achieve a solution. Crucially, researchers pinned their efforts on equally 'pure' insight problems (Weisberg, 1995), an a priori carving of problems into two natural kinds: those requiring insight for their solution, and other problems, analytic problems—e.g., mental arithmetic or the Tower of Hanoi—which can be solved in the absence of an insight sequence, since the agents are said to understand the nature of the solution and the operators required to transform the start state into the goal state.

While insight problem solving is still dominated by a quantitative research programme, some of the more important findings recently have come from more qualitative approaches. These finding have cast doubt on the idea of a pure insight sequence which can be extracted from aggregated scores whether that is on a procedural or phenomenological level. It is important to note that these qualitative approaches offered the only way that the pure insight sequence rhetoric could be challenged. Prior to this, certain aspects were assumed because they were built into the model and hence were sheltered from critical reflections. However, there is converging evidence that points to equifinality in the problem-solving solution and this needs to be considered in building predictive models: There are many different routes to the same solution and there is no guarantee that any two problem solvers will reach the same answer via the same route so taking problem solution rates as evidence of process may not be helpful. The qualitative research to date has taken two main forms: in task verbal protocols and post task self-reports. There have also been attempts to map the idiosyncratic nature of the thought process in insight through detailed case studies. Here we briefly review these before moving on to illustrate our own contribution to this growing and important literature.

Verbal protocols

Verbal protocols are perhaps the most common way of tracking process. They consist of asking participants to speak while they are performing a task, in this case solving a problem. There are two main problems with this, one theoretical and one practical. First, cognitive psychology posits the presence of unconscious processes which are beyond understanding (Ball & Ormerod, 2017) and so reliance on an individual's in-the-moment introspection may mean that important processes and explanatory factors that occur outside of the problem solver's conscious awareness go unnoticed. Therefore, it is a technique for understanding the information which participants are paying attention to rather than all the contributory factors. Second, the use of these think aloud techniques may have overshadowing effects: speaking while problem solving may change the process. However, the extent to which this affects performance on insight tasks is unclear (Fleck & Weisberg, 2013). Despite this, think aloud protocols have many benefits for fleshing out process beyond analysis of latencies or binary performance outcomes. For example, Fleck and Weisberg's (2013) study employed verbal protocols specifically to examine when and how often a "pure" insight sequence occurs with participants working on insight problems. The data they report from this more granular, process-based method suggests that the nature of insight is more complex and diverse than existing models (e.g., Ohlsson, 1992; 2011) may assume. It is interesting to note that the verbal protocols cited at length in Fleck and Weisberg (2013) were taken from participant working on solving a problem with a physical model of the solution. One of these problems was the triangle of coins problem (as described more fully below). The changes in the physical configuration of the problem were observed by the participant, which cued new actions, promoting the dynamic transformation of the model of the solution. The verbal protocol procedure employed by Fleck and Weisberg was not coupled to a detailed coding of the actions and changes to the model of the solution. Thus, in the absence of a granular temporal juxtaposition of narrative and physical transformation, the verbal protocols may reflect a post hoc narrative of actions and their consequences, and as such offer a distorted window on the actual process that drove problem solving activity (see Vallée-Tourangeau, 2014).

Self-report

The other evidence for different ways of solving the problem comes from reports from participants themselves. These reports are often collected after the task and relate to the feelings elicited on realizing the solution to the problem. Insight is considered to have a distinct phenomenological marker, corresponding to the impasse resolution stage. Research from Webb and colleagues (2016, 2018) across two studies using these post task reports now suggest that the binary split between analytical and insight problems, a key theoretical foundation stone, may be misplaced. Rather, insight is idiosyncratic and unreliable and is not guaranteed by a certain class of problems. However, there are problems with self-reports. As outlined above, the processes leading up to insight are theoretically not consciously available to the problem-solver limiting the usefulness of the reports. In addition, self-reports rely on the participant in the experiment having the same understanding as the researcher and it not clear, certainly for insight, that is always the case (Bilalić et al, 2021).

Theoretical models of the cognitive processes underlying insight problems have been updated after behaviour and self- report are taken into account; the moment of impasse has been downgraded and the realisation that problems are solved in diverse ways which cannot be easily modelled from the problem itself. In the instances of the measuring of phenomenological approaches to insight, it is still unclear that this adds to an explanation of process. The distinction between phenomenology and process is being collapsed and problems which generate higher self-report scores of insight are said to be solved more insightfully but as evidence emerges that propensity to experience insight may be an important individual difference (Webb et al., 2021), the link between phenomenology and process needs to be established rather than assumed.

Kinenoetic Analysis

We recently explored how people discover the solution to a traditional “insight” problem, namely the triangle of coins (AUTHORSa). The problem is presented as 10 coins that configure a triangular shape pointing down (see Figure 1 top panel). The goal is to transform the shape into a triangle that points up. Unconstrained, people can easily conjure up the solution. The impasse is created with the following constraint: only three coins should be moved to achieve the solution. The conceptual shift concerns the status of the coins as contenders for movement. At the start all 10 coins are plausible candidates. The interpretation of the problem is restructured when participants understand that not all coins are equal contenders; only the corner vertices should be moved. We instrumentalized this traditional problem by laying out the coins on a 9 x 9 grid with numbered rows and lettered columns; we also labelled each coin (the corner coin labels are colour coded here, but they were not for the participants in our experiment).

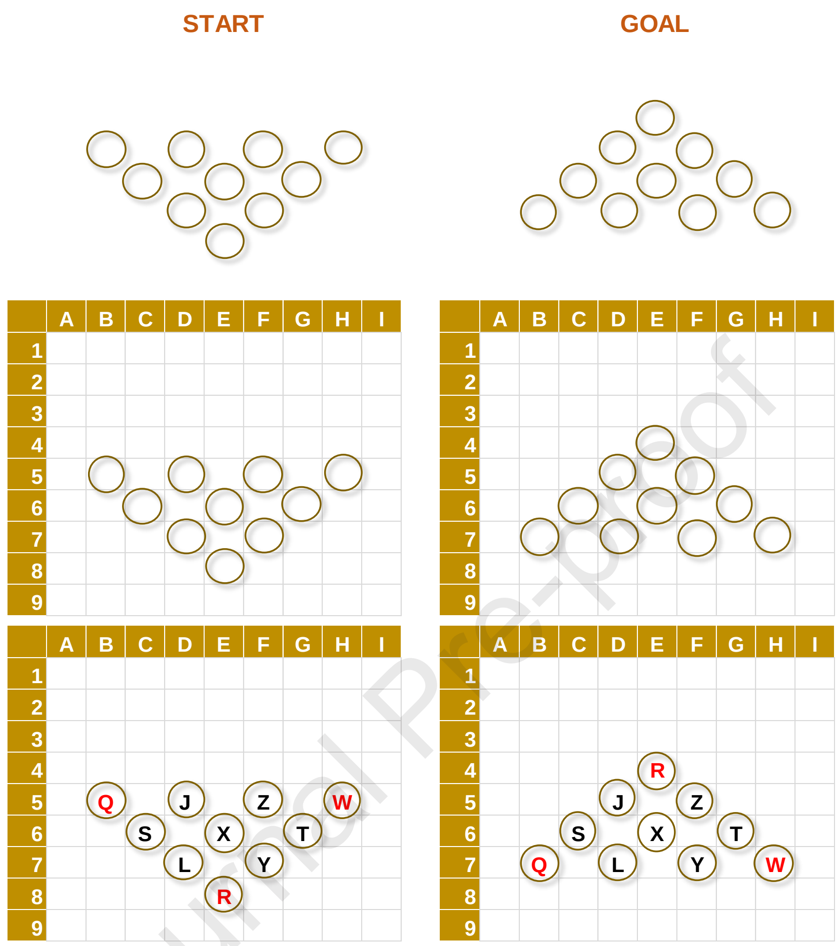


Figure 1. Instrumentalizing the triangle of coins problem.

We presented the problem on a computer tablet (see Figure 2) with which participants can touch, move and ‘drop’ coins on the grid as they labour to discover the solution. Each move transforms the physical presentation of the problem. This physical presentation is the object that is manipulated by the participants. We filmed the participants, and then coded the videos to extract each change in the physical presentation of the problem, mapping in granular detail the spatio-temporal changes to the proto-solutions that eventually corresponded with the normative configuration. Participants can *see*, rather than mentally simulate, the physical result of these transformations. In turn, as researchers, we can capture more precisely and *see* the trajectory of changes.

The triangle of coins problem is a difficult problem: fewer than 10% solve the problem with their first three moves or solve it quickly. Participants work long and hard, exploring many different configurations; rather than a sudden flash of insight, solutions are enacted gradually. Take, for example, the frame by frame changes to the problem presentation enacted by one of our participants (Figure 3; these are the last 20 moves leading to the discovery of the solution; this participant solved the problem with 71 moves). The first two rows in Figure 3 illustrates a common but unproductive strategy, namely moving coins up (e.g., see configurations created after move 54, move 60) resulting in configurations that force participants to move more than three coins to achieve the solution. The last two rows (moves 62 onwards) illustrate a more productive strategy, namely moving coins down to, widen the base of the triangle. Note, however, that the participant cannot be said to have mentally simulated the solution but rather, these more productive configurations encouraged and prompted different movements, that eventuated in the solution.

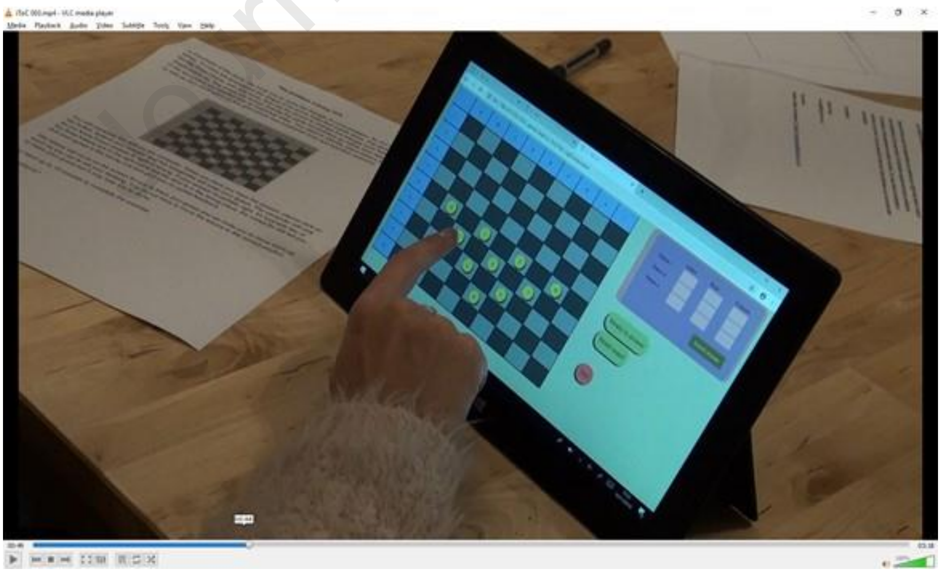


Figure 2. The triangle of coins problem programmed on a tablet; participants are filmed working on the problem. Each move and resulting transformation of the problem presentation can be coded along with the move latencies.

Figure 3. The last 20 moves and resulting transformation of the problem presentation leading to the discovery of the solution by a participant.

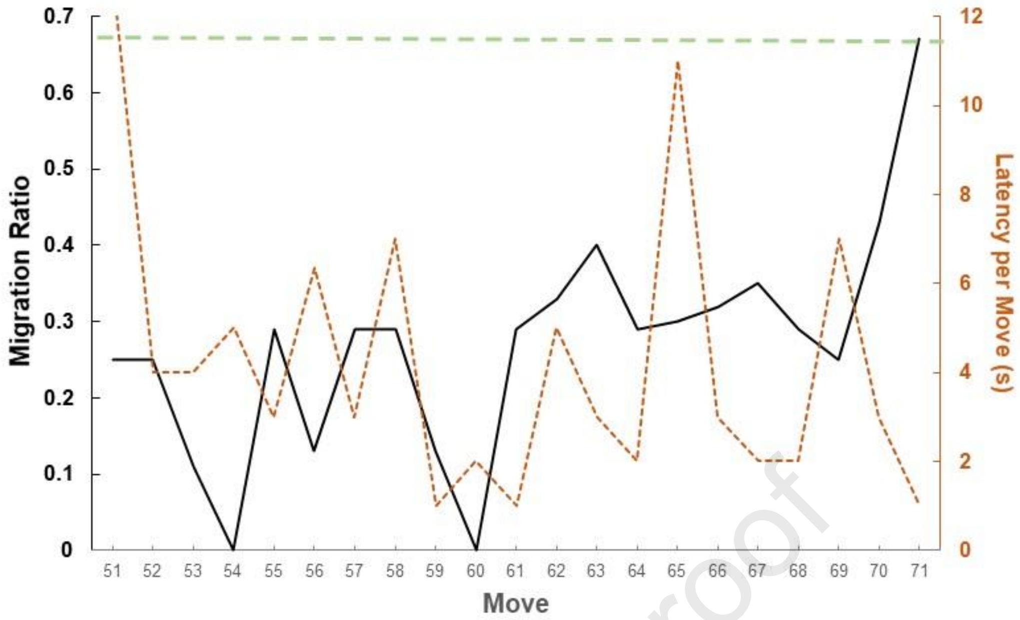


Figure 4. The migration ratio (primary y axis) and latency per move (secondary y axis) for the last 20 moves of a participant working on the triangle of coins; these data correspond to the last 20 moves illustrated in Figure 3 above. The green dotted line is the target migration ratio that corresponds to the solution of the problem.

To capture the spatio-temporality of the construction of the solution, we developed an index termed the migration ratio which gauges the degree to which the configuration of coins approximates the normative configuration. The target migration ratio[1] that corresponds to the correct configuration is .67, and Figure 4 plots how this migration ratio evolved for the moves made by the same participant whose last 20 moves were illustrated in Figure 3. Based on the video data, we could measure the latency per action that changed the configuration, and this is plotted on the secondary axis of Figure 4. This figure enables us to see two key aspects of creative problem solving. The first is that a productive configuration evolves slowly over trials, with much turbulence as the right configuration takes shape before the

[1] The migration ratio is the ratio of coins on row 7 over all coins above on the grid: in the start state the ratio of coins in row 7 over all coins above is 2/7 or .29 (see Start panel in Figure 1). The goal state involves widening the base of the new triangle on row 7, thus migrating down the two corner vertices (coins Q and W) on that row, resulting in a migration ratio of 4/6 or .67 (see Goal panel in Figure 1). Calculating the migration ratio after each move mapped a participant's efforts to create a configuration that would more productively evince a solution.

correct one is constructed (as illustrated by the primary data series plotted with the black line); the second is the variability in latency per move: some moves are enacted quickly, other much more slowly (plotted as the secondary data series with the dotted line). Latencies drop sharply once the correct configuration is produced, and at this point, the agent's knowledge of the solution and its physical realization are correctly aligned. And while the last few moves are quite quick, the video evidence suggests that the participant reified a solution, but actions were not predicated on a clear hypothesis: That's because upon observing what he had done, the participant physically expressed surprise: rather than experiencing insight, the participant seemed to have experienced 'outsight': the solution appears to have caught him off guard as it were (the video can be accessed here https://youtu.be/ZZSC549UyTg; note the sudden exclamation of success at 0:00:07 *after* creating the solution).

Uncovering Novel Mechanisms: Serendipity Found and Lost

We have conducted similar detailed research on performance on word games, both Scrabble ™ style tasks (AUTHORSb) and anagrams (AUTHORSc). The use of movable, lettered tiles allowed us to take a granular approach to the process of problem solution and map strategies using the letters on the tiles as a natural path marker. Importantly, this allows us to track what happens when people do not get the correct solution which can occur for many as yet unexplored reasons. Mapping the process of problem solution as it unfolds over the course of problem-solving trials, we can pinpoint the moments of transformation from a state of ignorance to one of knowledge through action but also when that transformation was thwarted. Word tasks are particularly suited to this sort of analysis because the changes of the letter arrays can be clearly mapped and proximity to a solution can be more easily measured.

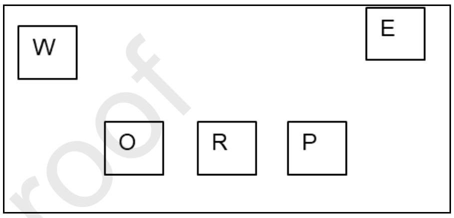
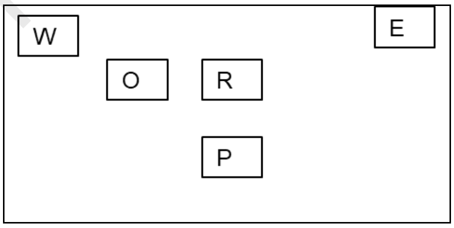
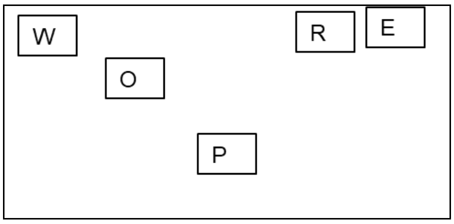
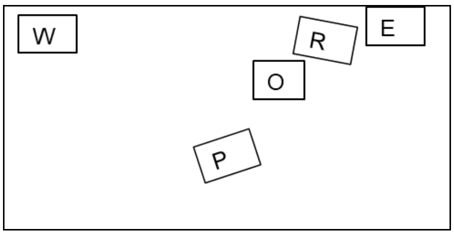
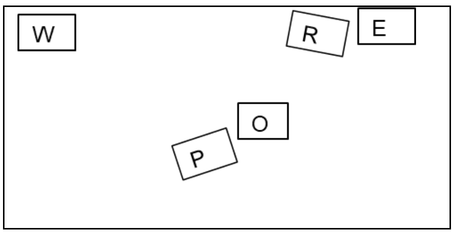
By viewing experiments not as measures in support or not of intuitive hypotheses but as tools to observe the formation of soft assembled cognitive systems under controlled circumstances, we open up the research field to other explanatory factors. Take for example the role of accidents: When participants are provided with cognitive artefacts to scaffold their thinking either as part of intentional focus as in research in interactivity or as an unconsidered artefact of the environmental set up, the idea of chance is often mentioned. Fioratou and Cowley (2009), for example describe a version of the cheap necklace problem and suggest that 6 of the 21 solvers (almost a third) solved the problem through the exploitation of an accident. This same observation occurs in Chuderski et al. (2020, p.18) who suggest that "in the [interactive] matchstick algebra problem, it is arguably easier to arrive at the solution by accident or trial and error, for instance by realizing as a result of a random movement of a stick that it could act as a negative sign." In one of the few qualitative approaches to insight problem solving, Steffensen et al.'s (2016) finely grained analysis of problem solving (using the 17 animals problem described earlier) suggests that the solution hangs on an accidental moment.

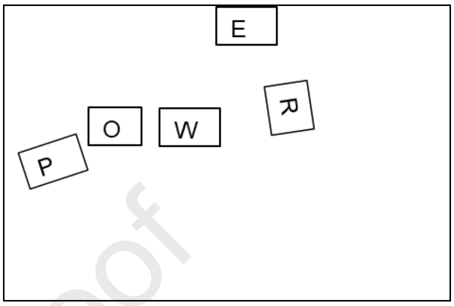
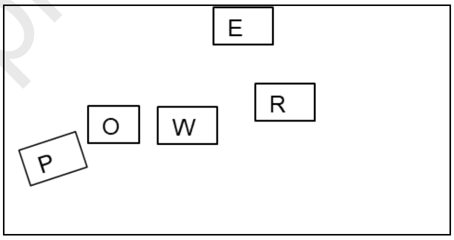
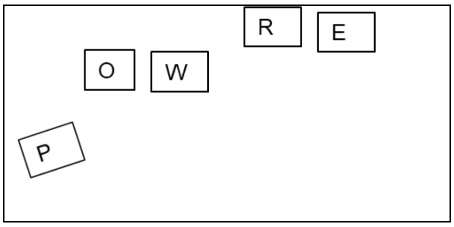
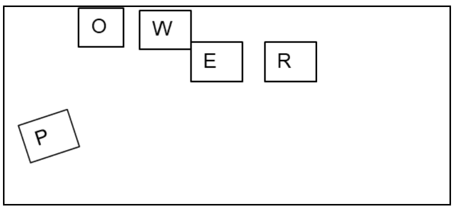
The course of this analysis has allowed us to elucidate the moments when a problem solver is close to the answer through the arrangement of tiles during which we uncovered moments of accidents which were responsible for the genesis of new ideas. Take for example, a participant in the word production task who was working with the letter set COTFAED. After making the word DEAF the three letters COT were left in full view. Much as the participant above who recognised the solution to the triangle of coins after constructing it, this unplanned moment of success was accompanied by clear phenomenological markers akin to the affective markers of insight (the video can be accessed here: https://youtu.be/3sV1vdM-93k).

The same accidental and unplanned solving was true of the anagram tasks as illustrated by a participant working towards the solution of the word POWER (see AUTHORSc).

Table 1

A Participant Solving the Anagram WORPE; Each Letter Tile Move Results in a Change in the Array of Letters (Shown on the Right Column).

Time (s:ms from start of problem)	Description	Resulting Array
15.241	Starts to move the P	
15.741	P dragged to below the main array	
16.375	R moved out of way	
17.310	O moved down next to P	
18.411	P and O grouped together	

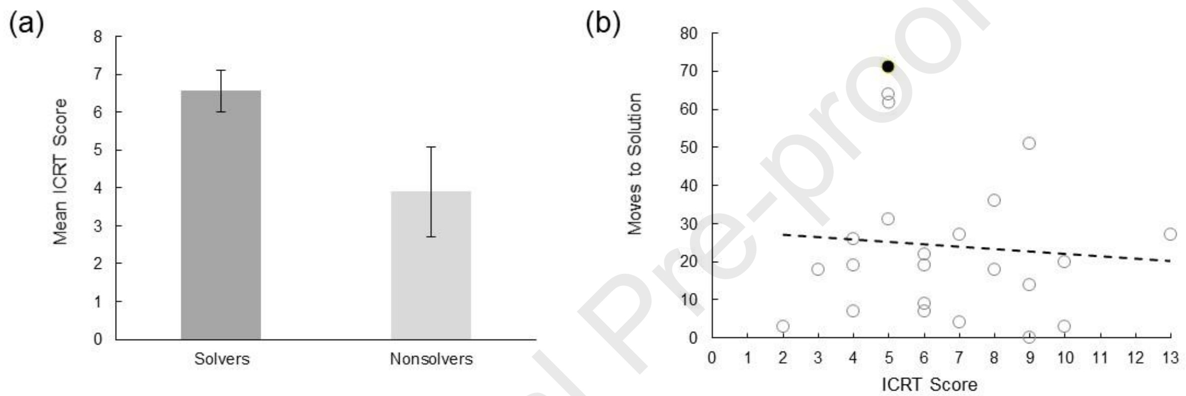
18.411-19.178	Array is considered, head moved back, fingers off tiles	
19.178	The letter W is selected for the next move	
19.779	W is moved next to P and O. the move knocks the R tile and pulls it with the W tile in line with the P and the O but tilted on its side	
20.646	P71 tidies the array so that R is straight	
21.780	P71 moves the E down so the tiles are in a straight line.	
21.780 -23.180	P71 considers the array	
23.180	P71 traces her fingers over the R and the E	
24.450	P71 forms the word POWER	
25.404	P71 announces the correct answer	

More important and unexpected however, is that an observational analysis of this kind allows us to track the moments of missed opportunities. For example, in the anagram task participants often come close to solving the anagram but do not "see" the answer. These important findings are only possible with the sort of observational analysis we suggest here coupled with a clear instrumentalization of the experimental task. The implications of these missed connections are important for understanding how environmental and human agency interact (Ross & Vallée-Tourangeau, 2020).

Missing the Tree in the Forest

The granular analysis of one participant's effort to discover the solution to the triangle of coins reported earlier revealed important features of creative problem solving. Experimental research on creative cognition, however, usually shuns this type of idiographic approach, and relies in turn on group means and correlational evidence. For example, the physical transformations of the problem presentation illustrated in Figure 3 and the spatio-temporal trajectory to the solution in Figure 4, is a case study selected from a sample of 33 participants who attempted to solve the problem (70% did). We also measured their visual imagery abilities with the Image Control and Recognition Task (ICRT; Irving et al., 2011). This is a visual guided synthesis task where participants are asked to form a mental image of a shape described in terms of a series of simple instructions (such as "imagine a capital letter D, rotate it 90^0 to the left, put a capital J underneath, what do you get?"; an umbrella). The task is composed of eight items, and participants score a point each for their ability to name the object described and to draw it (for a total maximum score of 16). Scores on the ICRT differ significantly between those who solved the triangle of coins problem and those who did not (Figure 5a). This suggests that visual imagery skills are implicated in creative problem solving involving a visuo-spatial problem. So far so good. We can also look at the correlation between scores on the ICRT and moves to solution among the 70% participants who solved the problem (Figure 5b). Here the statistical evidence is much weaker, the power of the sample as it were, is insufficient to detect a robust correlation: As it stands, there appears to be a weak negative correlation between ICRT scores and number of moves required to solve the problem. This also makes sense. But what do these data and these analyses tell us specifically about the process involved in discovery? Very little actually.

Figure 5. Mean ICRT score for solvers and nonsolvers (panel a; error bars are standard error of the mean); correlation between ICRT score and moves to solution among solvers (panel b); drawn from data reported in (AUTHORSa).



The black data point in Figure 5b is the participant whose efforts to construct the correct triangular configuration were illustrated in Figures 3 and 4. The participant's score on the ICRT is lower than the average score for the solvers. Aggregate measures of performance and correlational analyses do not unveil the microprocesses involved in creativity. These analyses must be complemented with a granular description of the transformation of the physical presentation of the problem over time. In the absence of these case studies, the genesis of a new idea will remain hidden behind aggregate measures of performance.

Methodological Recommendations

It was only through more finely grained analysis whether of phenomenology or process that the model of insight was challenged and extended to reflect participant behaviour. Tracking where the models overlap with behaviour and where they do not is essential to test the assumptions of underlying models. Such an analysis is designed to be complementary to the existing quantitative research field.

The research that we have been doing follows a simple three stage process. Experimental situations are designed which allow for thought as action to be traced. Quantitative analyses are conducted but so also are two further forms of analysis: Extrospection and cognitive cases. This mixed method approach allows us to triangulate levels of evidence to focus on process rather than outcomes.

Extrospection

Alongside quantitative analyses of behaviour, we suggest the use of finely grained observational data to support and explain the quantitative outcomes. This allows a large-scale analysis of behaviour. This draws from the interaction analysis, the systematic analysis of behaviour through observation (Bakeman & Gottman, 2009; Bakeman & Quera, 2011). The coding schemes can be generated in two ways: through an iterative process which allows themes to be generated through repeated watching of the data or by pre-specified coding to support prior hypotheses. Often the two ways can inform each other with a first round of coding using preformed codes also yield observations which can be categorised as exploratory. This use of codes to generate quantitative data from observations is central to the approach – it is systematic and quantitative rather than qualitative (Bakeman & Gottman, 2009).

Extrospection can support an understanding of process outside of the subjective feeling of the participant. Inevitably, subjectivity remains in the researcher not only in the coding but the choice of behaviours to code. Such a technique was used by Christensen and Friis-Olivarius (2020) who asked participants to brainstorm on sticky Post-it™ notes and used these external traces to make inferences about the internal traces. Recently, Kupers et al.

(2018) proposed a granular and generic method to capture the micro-developmental trajectory of creative cognition. They describe a coding scheme to capture the novelty and appropriateness of ideas as they are formulated over time in creative problem solving. In this manner, they can trace the non-linear and gradual trajectory of creativity on the basis of what they call ‘state space grids’. These problem-solving efforts can take place through interactions with an interlocutor, and these inscription devices (viz. state space grids) can be augmented by intersecting data that capture the conversational prompts from a teacher or facilitator.

Cognitive Cases

Steffensen (2016) has suggested that cognitive psychology could benefit from the application of what he terms the ‘probatonic principle’. That is, a principle which focuses on the “single sheep that has our full attention and which is not reducible to being part of the herd” (p. 30). The argument for such a shift in focus is that the unique cognitive system which coalesces around each problem-solving agent displays a form of variability which a traditional analysis that focuses only on a binary correct or incorrect answer will inevitably fail to identify. Steffensen suggests we can investigate this through Cognitive Event Analysis – a finely grained analysis which looks for pivotal moments in a problem-solving trajectory, phase transitions necessary for the solution to be articulated. The method relies on case studies and identifies small moments which may be missed in traditional experimental analyses. Steffensen argue that such a method is useful for generating hypotheses based in behaviour rather than inferences from computational models.

The additional analysis we present in our research is the selection of a few critical cases. Unlike the coded interaction analysis outlined above, the case study is intended to demonstrate existence not incidence (Smith et al., 1995) although it could inspire a new set of coding schemes or even future experimental research although not all variables will lend themselves to this. This phase of data analysis is inductive in nature and reduces the sample size to generate key critical themes that can be evidenced by behaviours. There is a necessary subjectivity on the part of the researcher at this stage, however, the role of such an analysis is not interpretative but rather focuses on a detailed description. The cognitive cases form part of a preplanned mixed analysis plan, their purpose to elucidate conclusions drawn from the experimental manipulations and the statistical analysis of data sets. While it can be understood on its own, it is not designed to be read in such a way and the conclusions drawn and the levels of analysis required are driven by a requirement to understand and enrich the quantitative data. Its primary function is exploratory and descriptive (Yin, 2014) because the causal mechanisms implicit in the experimental form provide the hypothesised explanatory mechanisms

One way a detailed granular analysis of particular participants can add to our understanding of a phenomenon is to assess whether the explanatory mechanisms we have assumed in our experimental manipulations are actually those which we hypothesised beforehand rather than assuming them from the outcome. Thus, this deeper level of analysis straddles the observational and the experimental. It also does not derive its validity from positing causal explanations but rather by suggesting the mechanisms through which the causal explanations already established by the experimental results are realised. It may be that the hypothesised explanatory factors map easily identifiable in the case study material or it may be that other factors emerge. Either way, it acts as a convenient and in-depth manipulation check.

The granularity afforded by this deeper level of analysis allows us to be more exact about the mechanisms behind any effect detected in the larger population. For example, in (AUTHORSa) participants were invited to solve the triangle of coins problem in a low interactivity condition and a high interactivity condition. Crucially, they were only allowed one guess at the solution. While high interactivity participants solved the problem more often, they did so with longer solution latencies. A survey of the video material showed that in the high interactivity condition participants would solve the problem but because the interface afforded them an easy opportunity to check their answer, they would do so, that is reset the board and construct the solution a second time, and as result their performance latency was longer. So, while the condition was the cause of the difference in latency, the mechanisms through which it caused that difference were only revealed by case study analysis. The material traces of the physically realised actions involved in problem solving allowed the thought process to be traced.

This level of analysis is useful to unpick the effect of the experimental manipulation which in turn allows us to test some of the models which are being proposed. We cast problem solving as a process of physical transformation and so it becomes important to map these transformations with a high degree of granularity. The benefit of placing participants in first order problem solving environments is not just that we can assess the potential benefits of this type of environment but also because we can use the material traces of problem solving to guide our understanding of how problem-solving progresses. This return to data and to behaviour in action reflects a pragmatist perspective rooted in observable action.

Like Steffensen's Cognitive Event Analysis, this level of analysis does not require naturalistic material. Indeed, in these cases the analysis is bound to a single problem-solving moment generated by an experimental situation. Thus, while the analysis deals with a small number of cases, the function of the analysis we are describing is more reductive than typical case studies: it is temporally and artificially bounded around the cognitive tasks. In many ways this level of analysis functions to replace the discussion section of a typical quantitative only research paper which is replete with – 'it is plausible that', or 'informal observations suggest that' which are offered as explanatory mechanisms beyond the aggregated means.

Furthermore, such qualitative work gives empirical support to principled hypothesis formation (Steffensen et al., 2016) and stretch out the boundaries of a theoretically driven research programme.

The Benefits of a Qualitative Approach to Insight Problem Solving

What defines qualitative research is often a negation: Quantitative research is numbers and qualitative research is what is left, often text based (Ketokivi & Choi, 2014). The analysis we propose here takes a higher granular and qualitative approach looking at a whole data set and then homing in on one or more critical cases until a fuller understanding emerges from this plurality of perspectives. It looks more broadly, although in detail, at bounded cognitive events where the population of principal inference is the experimental population. It is not intended to replace quantitative and aggregated results but rather enhance the understanding of the mechanisms through which the effects of the experimental manipulation are realised. Bennett and Elman (2006) contrast these two aims thus: quantitative research takes an effect of causes approach by manipulating the cause and measuring the effects whereas qualitative research takes a causes of effects approach. Martin and Bateman (1993, p. 3) stress the importance of a study of behaviour through the use of an analogy: "perfect knowledge of how many times each letter of the alphabet recurs on this page would give no indication of the text's meaning". We argue that kinenoetic analysis as described here can strengthen both understanding of cognition but also how thought can be traced.

There is no principled way of knowing a priori what the important moments of variability might be rather "to identify stable patterns, one has to investigate (the trajectory of) the cognitive probatonics of individual agent-environment systems" (Steffensen, 2016, p. 31). Each time a participant enters an experimental situation, a system forms which is dynamic, fluid and idiosyncratic (Ross & Vallée-Tourangeau, 2021). This is true even if the researcher treats the system as a closed one. Quantitative research prespecifies the questions it will ask before observing the data. The prespecification is necessary because human behaviour is not directly expressed in numbers, therefore quantitative research has to decide what aspects of performance to convert for analysis through statistical tests. This allows it to test these prespecified hypotheses but variables which are not already identified will necessarily be excluded. Kineneotic analysis allow the testing of typically measured quantitative outcomes alongside a inductive approach to group and individual observational data. A research programme which profiles binary outcomes and perhaps some psychometrics can tell us how successful certain people can be in problem solving but it can only speculate on the reasons for why. The speculative nature of the conjectures is attenuated considerably when the analysis proceeds through the detailed recording of actions and the resulting changes in the object qua model of the solution. Kinenoetic analysis allows behaviour to be clearly measured through actions on objects. The overall findings can then add to an understanding of phenomenon under investigation.

Conclusion

Latour and Woolgar (1986) in *Laboratory life* demystify thinking, or specifically so-called scientific thinking in a chapter titled ‘the microprocessing of facts’. Scientific inferences are not special or different from non-scientific inferences: the same heterogenous microprocesses underpin any form of inference, scientific or pedestrian. Our research on insight problem solving suggests that ‘insight’ does not proceed on the basis of special unconscious mental processes. The trajectories mapped by migration ratios and latency per move in the insight problem solving experiment described above are the physical traces of heterogenous and heteroscalar microprocesses that shape the construction of the solution. A methodology that only looks at solution rates and correlational evidence is at risk missing the nature of creative cognition in problem solving. We would argue that embracing a more qualitative analysis of behaviour will yield new data that inform models of restructuring (cf. Fleck & Weisberg, 2013) and discovery. Restructuring is a key component of the "pure" insight sequence but happens unconsciously and in sequestered environments is both invisible. The analysis described here has the potential to open up these moments. This requires a substantial shift in the laboratory exploration of creative cognition, involving a mixed methodology: aggregate performance measures coupled with detailed case studies. To capture creativity, one must film it and code it: The granularity of analysis can reveal the microprocesses that undergird the emergence of creativity in a participant.

There is a move to use eye tracking measures to assess moments of insight and track unconscious cognitive processes (e.g., Bilalić et al., 2021). We suggest that similar behaviours become manifest when participants are placed in environments where they can move things. As Christensen and Friis-Olivarius (2020) argue, the use of movable objects allows us to track thoughts through action without the need for expensive technology. Furthermore, a kinenoetic analysis unveils previously hidden explanatory factors by removing the need for a participant to be aware of those factors. This detailed attention to environment chance and complexity and moving the focus away from the psychometric properties of the person, has important implications for the design of environments to maximise problem solving success. This type of deeper and more finely grained analysis becomes particularly important when we have little control over aspects of the experimental set up. This is particularly salient each time we embed participants in a complex, materially rich world. Furthermore, a case study analysis can allow us to avoid attributing behaviours to an average participant who does not exist (as in Cushen & Wiley, 2012).

If problem solving is seen as a change in the epistemic state of the participant, as moving from a state of ignorance to a state of understanding then it becomes clear that we need to assess (a) the original epistemic state (b) track the process of state change and (c) the final state. Current problem-solving research rests on the assumption that the original epistemic state is the same for all people (beyond a binary one determined by whether they have encountered the problem before or not), that the process of state change is the same and can be determined by the answer and also that the final state is binary: You have either solved the problem or not and a correct solution indicates a correct problem representation. Given the clear circularity here—a correct problem representation is the only way of getting a correct answer and the problem representation can only be measured by a tool calibrated by eliciting a correct representation—a return to observation, what people do, is required to ground the research and avoid regress. Relying on the aggregate measures will obscure a simple truth about creativity: it is not in the person, nor in the world, but rather in their co-constitutive coupling.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.