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From Insight to Outsight: When Solutions Are Enacted before They Are Recognized

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Abstract

Creative breakthroughs are typically described as sudden mental events, the "Aha!" moment.. Yet this formulation may fundamentally mischaracterize the process. Rather than solutions being discovered in the mind then implemented in the world, they may emerge through engagement with manipulable objects. We report an experiment comparing interactive and non-interactive conditions across two insight problems (Triangle of Coins, 10 Circles). Survival analyses confirmed that interactivity enhanced solution rates and reduced latencies for both problems. More critically, frame-by-frame multimodal coding of the video data (via ELAN) revealed the temporal coordination between speech, action, and evolving solution prototypes. Detailed analyses of two solution episodes demonstrate how restructuring can occur in the physical configuration of the problem rather than in the mind. These cases illustrate "outsight": solutions recognized after being enacted. By making the solution process visible, multimodal behavioural coding produces qualitative data that challenge cognitivist assumptions about how creative breakthroughs happen.

Keywords: Insight, Interactivity, Outsight, ELAN

Introduction

Creative breakthroughs are typically presented as sudden mental events, the "Aha!" moment when insight strikes. This narrative treats the material world as secondary, a passive stage on which mental processes perform. Yet this formulation may fundamentally mischaracterize the process. Rather than solutions being discovered *in the mind* and then implemented *in the world*, they may emerge *through* engagement with objects that can be manipulated, transformed, and interrogated.

The distinction between "science made" and "science in the making" that Latour (1987) introduced to science and technology studies applies equally to creativity research (March, 2025). The "made" perspective promotes hindsight narratives: solutions appear inevitable once discovered, and we retrofit explanations that privilege pre-existing ideas and mental representations. The "in-the-making" perspective, by contrast, considers the messy, contingent, iterative process through which new ideas actually emerge—a process fundamentally shaped by materials, tools, and the evolving prototypes that problem solvers construct (Vallée-Tourangeau & Soderberg, 2025). Adopting this perspective requires not just different theories but different methods capable of capturing the granular, moment-by-moment dialogue between person and prototype.

Insight Problems and The Methodological Bottleneck

Insight problems offer an interesting laboratory platform for studying creative breakthroughs. Unlike transformation problems that require the methodical application of known operators (such as multi-step arithmetic), insight problems are designed to create an impasse, a problem-solving cul-de-sac where an intuitive but incorrect interpretation must be abandoned before the solution can be discovered. These problems are relatively simple riddles, considered "knowledge-lean" in that their solutions do not require specific expertise, yet they can elicit the phenomenology of sudden breakthrough: the "Aha!" experience marked by feelings of joy, relief, and confidence (Danek, 2023). The transition from impasse to solution represents a microcosm of conceptual change, making insight problems valuable tools for understanding how new ideas emerge under controlled conditions.

Yet insight problem solving research has long employed what Vallée-Tourangeau and March (2020) term "second-order procedures", namely tasks that restrict or forbid interaction with objects. For example, when Knoblich et al. (1999) presented matchstick arithmetic problems as static images on computer screens, participants could not actualize the behavioural affordances of matchsticks: picking up, dragging, rearranging, creating tentative configurations to evaluate. Solutions, if achieved, had to be mentally simulated rather than physically prototyped. This methodological choice is not arbitrary: it reflects and reinforces a cognitivist ontology where problem solving is fundamentally mental, involving operations on internal representations rather than engagement with external materials.

Second-order procedures can only perform certain kinds of explanations. They suggest that creative breakthroughs result either from (1) effortful, conscious analysis that gradually restructures mental representations (the "business as usual" account), or (2) unconscious spreading activation

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in semantic memory that produces sudden insight (the "special processes" account). These explanations have been tested primarily through correlational studies examining whether working memory capacity predicts solution rates, a research strategy that has yielded frustratingly mixed results (DeCaro & Van Stockum, 2023; Gilhooly & Webb, 2018). More fundamentally, aggregate measures of solution rates and latencies cannot reveal *how* a given participant solved a given problem. The nature of the solution process remains opaque.

First-Order Procedures and the Problem of Granularity

Fleck and Weisberg (2013) made important progress by employing a concurrent embedded mixed methodology: they collected verbal protocols while participants worked on five insight problems, then analyzed these protocols to identify impasse, restructuring, and different solution strategies. Crucially, three of these problems involved objects participants could manipulate. Yet Fleck and Weisberg treated their five problems as interchangeable; the presence or absence of manipulable objects attracted no comment. Their analysis focused on what participants *said*, not on how actions transformed solution prototypes or how those transformations guided subsequent thinking.

The limitation is not just evidential but conceptual. Without the precise temporal coordination of speech and action, the analysis defaults to what Baber (2021) calls linear decomposition, namely the assumption that planning precedes acting, that ideas guide hands. This preserves a problematic asymmetry: human actors plan, objects comply. What remains invisible is the possibility that objects themselves actively participate in problem solving, that the appearance and behaviour of solution prototypes *cue* new ideas and *trigger* new actions, creating what Vallée-Tourangeau (2025) terms "outsight": solutions seen in the world rather than mentally constructed.

Multimodal Behavioural Coding: Making Thinking Visible

Frame-by-frame multimodal behavioural coding offers a solution to this methodological bottleneck. The principle is straightforward: video data are annotated along multiple parallel tiers that remain precisely time-locked, enabling simultaneous capture of (1) participants' verbalizations (what they say and when); (2) participants' actions (which elements move and when); (3) resulting changes to the solution prototype (what the object looks like at each moment). Several qualitative data analysis tools support this kind of multimodal annotation, such as BORIS (Friard & Gamba, 2016), nVivo or MAXQDA. In the present work we used the EUDICO Linguistic Annotator (ELAN; Wittenburg et al., 2006), a freely available platform originally developed for multimodal analysis in linguistics that provides frame-level precision across an arbitrary number of coding tiers.

This granular temporal juxtaposition reveals solution processes that would otherwise remain hidden. In a study using a matchstick arithmetic problem, namely III = II - I (Vallée-Tourangeau, 2025), a participant engaged in the task stated "this one I might have to move [the sticks]" then slowly dragged a stick from III to create II = III - I. The ELAN coding showed this movement lasted seven seconds; and it is *during* that movement, as the problem's physical appearance was transformed, that the participant discovered the solution. She confirmed afterward: "that was definitely as I moved it, it was like oh that makes sense." Here is a case where the new idea was *enacted in the movement* rather than mentally formulated then implemented.

In another case, a participant working on I = II + II decomposed the plus operator to create I = III - II. But three seconds elapsed before she experienced an emphatic "Aha!" moment marked by laughter and relief. The normative configuration was physically present before it was recognized. In the post-solution interview, she confirmed the movement wasn't guided by a hypothesis: "I just kind of moved the stick, and I just realized, oh...three minus two is one, but I had to actually accidentally put it in that place to find that out." This is outsight: the solution recognized *after* being enacted, visually prompted by the objects at play.

The Present Study

The study extends this methodological approach to two visuo-spatial insight problems: The Triangle of Coins (Fleck & Weisberg, 2013) and 10 Circles (adapted from the 17 Animals problem; Steffensen et al., 2016). Both problems create an initial impasse by encouraging an intuitive but incorrect interpretation. In the Triangle of Coins, the problem *seems* to be about redistributing coins from the bottom row, when actually the solution requires moving coins from corner positions. In the 10 Circles, the problem masquerades as simple arithmetic (distributing 10 circles to create odd numbers in each of three large circles), when actually the solution requires creating overlaps that enable double-counting.

Participants worked on both problems in counterbalanced order, either in an interactive condition where they could manipulate coins or drag circles on a monitor (thereby creating solution prototypes), or in a control condition where they viewed static images and hence no prototyping was possible. All sessions were video recorded. We provide aggregate performance data (solution rates and latencies) analyzed using survival analysis to account for censored cases. Critically, we also present detailed ELAN-coded analyses of two solution episodes, one for each problem, to demonstrate how this methodology makes visible the temporal coordination of speech, action, and prototype transformation. Richly analyzed cases can demonstrate what becomes observable when verbal protocols are precisely time-locked to actions and their material consequences. Our aim is to showcase the potential of multimodal behavioural coding for revealing solution processes, particularly outsight sequences where solutions are enacted before being recognized, while acknowledging that systematic quantification of these processes across the full dataset remains for future work. The quantitative analyses establish that interactivity influences problem-solving outcomes; the qualitative analyses illuminate *how* those outcomes emerge through interactivity.

Our primary aim is not merely to demonstrate that interactivity facilitates problem solving; rather, we aim to showcase how multimodal behavioural coding makes visible the *process* through which solutions emerge. By providing frame-by-frame evidence of how actions reshape prototypes and how transformed prototypes guide subsequent actions, we can distinguish between: (1) planning-then-acting sequences where verbal hypotheses temporally precede movements; (2) action-then-recognition sequences where solutions are physically created before being cognitively registered; and (3) co-constitutive sequences where thinking and doing are inextricably entangled. This granular visibility matters not just empirically but theoretically. It challenges us to rethink the locus of creative breakthroughs, not as sudden mental events but as emergent properties of a cognitive ecosystem encompassing person, prototype, and the evolving dialogue between them. Creative problem solving, from this perspective, is not about having ideas then implementing them, but about *thinking through making*, where objects serve as active interlocutors in the construction of new ideas.

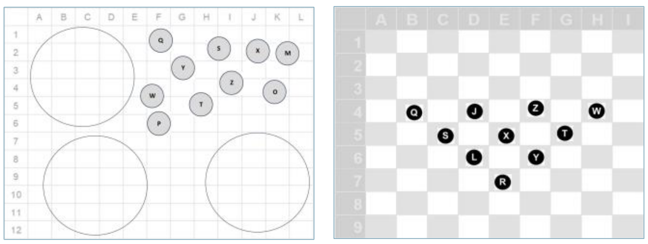

Figure 1. The 10 Circles problem (left panel); the Triangle of Coins problem (right panel).

Method

Participants

A total of 80 participants were recruited; video or audio recording failures led to the removal of 11 participants for a final sample of 69 participants; the sample was composed of university undergraduates who received course credits for their participation.

Procedure

Participants were randomly assigned to either an interactive condition or a control condition. In the interactive condition, participants could manipulate digital objects during problem solving; while digital drag-and-drop is an attenuated form of material engagement compared to handling physical objects, it nonetheless changes the topology of the problem space and enables action-based prototyping. In the control condition, participants viewed static images and solved problems mentally without interaction.

All participants completed two insight problems: the Triangle of Coins task and the 10 Circles task, presented in counterbalanced order. In the Triangle of Coins task, 10 small coins are arranged in a triangle formation pointing down (see Fig. 1, right panel). Participants were instructed to change the orientation of the triangle to point up by moving only three coins. The solution requires moving the three corner coins (Q, W, R). In the 10 Circles task, participants saw 10 small circles and 3 large circles and were instructed to arrange the circles such that there was an odd number of small circles in each large circle (see Fig. 1, left panel). The solution requires overlapping the large circles in a Venn diagram configuration to permit the double counting of some of the small circles.

After being guided through how to produce verbal protocols by the experimenter, participants completed a 3-minute word search warm-up task to practice speaking their thoughts aloud. The experiment was conducted via PowerPoint slides in edit mode, which enabled participants in the interactive condition to manipulate objects on screen by selecting and dragging them. Participants in the interactive condition first received instructions and visual examples for their first task; they were then presented with a practice slide where they clicked and dragged objects (e.g., three coins such as the ones employed in the Triangle of Coins problem) to familiarize themselves with the interactive procedure. Control condition participants received identical instructions and visual examples but without interaction. Once ready, participants had up to 5 minutes to solve each problem while thinking aloud. All sessions were video recorded to enable subsequent analysis of verbal protocols and, for the interactive condition, the temporal coordination between speech, actions, and changes to the evolving solution prototype.

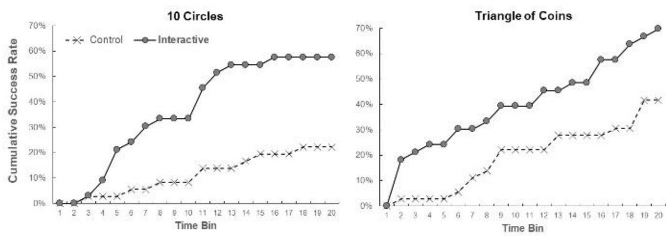

Figure 2. Cumulative Solution curves for the 10 Circles problem (left panel) and for the Triangle of Coins problem (right panel) in the control (x's) and interactive condition (closed circles).

Results

Solution rates. For the 10 Circles problem 19 of the 33 participants (or 58%) in the interactive condition announced a correct solution during the five-minute period, while 6 of 36 participants (or 17%) did in the control condition. For the Triangle of Coins problem, 23 of the 33 participants (or

70%) in the interactive condition solved the problem, while 15 of 36 (or 42%) did in the control condition. The 300-second period during which participants worked on each of the two problems was segmented in terms of 20 15-second time bins; the cumulative success curves for the 10 Circles and Triangle of Coins problem in the interactive and control conditions are plotted in Figure 2. A survival analysis using a log-rank test (Mantel-Haenszel) was performed to determine whether the cumulative success curves differed between the two conditions. For both the 10 Circles, $\chi^2(1) = 10.09$, $p = .001$, and the Triangle of Coins, $\chi^2(1) = 6.68$, $p = .010$, more participants announced the correct solution and did so with shorter latencies in the interactive than in the control

We were particularly interested in the solution processes enacted in the interactive condition, that is *how* solutions emerge through interactive solution prototyping. To make

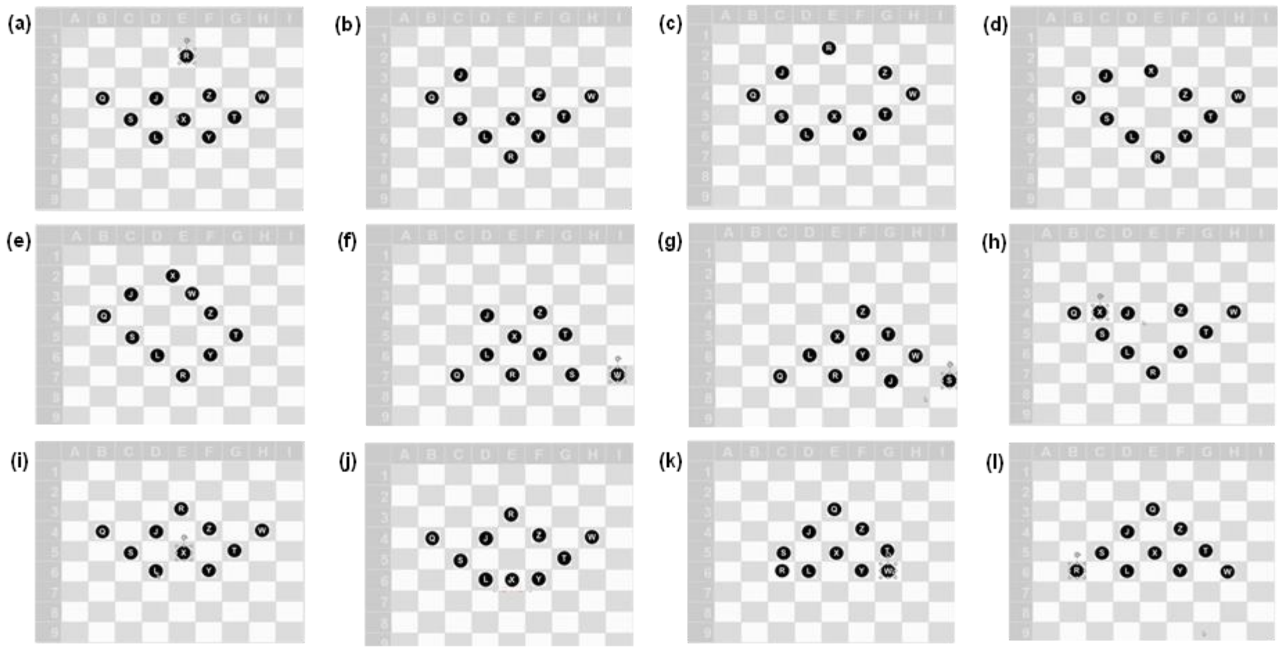

Figure 3. The prototype solutions constructed by the participant as she worked to discover the solution to the Triangle of Coins problem.

these solution processes visible requires frame-by-frame coding of verbal protocols precisely time-locked to actions and their material consequences. The two illustrative examples presented below showcase the capacity of multimodal behavioural coding to reveal the temporal coordination between speech, action, and prototype transformation. Each example documents a successful solution: one participant solving the Triangle of Coins, another solving the 10 Circles problem. These cases were selected as demonstrations of methodological possibility, revealing solution processes that would remain invisible without the precise temporal juxtaposition ELAN affords, particularly sequences where restructuring occurs in the physical configuration of the problem rather than in the mental representation of it. The video of the sessions can be accessed or downloaded from the OSF: https://osf.io/twfhb/overview?view_only=e2c23bc697b04bc8ae3007cd9aee9968

Illustrative Example 1: Triangle of Coins

The participant's prototyping efforts are segmented into 12 different stages in Figure 3. What is apparent in Panels (a) through (e) is the indiscriminate upward movement of the vertices and the coins from the central core (the rosette); this north migration is a very common strategy employed by participants when they first start working on the problem, since the triangle should point up, moving coins up makes initial intuitive sense for most participants. Thus, the two ideas required to solve this problem, namely (i) only moving the corner coins and (ii) lowering the base of the triangle, that is migrating coins down rather than up, is not apparent in her behaviour, the prototypes created or in her verbal protocol. The participant bemoans the resulting shape ("it's like not looking like a triangle at all" 01:25) definitely not a productive prototype solution. A new strategy is adopted at 01:33 "I'm thinking moving Q downwards rather". What is the source of this idea? The participant doesn't say or may not know. But this initiates a south migration movement that widens the base of the triangle and makes it point up (panels (f)-(g)); at this point perhaps the idea that it's the corner coins that are important is central to the participant's thinking, but other coins are migrated down (the S in Panel (f), the J in Panel (g)), and while the prototype in Panel (g) looks perfect, it was constructed out of the movement of four coins namely

L, S, J, and Q, only one of these is a corner coin (viz. Q). It's interesting to note that however promising this prototype might be, it's not immediately exploited.

After resetting the shape to its initial configuration, the participant moves the centre coin X, then tries R up (corner coin), and asks the researcher whether the resulting shape can be hollow ("does it matter if I have something in the middle of triangle?" 03:02). She resets the starting position and says "I want to try moving from the sides (…)" 03:16, because she says "if I move from the middle then I am moving way too many of them" 03:23). So, the idea that the corner coins might be more fruitful coins to move only comes to her after constructing prototypes by moving coins from the middle, but the resulting prototype is constructed in a manner that violates the three-coin constraint. Working from that hypothesis, she will focus on the corner coins, moving from the sides as she calls it. Has she solved the problem at this stage? No, she hasn't. The next prototype she constructs by only moving the corner coins is shown in Panel (k): that is an excellent prototype ("it looks like some weird triangle" 03:46, and then she says "Oh!" (03:48), and then from that solution prototype, she easily creates the final one that is the normative configuration corresponding to the solution of the problem, Panel (l). The participant did experience an aha! moment, but that moment was not triggered by a mental restructuring, it's the physical reconfiguration of the problem into a promising solution prototype that helped her see what the solution looked like. Perhaps the solution can be traced back to her hypothesis that moving the middle coins won't pay off in the end; yes, that certainly is important, and that led her to explore how moving the side coins might be more productive. The problem certainly wasn't solved then, and it wasn't even solved when she moved the three corner coins in the penultimate prototype model. The explanation of the emergence of these two ideas, namely moving the side coins and moving them in the right place only emerged from the efforts to construct solution prototypes, examining their properties and it is the information that these prototypes provided that guided her next action and that eventually cued the solution to the problem. The explanation of how this participant solve this problem is the detailed and granular capture of the co-evolution of her thinking about the problem and the shape of the solution prototype. This is how the solution to the problem was discovered; prototypes are partners in thinking.

Illustrative Example 2: 10 Circles

The participant begins by counting the ten small circles (00:03–00:04), and almost immediately recognizes a fundamental constraint: "Oh! so there's an even amount I've got to make it odd" (00:08–00:12). She has identified the arithmetic impossibility (viz. ten circles cannot be divided into three odd numbers). Yet rather than or immediately seeking a workaround, she proceeds to test this intuition empirically. Over the next twenty seconds, she methodically distributes three small circles into each of the three large circles (00:13–00:32; see screenshots of the session in Figure 4), leaving one remaining. This exploratory action confirms what she already suspected, making the stark reality of the problem visible and tangible. At 00:46, she asks "and I can move the big circles?" Having constructed a prototype that reveals the problem's constraints, she now seeks a different way of working. The experimenter's affirmative response triggers immediate action: she begins overlapping the large circles. But has she discovered the solution at this moment? No; she has discovered a new affordance, a different configuration space to explore. What follows is a series of manipulations testing different overlap arrangements and circle distributions. She creates a single overlap at 00:50 and from then on will construct different overlaps and placing at least one small circle in them. Crucially, the sequence is action-then-examination, not planning-then-acting. At 01:27 she articulates an emerging hypothesis: "I thought I could overlap two big circles...does that mean it's still in both of them?" (01:27–01:32). The experimenter confirms: she responds "Oh" (01:35), but immediately discovers this creates a new problem: "now they're all even again" (01:37). The prototype throws up an answer she doesn't like. More actions follow, more prototypes are constructed and evaluated. At 02:24, she announces a new strategy: "wait...if I put five in one" and proceeds to distribute the remaining small circles, placing one in one of the four overlaps currently on display (02:24–02:26). She counts the result: "1,2,3,4,5...1,2,3...1,2,3" (02:28), then experiences an Aha! moment: "ah! I think I've done it" (02:32). The experimenter confirms the solution is correct. What's striking is the temporal relationship between construction and recognition. The normative solution configuration was physically constructed through her actions. Only after building this prototype and examining its properties (counting the small circles in each big circle) did she recognize it as the solution. The "Aha!" follows the examination of the constructed prototype; it does not precede the construction. The discovery emerged through the iterative process of building, examining, and modifying prototypes rather than through pre-formed mental planning. The solution was seen in the world after being enacted, not mentally simulated then implemented.

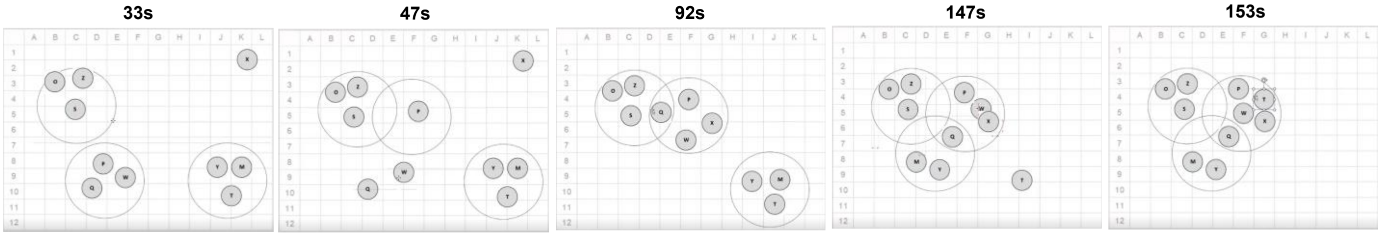

Figure 4. A participant discovering the solution to the 10Circles problem. At 33s, an odd number of circles are distributed in each big circle. At 47s, ask the experimenter if the big circles can overlap. At 92s whether the small circle in the overlap counts as belonging in each big circle (but realizes that there is an even number then). At 147s decides to place 5 small circles in the top right big circle. At 153s examines her constructed prototype and exclaims ‘Oh, I think I’ve done it’.

Discussion

The quantitative results indicate that interactivity facilitates insight problem solving, yielding higher solution rates and shorter latencies. Yet these aggregate statistics cannot reveal how solutions emerge through material engagement. The multimodal behavioural coding analyses provide this crucial visibility into the process of discovering the solution. Second-order procedures can only perform two explanatory narratives for creative breakthroughs: effortful analytical processing that gradually restructures mental representations, or spreading activation in semantic memory that suddenly crosses the threshold of awareness. Both locate the creative process exclusively in the head, operating on mental representations. Whether restructuring happens slowly through working memory or through unconscious activation, what gets restructured is always a mental representation.

First-order procedures can reveal a fundamentally different solution process where restructuring occurs in the world rather than solely in the mind. As participants interact with objects, the prototypes they construct provide continuous perceptual feedback. The appearance and behaviour of these evolving configurations cue new ideas and trigger subsequent actions, creating a dialogue of mutual transformation between problem solver and solution prototype.

The multimodal coding analyses illustrate this dialogic process. In both cases, solutions were either enacted during physical movement or recognized only after the normative configuration had been physically constructed. These solution processes exemplify outsight: solutions seen in the world rather than mentally simulated then implemented. Multimodal behavioural coding does more than simply record what happened: it makes the meaning-making process itself visible (Zheng and Peng, 2022). In our analyses, these semiotic resources include verbal articulations, movements, and the evolving visual appearance of solution prototypes. By time-locking these modalities with frame-level precision, the coding approach helps us step inside the cognitive system (to adapt Hutchins, 1995, p. 128) by making observable the different elements—some residing inside the individual (verbal hypotheses, intentions), some outside (prototype configurations, perceptual affordances)—that participate in the construction of a new idea. This visibility is not merely descriptive but theoretically generative: it reveals creativity as an emergent property of a coupled system rather than a mental event subsequently implemented in the world. Without such granular multimodal capture, the orchestration remains invisible, and we default to mentalistic explanations not because they are correct but because our methods cannot observe the alternatives.

If creative breakthroughs emerge through material engagement, we must reconsider where creativity resides. Rather than locating it exclusively internally, we need a distributed account recognizing the cognitive ecosystem encompassing person, prototype, and their evolving transaction. This adopts Latour's (1987; 2005) principle of symmetry: rather than privileging human mental activity over material artifacts, we assign equal importance to human and non-human actants in the construction of new ideas.

This does not deny the Aha! experience: it remains real and reportable. In addition, some of our participants solve these problems without interaction, preferring to "think things through" mentally, suggesting meaningful individual differences in tolerance for uncertainty or preferences for engaging with external materials versus internal mental simulation. Yet ethnographic studies of scientific practice, navigation, engineering design, and craft work consistently reveal thinking as distributed across people, tools, and representational artifacts. Laboratory procedures should not systematically exclude the material engagement that characterizes cognition in the wild.

The fundamental contribution lies not in discovering that interactivity helps; rather, it lies in demonstrating a methodological approach that makes visible the temporal coordination between thinking and making in creative problem solving. By revealing how solutions are enacted through constructing evolving prototypes rather than mentally simulated then implemented, we challenge the cognitivist presumption that creative breakthroughs necessarily originate in the head. Sometimes the mind discovers what the hands have already created.

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