Improving Selection of Analogical Inspirations through Chunking and Recombination

Arvind Srinivasan
arvind@cs.au.dk
Aarhus University
Aarhus, Denmark

Joel Chan
joelchan@umd.edu
University of Maryland
College Park, Maryland, USA

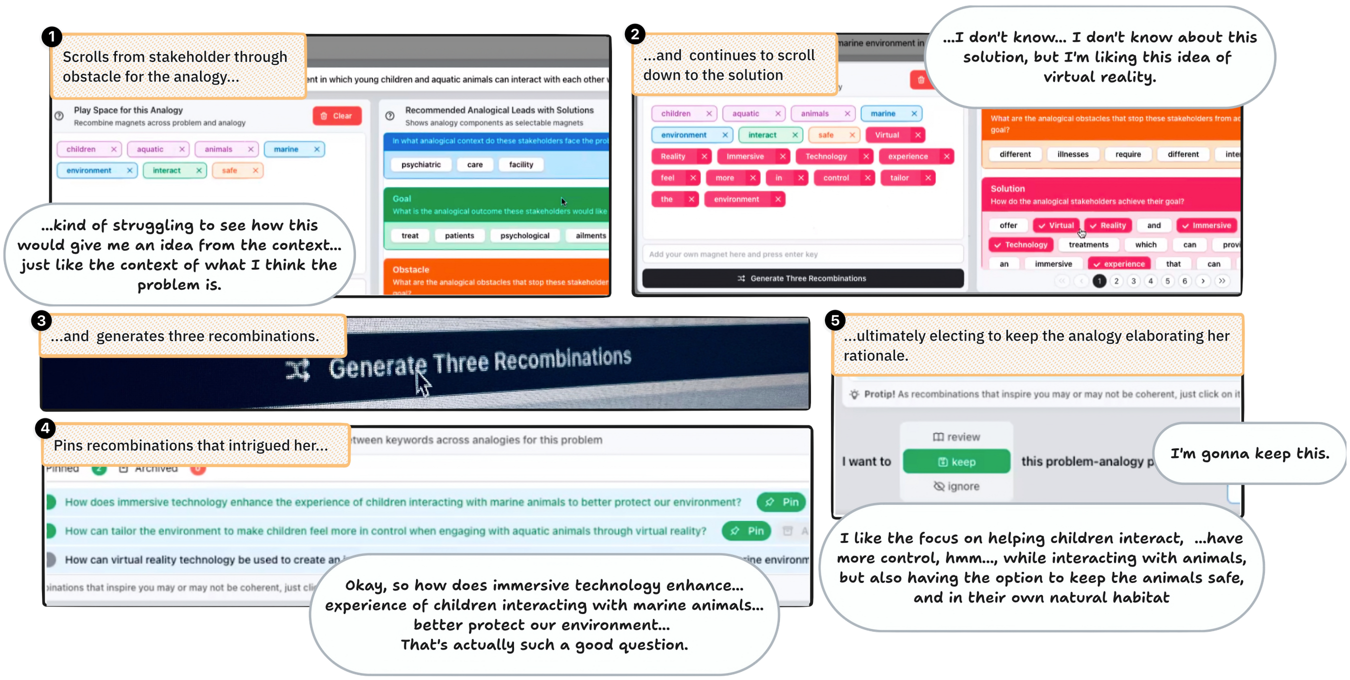

Figure 1: Illustrated flow (sequentially labelled from 1-5) of a participant using our system — `AnalogiLead` — to explore a cross-domain analogy for a problem. The participant is initially dismissive of the analogy (Step 1), but then is intrigued by *conceptual chunks* of the analogy (Step 2) and conceptual *(re)combinations* of these conceptual chunks with elements of their original problem, generated by our system (Steps 3 and 4), and ultimately elects to keep the analogy due to the new ideas it sparked.

ABSTRACT

Analogies can be a powerful source of new ideas; however, creators often fail to recognize and harness potentially beneficial analogical leads, especially from other problem domains. In this paper, we introduce `AnalogiLead`, an interactive interface designed to reduce premature dismissal of analogies by facilitating playful exploration of analogical leads. Drawing on cognitive mechanisms of conceptual chunking and recombination, `AnalogiLead` scaffolds users to engage with meaningful chunks of problems and analogies and recombine them into inspiring brainstorming questions. In a within-subjects experiment, participants (N=23) who used `AnalogiLead` dismissed analogies 4x less often, with 12x fewer decision changes, compared to a baseline interface with no chunking or recombination. This reduction in premature dismissal was associated with 64% longer processing time. Through qualitative analysis of video and think-aloud data, we describe how the chunking and recombination mechanisms facilitated playful engagement with analogies. These findings highlight opportunities and challenges for improving analogical innovation through careful theory-driven design of interfaces for selecting analogical leads.

C&C '24, June 23–26, 2024, Chicago, IL, USA

ACM ISBN 979-8-4007-0485-7/24/06
https://doi.org/10.1145/3635636.3656207

CCS CONCEPTS

• **Human-centered computing** → **Empirical studies in HCI**; **Interaction paradigms**.

KEYWORDS

Creativity Support Tools, Analogy, Large Language Models

ACM Reference Format:
Arvind Srinivasan and Joel Chan. 2024. Improving Selection of Analogical Inspirations through Chunking and Recombination. In *Creativity and Cognition (C&C '24), June 23–26, 2024, Chicago, IL, USA*. ACM, New York, NY, USA, 24 pages. https://doi.org/10.1145/3635636.3656207

1 INTRODUCTION

Analogical problem-solving involves generating new ideas and approaches for a problem based on connections to problems from other seemingly disparate domains based on structural similarities [27, 28, 38, 39]. Cross-domain analogies, in particular, have been instrumental in some of the most significant scientific and technological breakthroughs throughout history: for example, the Wright brothers invented their crucial breakthrough wing steering mechanism by analogy to bicycle control mechanisms and the warping action of a cardboard box when twisted [45].

Unfortunately, creators often struggle to retrieve, recognize, and apply analogies, especially across domains [29, 42, 68, 76]. In response to these challenges, researchers across the fields of psychology, design, and HCI have made substantial progress on developing systems to systematize support for analogical innovation. There is a particularly robust body of approaches designed to support the *retrieval* of appropriate analogs, either from creators' prior knowledge [52, 53], or from databases of potential analogs [11, 22, 26, 40, 61, 63].

In this paper, we consider the problem of **how to enable creators to effectively *recognize* and explore potentially inspiring analogies (especially across domains)** that have been retrieved by computational analogy systems. In computational analogy system evaluations, there is a recurring finding of people rapidly rejecting cross-domain analogies, only to realize after closer inspection that their initial rejection was premature. For example, in evaluation case studies with scientists using a novel computational analogy search engine for research papers, Kang et al [47] documented many instances where scientists quickly rejected cross-domain analogous papers as irrelevant, but upon later inspection of those papers, recognized novel insights that were not apparent on first glance, such as generative misalignment of problem attributes or constraints that provoked creative reconsideration of key problem assumptions. Similar rapid rejection of was observed in Portenoy et al's [67] evaluation of their novel system for recommending research authors working on analogous problems in different domains.

This analogical recognition problem is consistent with broader empirical and theoretical characterizations of the challenges of cross-boundary creative work, such as scholars' reliance on personal contacts to overcome the difficulty of recognizing and working out implications of cross-boundary ideas for their problems [65]. The difficulty of quickly identifying the value of cross-domain analogies (unlike a simple search relevance judgment) is also consistent with conceptualizations of the "oblique" nature of inspiration in the creative process: the value of ideas may not become apparent until after they have been iterated on [5, 13], and ideas and inspirations that are "bad" may actually be important stepping stones to breakthrough insights, such as Darwin's development of the theory of evolution drawing on "wrong" prior theories of coral formation and monad theories of evolution [33]. At a macro level, this can contribute to dynamics such as the "recognition penalty" for paper citations, where highly novel papers have fewer citations in the short run, despite being on average more likely to be in the top 1% of citations in the long run [75].

Here, we investigate **how we might address the analogical recognition problem through careful (re)design of interaction paradigms for computational analogy systems**.

Returning to Kang et al's [47] observations of premature rejection of analogies, one participant quote stands out as suggesting the need to revisit the interaction paradigm: *"I'd not consider... (because) they are totally different, right? They look irrelevant... until I think about it I can realize that it's useful. But if you give me the article, at first I don't realize that"*. We wonder about reframing the interaction paradigm from the query-response paradigm of a search engine (which frames the task as selecting one or two specific analogs that satisfy an information need) towards a more incremental, exploratory and playful, "berrypicking" approach [3] that incrementally integrates partial insights from multiple cross-domain analogies into novel ideas [36].

This research is timely and needed because the problem of analogical recognition has yet to receive systematic attention in research on computational support for analogical innovation. Of particular note is the relative stability on the interface side in computational analogical systems: most operate within a fairly traditional search engine interface, where a query is entered, and a set of results are shown in a list or collection, from which creators can select relevant analogs to pursue, much like a Google search. Two recent exceptions include Chan and Rudd's graph-based exploration of analogies [12] and Song and Fu's [71] VISION system that supports visual querying of an analogical network of patents. Given the substantial progress that has been made on systems for analogical retrieval, we believe the time is right for more research like this to focus sustained effort on addressing the analogical recognition problem.

To advance research on novel interfaces for interacting with analogies, in this paper we introduce **AnalogiLead**, an interface for screening analogies that emphasizes *incremental, playful exploration* rather than rapid selection of a few most relevant results.

Drawing on cognitive theories of conceptual chunking and recombination [14, 48, 77], AnalogiLead structures interactions with analogies in terms of exploring interesting recombinations of conceptual "chunks" of problems and analogies, such as goals, obstacles, stakeholders, or contexts. These chunks are embodied as interactive "*magnets*," which can be subsequently *recombined* — akin to magnet poetry[1] — to craft brainstorming questions, encouraging playful exploration of analogies. In a within-subjects evaluation study, participants (N=23) ignored analogies 4x less often, and with 12x fewer adjustments to their decision, compared to a baseline interface with no chunking or recombination. This reduction in premature dismissal of analogis was associated with 64% longer processing time. Through qualitative analysis of video and think-aloud data, we describe how participants used the chunking and recombination mechanisms to playfully engage with the analogies.

[1] https://magneticpoetry.com/

Our system design and empirical results highlight opportunities and challenges for improving analogical innovation through careful theory-driven design of interfaces for screening and recognizing analogies.

2 RELATED WORK

Our work contributes primarily to the literature on systems for supporting analogical innovation, and draws inspiration directly from cognitive theories of conceptual chunking and recombination.

2.1 Systems for Supporting Analogical Innovation

There is a robust interdisciplinary body of work on systems for supporting analogical innovation. The predominant threads of this work have focused on supporting *retrieval* of potentially inspiring analogs. For example, cognitive scientists have identified how comparing contrasting analogies can ensure they are schematized enough in memory to be retrieved and connected to analogous problems, even when there are surface dissimilarities between the analogies and the problem [16, 18, 29, 53]. In design, systematic techniques like Synectics [32], TRIZ [61], and the WordTree method [52] provide structured methods and databases for retrieving potential analogs for problems. Computational systems have been developed for representing databases of product ideas, research papers, and research authors, and retrieving them for analogous problems based on analogical similarity [30, 40, 41, 47, 67] (for a recent multidisciplinary review of this line of research, see [44]). HCI research has contributed patterns for crowdsourcing annotations of research papers to enable computational analogical matching [11], or searching for and describing potential analogs from large databases of product ideas [80–82]. These systems have been extensively validated in terms of their efficacy at retrieving novel and relevant analogies for problems [11, 40, 47] that can enhance novelty, quality, and creativity of ideas when provided directly as inspiration in ideation experiments [40, 80–82].

We extend this body of work by focusing attention on the *interaction paradigms* that mediate creators' initial exposure to retrieved analogs, so as to maximize the likelihood that creators will recognize and benefit from them. Our work adds to emerging reexaminations of interaction paradigms in computational analogical support systems. One recent example is [12], who drew on research from the learning sciences to explore how presenting cross-domain analogs in a graph of "bridging analogies" that link the analogs to participants' prior knowledge could enable more effective recognition and use of cross-domain analogs. They reported preliminary demonstrations of increasing depth of processing of far analogies when creators were shown analogical stimuli alongside bridging analogies tailored to their prior knowledge (compared to analogical stimuli alone). Another example is Song and Fu's [71] VISION system that supports visual querying of an analogical network of patents. These interaction-oriented approaches complement prior process-oriented interventions for maximizing analogical transfer, such as including images or descriptions that highlight core solution schemas from the analogy [10, 17, 19, 29], or inducing schemas from analogical comparison of two analogs with the same key relational schema [29, 53, 80]. These previous approaches are designed to help problem solvers notice and transfer specific solution components or relational mappings that are known in advance; however, they are not applicable in open-ended discovery scenarios where insightful relational mappings may not be known in advance, or where the goal of the problem solver is to use the analogies to trigger insightful reframing of their problem [21, 36, 47, 64], rather than transferring direction solution elements.

2.2 Conceptual Chunking and Recombination in the Creative Process

Conceptual (re)combination is a fundamental creative mechanism [1, 4, 6, 34, 37, 58, 78]. Creative recombinations, particularly of semantically distant component concepts, can lead to new insights that are not present when considering only the component concepts [24, 54, 77]. For instance, designers use visual juxtaposition of often contradictory themes, in the context of a coherent whole, on mood boards to productively reframe design problems [54]. Connecting these findings to Sosa's [72] argument that creators do (and should) evaluate ideas in the early stages of the idea accretion process based on the *generativity* of the ideas rather than their feasibility and usefulness, we hypothesize that fostering recombination of elements from analogies and a target problem can facilitate more effective recognition of the creative potential and applicability of analogs (compared to a more "relevance judgment" interaction paradigm).

A related line of research describes how careful consideration and representation of what conceptual components are available for recombination can substantially improve creative outcomes. This process of organizing and representing ideas into components has been theorized as "**chunking**": for instance, chess experts perceive chess games not in terms of individual features and pieces, but in terms of "chunks" of patterns of game states, enabling them to more effectively perceive and reason over game states [14]. Importantly, the way that knowledge is chunked can shape the degree to which novel recombinations are possible [48, 83]. For instance, in Duncker's [23] classic study of insight problem solving, given a candle, a box of thumbtacks, and a book of matches, participants struggled to devise a way to attach the candle to the wall so it could be lit without dripping wax on the floor. This is because theywere fixated on the traditional use of the box; but when the thumbtack box was emptied, thus de-emphasizing its conventional use as a container, and highlighting the availability of the thumbtacks as components, participants were more likely to devise the insightful solution of attaching the box to the wall as a platform using the thumbtacks. A similar effect was observed when Frank et al [25] manipulated the verbal presentation of the objects so as to highlight their component features (e.g., underlining "box" and "tacks" separately, rather than "box of tacks" as a phrase).

Some creativity techniques also directly scaffold reorganization and decomposition of ideas into chunks to facilitate more creative recombinations, such as highlighting "obscure features" of items [59]. And some work in HCI has also explored representing design knowledge in more atomic and reusable components, such as claims [60] or design patterns [51]. Building on these insights, we

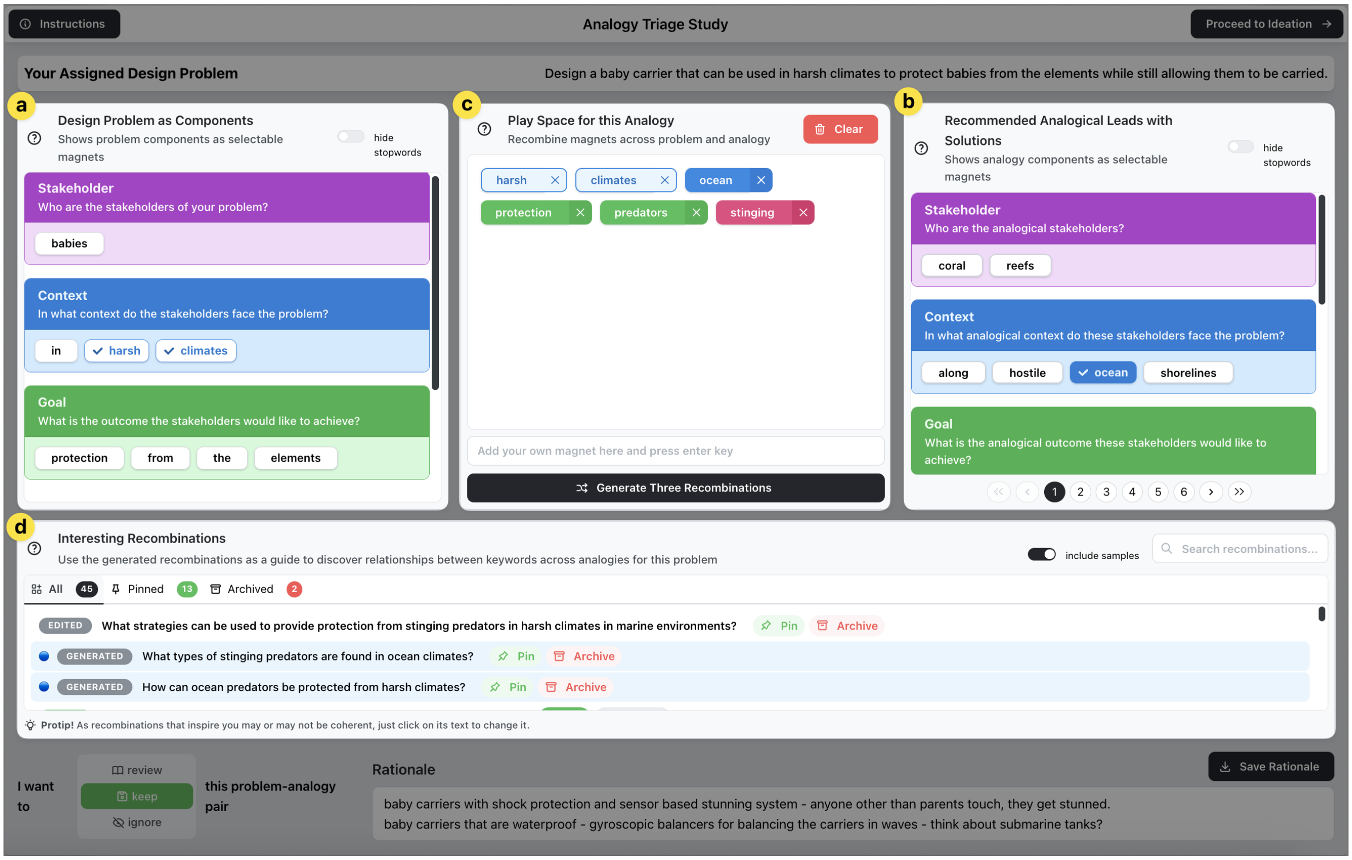

Figure 2: Components of the AnalogiLead Prototype for Playfully Exploring Analogical Leads. AnalogiLead is designed to facilitate the processes of recognition and selection of useful analogical leads while providing intuitive interfaces to ease the process of recombination. To address this, the interface contains *four* key components. First, the Problem Space (A) is where the assigned design problem is broken down into components representing the functional components of Stakeholder, Context, Goal, and Obstacle, and the words within each are broken down into selectable words known as "*magnets*." Second, the Analogy Space (B) is where each recommended analogical lead is broken down in a similar manner, with an additional component for the functional component of Solution. Users can click through to paginate to the next or previous analogical lead for processing. Third, the Play Space (C) is where the selected magnets from the aforementioned spaces can be *added*, *edited*, *deleted*, *cleared* and recombined through spatial maneuvers such as drag-and-drop to mirror the usage of real-world fridge magnets. Fourth and finally, the Recombination Space (D) is where the magnets are recombined into provocative guiding questions or "*prompts*" through the use of Generative Pretrained Models (GPT) with the aim to facilitate divergent thinking while giving users the ability to *edit*, *pin* or *archive* interesting recombinations. Users can record their decisions to review/keep or ignore the analogical lead based on their explorations, as well as record notes about their decision rationale.

hypothesize that careful selection and highlighting of the component "chunks" of analogies and their target problems could facilitate more creative recombinations, and subsequently more effective recognition of inspiring analogies.

3 SYSTEM DESIGN

Our high level design goal is to enable more effective recognition of analogies, including reducing premature rejection of promising cross-domain analogies. Our core design argument is that this can be accomplished by **supporting exploration of analogies based on inspiration potential, rather than emphasizing relevance only**. Drawing on theoretical and empirical research on cognitive mechanisms of chunking and recombination, we further argue that this shift to inspiration-based exploration is facilitated if users' primary mode of interaction with analogies is focused on **exploring recombinations of conceptual chunks from the design problem and analogy**.

Our approach to the overall user experience was inspired by the practice of magnet poetry, where people playfully recombine small magnets — that contain (fragments) of words and syllables — into novel phrases and poems, often on everyday surfaces like a refrigerator [2]. Connecting this design inspiration to the literature

[2]https://magneticpoetry.com/

on cognitive mechanisms of chunking and recombination, we designed two core interaction mechanics: 1) **selecting functional component "chunks"** from an analogy and a design problem to recombine, and 2) **generating and considering recombinations** of those chunks. Figure 2 shows how these interaction mechanics are integrated into a single interface.

3.1 Selecting Functional Component "Chunks"

One key design choice is how to decompose analogies into chunks. Grounded in Structure-Mapping Theory [27], we aimed to decompose analogies in into conceptual chunks that highlight relational correspondences rather than merely attribute similarities. Informed by prior conceptualizations of schemas and analogical transfer, where successful analogical innovation involves attending to relational/functional components such as goals or constraints and solutions [29, 40, 81], we therefore chose to decompose the design problem and analogies with solutions first into **functional component chunks**. We adapted Macneil et al's [56] typology of functional components, which has proven useful for scaffolding creative problem (re)formulation amongst design novices:

- **Stakeholder:** This functional component highlights the beneficiaries who will be affected by the assigned design problem.
- **Context:** This functional component highlights the context in which the aforementioned stakeholders face the assigned design problem.
- **Goal:** This functional component highlights the goal that the stakeholders need to achieve to solve the assigned design problem.
- **Obstacle:** This functional component highlights an obstacle that hinders the stakeholders from achieving their goal for the assigned design problem.

Alongside these functional components, the recommended analogies add an additional functional component to highlight the solution:

- **Solution:** This functional component highlights the solution proposed to solve the goal of the recommended analogy.

Based on previous studies on the effects of chunked visual representations [48] of linguistic features on optimal solution finding [25, 31], we also decompose the sentences within each of the functional components into selectable *"magnets"* (inspired by their functional analog of real-world fridge magnets).

Further, since prior work suggests that de-emphasizing familiar chunks, and enabling recognition of more obscure component features, may enhance creative repurposing and recombination of concepts [25, 31, 48, 79], we hypothesized that enabling users to hide non-functional words might help focus attention on conceptual chunks. We therefore provided a feature to hide *stopwords* — words with high frequency automatically omitted during natural language processing — to enable them to only focus on key function words.

3.2 Generating and Considering Recombinations

To nudge users towards exploring recombinations (rather than judging relevance only), we designed a "playspace" for juxtaposing conceptual chunks (as magnets) from the design problem and analogy. Users can rearrange and edit magnets in the playspace, similar to a magnet poetry experience.

Drawing inspiration from prior research on the use of frames and open-ended questions to inspire more creative ideation [50, 70, 73], we also experimented with integrating Generative Pretrained Models [9] to quickly construct insightful, divergent questions from combinations of the selected "magnets" in the playspace. In our pilot testing with initial prototypes, we found that providing generative AI suggestions for recombinations to users was more helpful for nudging towards exploring recombinations than simply instructing users to do so, and seemed to lower the barrier to thinking of interesting recombinations.

For the purposes of this interface at the time of conducting the study, we used the (then) recent LLM from OpenAI: `text-davinci-002`, to generate recombinations in a zero-shot learning paradigm using the following prompt:

```
By combining the following list of words together,
generate [n] meaningful questions with insightful
relationships: [word1, word2, ..., wordN]
Output:
1.
```

We set model parameters to balance the need for creativity and diversity in the model's responses with the need for coherence and relevance to the input keywords (magnets) sourced from the playspace. `Temperature` was set to 0.75 (slightly larger than the default) for a moderate level of randomness. `Frequency_penalty` and `presence_penalty` were set to 0.5 and 0.25, respectively, to allow for proper sentence structures and moderately curb the presence of repetitions in output. Since generated prompts might not always be relevant or semantically meaningful [15], we also provided the ability to edit the generated prompts.

3.3 Intended User Flow

Putting these component mechanisms together, our intended user flow was for users to interact with analogies by 1) selecting magnets (representing meaningful conceptual chunks) from the problem and analogy, and then 2) generating (and editing) recombinations of these chunks to explore and ideate with. The user should then assess the analogy in terms of its inspirational potential (e.g., what new ideas or insights are sparked by the recombinations and magnets), rather than narrow relevance or similarity of the analogy as a whole to the problem.

4 METHODS

4.1 Study Design

To evaluate `AnalogiLead`, we conducted a within-subjects user study where participants used our intervention interface (AnalogiLead) or a baseline interface without the key interaction mechanics of chunking and recombination) to screen analogies, and then attempt to generate ideas for a problem with the analogies they chose to

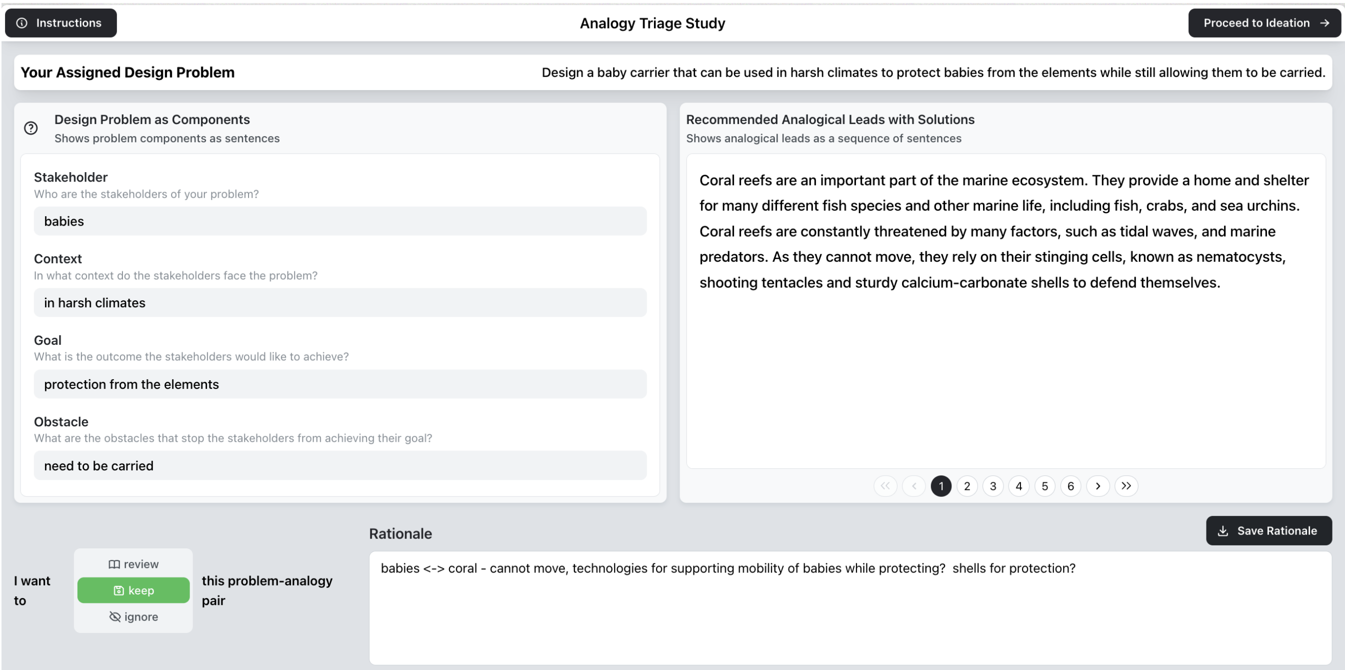

Figure 3: *Baseline Interface for the Screening Task*. This screenshot highlights the key components in the screening interface used for the baseline condition. As discussed in section 4.1, the key differences from the AnalogiLead interface are the presentation of analogies as paragraphs of text, and the lack of affordances for recombining elements of the problem and analogy.

keep. The ideation task was designed to provide an authentic task context within which to evaluate analogies (vs. judging analogies in isolation, in the abstract), and to offer the opportunity to revise initial decisions about analogies.

The baseline screening interface used for this study (see Figure 3) was different from the intervention interface in three key respects:

(1) The design problem is not further broken down into selectable chunks (magnets).
(2) Each analogy is presented, not as chunked components, but as abstracts of text that elaborate on the analogy with the proposed solution weaved in the text.
(3) The recombination generation mechanism is removed

This baseline is a strong contrast to the intervention, removing both the chunking and recombination mechanisms, allowing for initial holistic testing of our design argument.

4.2 Participants

A total of 23 people participated in the study. Participants were from diverse gender identities (12 women, 10 men, 1 non-binary), age-groups (15 between 18 and 25, 2 between 30 and 45, 3 between 46 and 59, 3 over 60), ethnicities (8 Caucasian, 9 African-American, 4 Asian, 1 Hispanic, 1 Asian American and Caucasian) and education-levels (13 Bachelors degree, 6 Masters degree, 3 Ph.D. or higher, 1 from some high school). Participants were recruited using Listserv emails and social media platforms. The only requirement for participation was age: participants had to be at least 18 years old.

4.3 Materials

4.3.1 Source Problems. Source design problems were selected to be accessible to participants across diverse backgrounds (e.g., not requiring specialized knowledge to develop ideas), while still requiring creative thinking to come up with innovative solutions.

Table 1 shows the three design problems used in this study, along with their functional component breakdowns.

4.3.2 Target Analogies. Participants were provided six analogies (3 near and 3 far) for each design problem. The number of analogies was chosen to provide sufficient opportunities to observe variation in processing and provide some time pressure to allocate scarce attention across the analogies, while balancing feasibility of processing all analogies within the constraints of the time budget for our within-subjects design.

We manually constructed analogies for each problem to ensure their analogical relevance, while systematically varying their analogical distance, with equal numbers of near and far (cross-domain) analogies for each problem. See Table 2 for a summary of the analogies, and Tables 6, 7 and 8 in Appendix A for full descriptions.

4.4 Procedure

4.4.1 Main tasks: screening analogies, and ideating with analogies. The main procedure was structured as two blocks of two tasks each:

(1) In the **screening task**, participants were given 16 minutes to *choose analogies to carry forward to an ideation task to inspire creative new solutions for the assigned design problem.* Participants could make one of three decisions about each

Table 1: Source Problems used for this Study.

Problem	*Problem Description*	*Problem Components*	
Baby Carrier	Design a baby carrier that can be used in harsh climates to protect babies from the elements while still allowing them to be carried.	*Stakeholder* *Context* *Goal* *Obstacle*	babies in harsh climates need protection from the elements need to be carried
Marine Environment	Design a marine environment in which young children and aquatic animals can interact with each other while keeping both safe.	*Stakeholder* *Context* *Goal* *Obstacle*	young children and aquatic animals in a marine environment interact with each other keep both safe
Weight Training	Design a weight training program that can be done while on the go for business people who are busy frequent flyers.	*Stakeholder* *Context* *Goal* *Obstacle*	a business person is a busy frequent flyer do weight training always on the go

Table 2: Analogies used for this Study.

Design Problem	*Analogical Leads*
Baby Carrier	NEAR: Baby Gates, Mosquito Netting, Kangaroo Pouches FAR: Coral Reefs with Stinging Cells, Ground Launched Missiles, Convertible Cars
Marine Environment	NEAR: Shark Cages, Expert Dolphin Trainers, Deep Sea Submersibles FAR: Virtual Reality Psychiatric Treatments, Lane Assist Technologies, Negative Room Pressure
Weight Training	NEAR: Resistance Bands, Sandbag, Desk Cycle FAR: Protein Biosynthesis, Passively Designed Popup Houses, Inflatable Air Mattresses

analogy: 1) "**ignore**" (like archiving, they would no longer see it in their list in the downstream ideation task unless they consulted the archive of ignored analogies), 2) "**keep**" (like bookmarking, these analogies would appear at the top of their list of analogies for the downstream ideation task, or 3) "review" (keep it in the list for the downstream task, but not at the top of the list). Participants also had a textbox to record the *rationale* for their decisions. Participants were instructed to think aloud while doing this task.

(2) In the **ideation task**, participants were given 8 minutes to *come up with solutions that are as creative as possible for the assigned design problem* using the analogies they screened in the previous task as a guide. They were also instructed to think aloud while doing this task. To ensure that the participants were not constrained by the task or the open-ended nature of the selected problems, they were explicitly allowed to add or modify assumptions or aspects of the design problem. Participants had access to a searchable list of all the recommended analogies that they had screened, and a text area to enter/scrap their ideas. Participants could also make changes to their decisions about analogies.

In each block of tasks, participants were randomly assigned one of the three design problems (and its associated 6 analogies) as well as either the baseline or intervention condition. The difference between the intervention and baseline screening interfaces is described in Section 4.1. The ideation task interface differed between the baseline or intervention conditions in terms of 1) whether analogies were shown as full descriptions (like in the baseline screening interface) or with associated functional component chunks and magnets, as well as associated bookmarked recombinations (in the intervention condition), and 2) whether participants could return to the screening interface to revisit their assessment of analogies (intervention condition allowed for this since the interactions for "judging" an analogy were anchored in the magnet recombination playspace mechanics of the intervention screening interface). Figures 8 and 7 in Appendix B show screenshots of ideation task interfaces.

All participants completed procedures via Zoom: the sessions were video and audio-recorded with the participants' screen sharing. All study procedures were approved by the authors' institution's IRB.

4.4.2 Instructions to participants. Prior to the task blocks, participants were introduced to the study and the think-aloud protocol, and engaged in a brief practice run of thinking aloud over an unrelated task. If a participant failed to think-aloud for a consecutive couple of minutes, the participants were explicitly asked to "*speak what is on their mind*".

Before the interaction with each main task interface, a demo of that interface was performed with an example problem (different from the problems assigned to the participant). Participants could ask clarifying questions about the functionality of the interfaces before proceeding.

After the main task blocks, participants engaged in a 10-minute debriefing interview. They were asked about their experience using the interfaces and how useful they were for the goal of selecting inspiring leads that led to the most novel, creative and innovative solutions.

4.5 Measures

4.5.1 Decisions and Revisions. One primary dependent measure was the initial decisions for each analogy during the screening task. Given our interest in the core issue of premature rejection, our primary analysis focused on whether participants made a **decision to ignore** (vs. keep or review) each analogy. We also constructed a binary measure of **decision revisions** to capture the potential phenomena of potentially missing insights in analogies or overfocusing on surface similarity and relevance on first encounter: any changes to decisions such as *Ignore→Keep/Review*, *Keep→Ignore/Review*, and *Review→Keep/Ignore*, if found, were coded as revisions.

Decisions during the screening phase were sourced from the interaction logs while their final decisions were taken from the final state of their decisions in the stored data. These decisions were then mapped together with their problem, analogy, interface and condition prior to processing.

4.5.2 Processing time. We also measured *processing time* for each analogy, defined as the delta in seconds from the timestamp at first paginating into a given analogy, to the timestamp where participants clicked to paginate to the next analogy. If participants returned to an analogy, processing time was incremented only if it exceeded the current processing time for that analogy.

4.6 Analysis

Quantitative variations in decisions, revisions, and processing time across the conditions were analyzed with **Generalized Linear Mixed Models (GLMMs) mixed effects models** to account for correlation between repeated measures within an individual participant.

For each set of models, we first build the baseline null model that only models the random effects of the participant in the absence of additional predictors to understand the within-participant variation. We then estimate a model with a fixed effect of *Analogical Distance* (Near or Far) and another model that adds an additional fixed effect of *Experimental Condition* (Baseline or Intervention). We complemented this quantitative analysis with a qualitative **thematic analysis** [8] of the video recordings and transcripts of the think-aloud and interview.

Our goal was to characterize whether and how interactions with the analogies via our chunking and recombination mechanisms approached our intended user experience of playful engagement. Our analysis was inductive, but also informed by theoretical conceptualizations of play. We drew in particular on a recent transdisciplinary synthesis of conceptualizations of play across the fields of HCI, education, psychology, game studies, and linguistics [57]. Due to technical difficulties with the Zoom meeting (including total loss of video recordings in 4 cases, and dropped calls in the 6 cases), we were only able to analyze 13 of the 23 participant protocols in detail.

5 RESULTS: QUANTITATIVE ANALYSES

5.1 Decreased likelihood of ignoring analogies in intervention interface compared to baseline

Our fully specified GLMM (Table 3, last column) estimated significant fixed effects of both analogical distance and interface condition. Near analogies were significantly less likely to be ignored, but analogies overall were less likely to be ignored in the intervention condition, B = -1.38, 95% CI=[-2.29, -0.48], $p < .01$ (raw observed proportions in Figure 4A). Note that the analogical distance predictor was dummy coded so that "distance = near" was the reference class; similarly, the interface condition was dummy coded so that "interface condition = intervention" was the reference class. This dummy coding applied across the remaining models.

In odds ratio terms, participants were 4x less likely to ignore analogies when using the intervention screening interface (i.e., AnalogiLead), compared to when using the baseline screening interface (Odds Ratio = 0.25). The decreased Akaike Information Criterion (AIC; 174.2 for full model vs. 190.7 for null model) and Bayesian Information Criterion (BIC) measures (188.5 for full model vs. 197.84 for null model) suggest that the gain in overall model fit with these coefficients is not due to overfitting.

A model with an interaction term between analogical distance and interface condition failed to converge, possibly due to the sparsity of data.

Note that participant-level random effects were estimated as zero, indicating a singular fit; this may be caused by very low variation in the ignore decision outcome across participants. A simpler generalized linear model without participant-level random effects yielded very similar coefficient estimates as our full model here (see Table 9 in Appendix C).

5.2 Fewer revisions in intervention interface compared to baseline

Our GLMMs estimated no significant effect of analogical distance on the likelihood of revisions, but did estimate significant fixed effects of interface condition. In both the full model (2nd to last column in Table 4) and model with only interface condition as a fixed effect (since model fit was worse with the analogical distance fixed effect included), decisions about analogies overall were less likely to be ignored in the intervention condition. In the best-fitting model with only fixed effects of interface condition, the coefficient estimate was B = -2.49, 95% CI=[-4.69, -0.29], $p < .05$ (raw observed proportions in Figure 4B).

In odds ratio terms, participants were 12x less likely to revise their decisions about analogies when using AnalogiLead compared to when using the baseline screening interface (Odds Ratio = 0.08). The decreased AIC (77.9 for the interface condition only model vs. 84.0 for null model) and BIC measures (87.8.5 for full model vs. 90.5 for null model) suggest the gain in overall model fit with these coefficients is not due to overfitting.

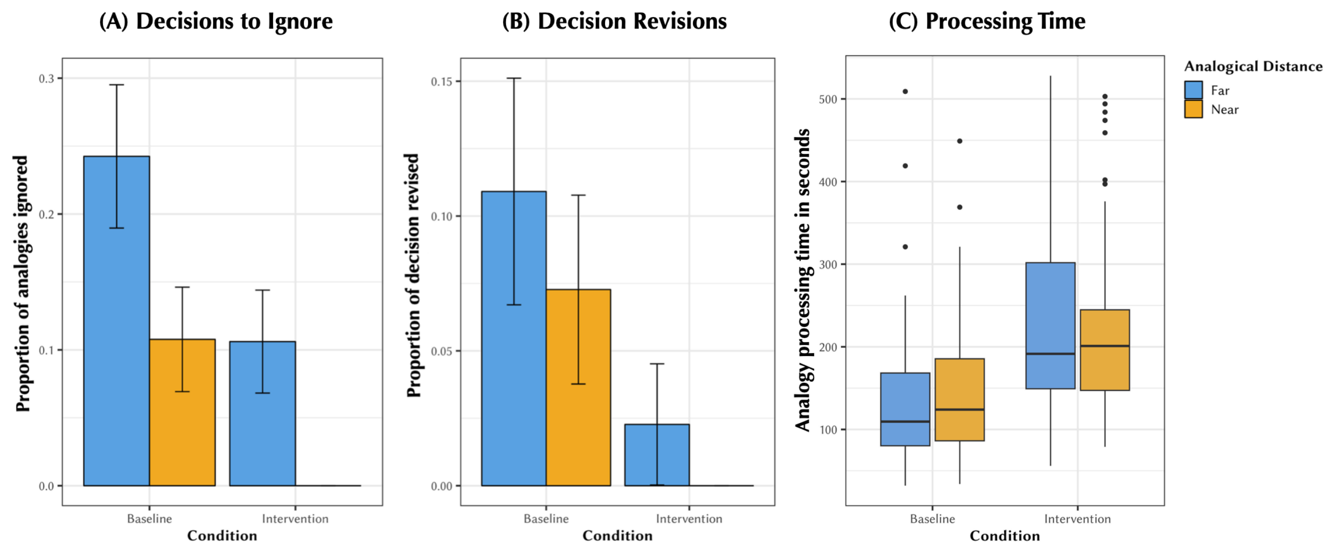

Figure 4: Observed proportion of analogies (A) ignored, and (B) with decision revisions, by Analogical Distance and Interface Condition. Error bars are +/- 1 Standard Error of proportion. (C) shows a box plot of observed mean processing time (in seconds) per analogy, by analogical distance and interface condition.

Table 3: GLMM models predicting whether an individual analogy received an "ignore" decision

	Null model	*Near Analogy Only*	*Full Model*
Fixed Effects			
Intercept	-2.05*** (-2.43, -1.67)	-1.56*** (-2.01, -1.11)	-1.03*** (-1.58, -0.47)
Near Analogy	-	-1.32*** (-2.20, -0.43)	-1.37*** (-2.27, -0.46)
Intervention	-	-	-1.38*** (-2.29, -0.48)
Random Effects			
Participant ID	0	0	0.02
Model Fit Statistics			
Log Likelihood	-93.35	-88.37	-83.10
AIC	190.70	182.74	174.21
BIC	197.84	193.46	188.50

*p<0.1; **p<0.05; ***p<0.01; Confidence intervals for fixed effects are 95% confidence intervals; AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion

5.3 Longer processing time per analogy with intervention interface compared to baseline

Because processing time was right-skewed with an increasing variance-to-mean ratio, we used a Gamma Distribution with a log-link function for this set of GLMMs.

Our fully specified GLMM (Table 5, last column) estimated significant fixed effects only of interface condition: participants overall took longer to process each analogy in the intervention condition compared to the baseline condition, $B = 0.530$, 95% CI=[0.397, 0.663], $p < .01$ (see distribution of processing times in Figure 4C). This estimated increase of approximately 90 seconds compared to the baseline translates to approximately a 64% increase in processing time per analogy when using the AnalogiLead screening interface. The decreased Akaike Information Criterion (AIC; 2279.87 for full model vs. 2329.49 for null model) and Bayesian Information Criterion (BIC) measures (2296.26 for full model vs. 2339.33 for null model) suggest that the gain in overall model fit with these coefficients is not due to overfitting.

6 RESULTS: QUALITATIVE ANALYSIS OF INTERACTIONS WITH ANALOGIES

We now turn to our qualitative analysis, with a goal of complementing the quantitative analysis with detailed descriptions of *how* Analogilead's chunking and recombination mechanims might have

Table 4: GLMM models predicting whether an individual analogy received a "revision" of decision

	Null model	*Near Analogy Only*	*Full Model*	*Intervention Only*
Fixed Effects				
Intercept	-3.65*** (-5.19, -2.10)	-3.40*** (-5.02, -1.79)	-3.02*** (-4.86, -1.17)	-3.30*** (-5.07, -1.53)
Near Analogy	-	-0.59 (-1.92, 0.74)	-0.68 (-2.09, 0.73)	-
Intervention	-	-	-2.53** (-4.74, -0.31)	-2.49** (-4.69, -0.29)
Random Effects				
Participant ID	1.98	2.00	2.83	2.77
Model Fit Statistics				
Log Likelihood	-40.00	-39.61	-35.50	-35.97
AIC	83.99	85.21	79.00	77.94
BIC	90.54	95.03	92.09	87.75

*p<0.1; **p<0.05; ***p<0.01; Confidence intervals for fixed effects are 95% confidence intervals; AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion

Table 5: GLMM models predicting the processing time for an individual analogy (with Gamma Distribution)

	Null model	*Near Analogy Only*	*Full Model*
Fixed Effects			
Intercept	5.195***(5.184, 5.205)	5.155***(5.012, 5.299)	4.876***(4.718, 5.033)
Near Analogy	-	0.076(-0.076, 0.227)	0.055(-0.078, 0.187)
Intervention	-	-	0.530***(0.397, 0.663)
Random Effects			
Participant ID	0.028	0.0294	0.0371
Model Fit Statistics			
Log Likelihood	-1161.75	-1161.27	-1134.93
AIC	2329.49	2330.53	2279.87
BIC	2339.33	2343.64	2296.26

*p<0.1; **p<0.05; ***p<0.01; Confidence intervals for fixed effects are 95% confidence intervals; AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion

enabled playful engagement (vs. narrow relevance judgments) with the analogies.

A portion of P23's screening task with the intervention illustrates the core themes of how our participants interacted with analogies in Analogilead (see Figure 5 for a visual walkthrough of this case). Here, P23's assigned problem was the Marine Environment problem, and the assigned analogy was the (cross-domain) Virtual Reality Psychiatric Treatments analogy. P23 began by attending to key concepts from the problem, represented by the magnets for the stakeholder ("children", "aquatic", "animals"), context ("marine", "environment"), goal ("interact"), and obstacle ("safe") . Each of these key chunks were added to the playspace to juxtapose with the analogy. She then scrolled through the stakeholder, context, goal, and obstacle elements of the analogy, and reacted with initial dismissal, saying *"I'm kind of struggling to see how this would give me an idea from the context, and just like from just the context of the what I think the problem statement is"* (Figure 5.1). This skepticism persisted after reading through the solution component of the analogy, but then transitioned to openness and curiosity about the conceptual chunk of "virtual reality" in the solution, as she expressed: *"I don't know about this solution, but I'm liking this idea of virtual reality...because that's something I did not think about."* (Figure 5.2)

From here, she began to attend to a cluster of related conceptual chunks from the solution, including "virtual reality", "immersive technology", and "immersive experience", adding each to the playspace in turn. She then attended to and selected other conceptual chunks of the solution, such as "feel more in control", and "tailor the environment". After that, she triggered the "generate three recombinations" button, and was intrigued by the first recombination question (Figure 5, steps 3 and 4):

> *Okay, so how does immersive technology enhance the experience of children interacting with marine animals and also better protect our environment? That's actually such a good question...cause, like you know, we always talk about like aquariums, and how like, it's really a bad idea to have these animals in my activity right? Because they should be out there in the wild doing what they*

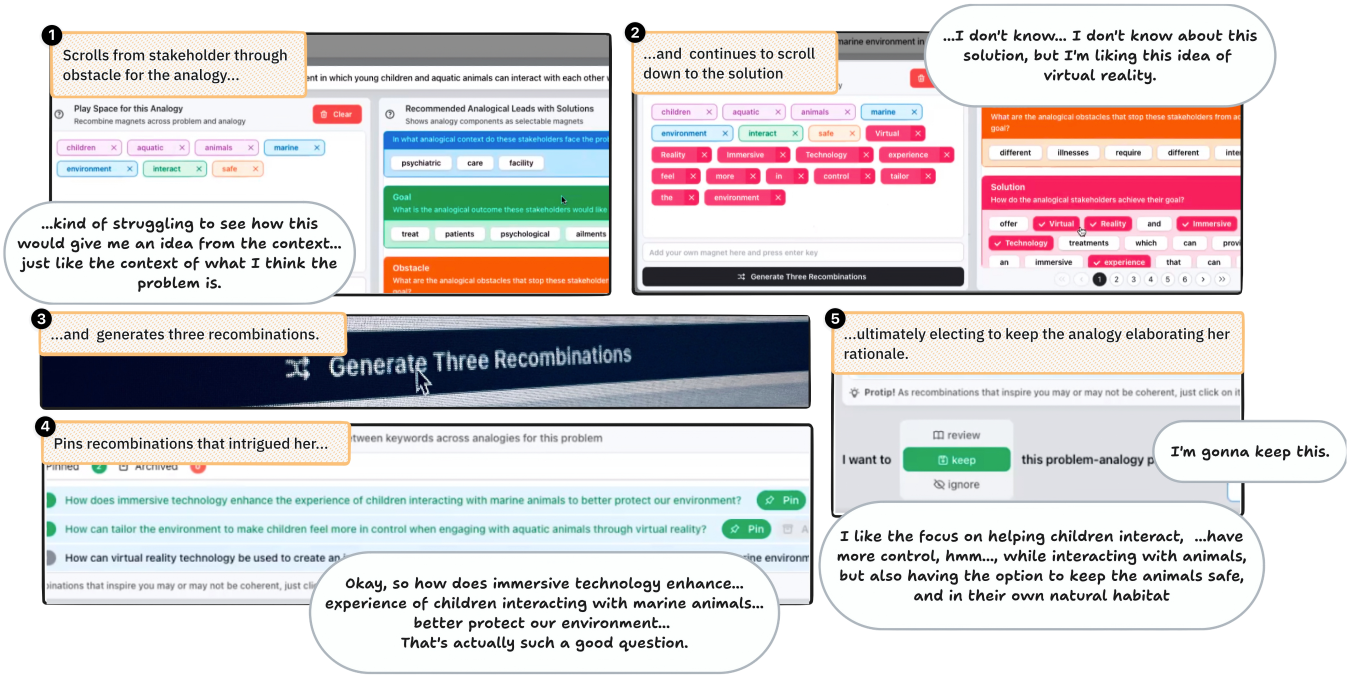

Figure 5: Illustrated flow (sequentially labelled from 1-5) of P23's Screening Task for the Marine Environment Problem while interacting with the Virtual Reality Analogy, showing them (1) exploring the analogy, (2) identifying an inspirational idea, (3) generating recombinations after choosing magnets in the playspace, (4) pinning intriguing recombinations, and ultimately (5) electing to keep the screened analogy with reasoning.

> *want to do. So we could use immersive environments to help children still kind of like feel like they're in there and kind of like experience in it, without actually harming the animals themselves. That's a good idea. Actually, I like this, a lot.*

P23 decided to keep the analogy, elaborating as she wrote her rationale (Figure 5.5): "*I like the focus on helping children interact, children kind of like have more control, hmm, while interacting with animals, but also having kinda like the option to keep the animals safe, and in their own natural habitat instead of in captivity.*"

This example illustrates a core flow we saw across the participants: 1) *focusing* on interesting conceptual chunks of the problem and analogy, even when other elements of the analogy appear to be irrelevant, and then 2) moving towards curiosity and engagement by *interacting with and responding to* the generated recombination questions, which often involved some degree of *reframing* of the analogy and/or problem. In P23's case, she focused initially on the intriguing conceptual chunk of virtual reality from the analogy's solution chunk, even though she was initially dismissive of the other elements of the analogy; she then was able to consider novel angles on the problem (a sense of control, and considering the needs of the animals) in response to one of the recombination questions generated from the conceptual chunks to which she was attending.

To explore how the interactions and behaviors of this core flow might be associated with playful engagement, we drew on Masek and Stenros's [57] qualitative meta-synthesis of theoretical conceptualizations of playfulness. From a trans-disciplinary review of conceptualizations of play across HCI, education, psychology, game studies, and linguistics, Masek and Stenro synthesized a set of conceptual themes that describe *methods* of structuring playful engagement, and complementary themes that outline structural characteristics of *environments* conducive to playful engagement. Given our focus on how to structure *interactions* with analogies to foster playful engagement (vs. studying environments conducive to playful engagement), we focus our description on the following set of method-focused themes:

(1) **Focus**. Building on concepts like Moon and Kim's [62] influential concept of "perceived playfulness", and Csikszentmihalyi's concept of "flow" [20], among others, this theme describes play as deep engagement in a single context that combines immersion or focus with a playful attitude, often accompanied by the presence of curiosity and positive emotional affects, such as excitement, joy, and interest.
(2) **Openness**. This theme describes playfulness as a "ludic" approach towards a task that emphasizes flexibility, spontaneity, and a willingness to explore various perspectives and possibilities.
(3) **Framing**. This theme conceptualizes playfulness as an active and intentional process of altering one's perceived context to enhance engagement and evoke emotional responses in oneself and others. This involves a dynamic and creative reshaping of situations or environments to introduce elements of amusement, humor, entertainment, intellectual stimulation, or whimsicality.

6.1 Fostering Playful Focus

Recombinations sometimes motivated playful focus via progressively deeper inquiry. For instance, one of the recombinations for the Shark Cages analogy for the Marine Environment problem was "How do children's interactions in aquatic environment influence hostile behaviour of nearby sharks?" P12's initial reaction was intrigue (*"That's an interesting question"*) as she read it aloud. She mulled over an idea about setting up *"shark netting so that children's behaviour does not lead to being eaten even if the sharks are nearby and hostile"*, and then dug deeper into how this uncovered a previously overlooked aspect of the problem: '*'I guess the only question would be teach children not to act like shark prey"*. She then deepened her inquiry by reflecting on connections to her childhood experiences:

> *That's what they do where I grew up: [laughs]: Try not to look like a seal! Because the great white sharks want to eat seals, they don't want to eat you. That's part of the problem, they have surfers: I'm from Northern California, it's too cold to surf without a wet suit on, so you put a wet suit on and you surf, but with a wet suit you look like a seal.*

P13's session showed similar instances of affective responses of surprise and curiosity to the generated recombinations. For example, when looking at a recombination of elements of the Marine Environment problem with the Deap Sea Submersibles analogy, P13 expressed, *"I love the idea of, um, yeah, interaction and the depths of an ocean. I think that's a good question."* This positive affective experience was also echoed in some debriefing interviews: for example, P7 mentioned that they found our proposed interface a lot more generative than the baseline for coming up with ideas, saying:

> *maybe it's because the first time I used it, but I got really excited about trying trying different things rather than actually focusing on my goal... which again, if I was trying to think of a different aspect or something maybe that would have helped but... For this I was like, oh, let me try a bunch of different things. But it was also super fun. Right? It was so generative!*

This generative and fun experience was echoed by P23 (as a contrast to the baseline interface): after ignoring an analogy in the baseline interface (the third analogy she was processing), she sighed and expressed: *"I don't know. I think I like the other interface. This is becoming. This is draining. I was more excited for the other time"*.

6.2 Fostering Playful Openness

We observed a robust cluster of behaviors around a playful approach of openness to recombinations with our intervention. One interesting recurring pattern was verbal expressions of curiosity about what interesting recombinations might be generated from a set of problem and analogy magnets. Phrases like *"I'm gonna turn this around!"* (P04), *"let's see what it comes up with"* (P12), *"I'm gonna...see what happens"* (P01), *"What does that give us?"* (P13), and even *"why (the heck) not?"* (P12) were common precursors to initiating AnalogiLead's recombination generation feature.

This posture of curiosity and openness was observed even when there was initial skepticism: for example, while processing the Shark Cages analogy, P23 expressed strong repulsion to an idea, but still expressed and acted on curiosity about potential recombinations:

> *Okay. Some shark cages. Do we want to put children in cages? That sounds like some trump shit. No, let's not do that. Let's not do that. But I'm actually curious to see what this would come up with...Oh, boy! What I was trying to do. Right?*

Additionally, sometimes, when participants did not get useful recombinations the first time around, they regenerated the recombinations, indicating further openness to exploration.

6.3 Fostering Playful Framing

Similar to the case of P23, participants often leveraged the magnets to manipulate their frame of reference for analogies, ignoring aspects that were deemed irrelevant in favor of conceptual chunks that caught their interest. P14, for instance, noted that the overall context of sleep and elderly people in the Inflatable Air Mattresses analogy did not *"seem too relevant here"* for the Weight Training problem, but noted, *"I think the portable thing has value"*. She went on to add that magnet from the analogy to the playspace, and rearranged it into a rephrasing of the problem as a sentence along with other magnets from the problem that centered on the property of portability ("need good portable weight training away from home").

Along these lines, a number of participants played around with the magnets from the problem and analogy components in the playspace by attempting to form "complete sentences" in varying degrees (see Figure 6). We considered this to be "framing" taken literally: problem and analogy conceptual chunks were composed into a "different frame" in the form of a new sentence, using affordances like dragging (P14, P17). For instance, P14 rearranged the playspace combining the analogical obstacle magnet "recurring" with the problem goal magnets "weight training" to form "recurring weight training". Sometimes, while doing so, they added their own magnets stitching in their train of thought together during this reframing (P04, P14). For instance, while processing the Sandbag analogy for the Weight Training problem, P04 added their own magnets while forming sentences *"There's professionals, I guess. And they're in the plane. They want to improve. Weightlifting. Obstacles are that. Tired maybe because they fly so much. I think that's a good thing."* Some participants even added their own stopword magnets to form more complete sentences (P03, P23).

Recombinations, too, would spur reframing of the original *problem*, enabling further engagement with the analogy's ideas. For example, when considering the (cross-domain) Protein Biosynthesis analogy for the Weight Training problem, P22 added magnets about "immune system", "biosynthesis", and "deterioration" to the playspace alongside the problem magnets, exclaimed *"ahh, this is going to make something interesting!"*, and generated recombinations: among the recombinations were "How does degradation of structural proteins help weight loss training?", "How can an equilibrium of weight loss be achieved at a cellular level?", and "How can a business person balance the loss of weight training?". Pondering these recombinations during the later ideation task, P22 reframed the problem to one of maintaining health when workouts were

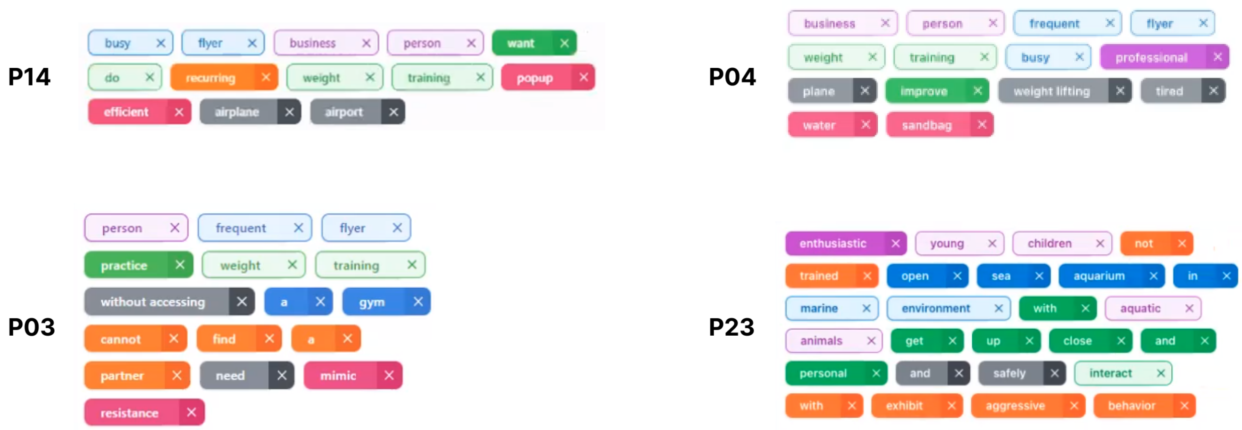

Figure 6: Examples of participants manually rearranging magnets in the playspace to reframe the problem/analogy into complete phrases or sentences, similar to magnet poetry.

not possible (rather than finding ways to workout on the go), saying *"it's all about eating and staying healthy! its a good thing!"* and wrote an idea "When you are on the fly, eat some magical protein supplement that will allow you to have many no workout days."

We observed a similar reframing in P12's response to a recombination for the Marine Environment Problem with the Deep Sea Submersibles analogy: *"The young children interacting safely with marine aquatic animals in their environment, that one I think is important."* In pondering this, P12 noted a possible reframing of the problem away from a focus on the environment to a focus on *interaction*:

> *that's really kind of a restatement of the problem. So it's really saying, so we're going to design the marine environment where they can interact and the question becomes how do they interact safely? So this is a precursor to designing the marine environment. So... how to interact safely is an input into how to design an environment that allows or encourages this kind of interaction. So maybe they can interact through sound or sight. Which suggests sound, maybe microphones and speakers for interaction or sight. Maybe clear barriers that both can see through. And some signals that the child could use that the animal knows are meaningful and gets the animal a treat. That's a form of interaction.*

7 DISCUSSION

In this paper, we explored how to structure initial encounters with analogies in computational systems to enhance recognition of — and reduce premature rejection of — inspiring analogies. Drawing on cognitive mechanisms of conceptual chunking and recombination, we designed the AnalogiLead prototype interface to facilitate playful exploration of recombinations of conceptual chunks.

Our experimental evaluation revealed notable changes in the way users engaged with with analogies using AnalogiLead (compared to a baseline interface). Participants were about four times less likely to overlook analogies and twelve times less likely to revise their initial decisions about them. Additionally, there was a 64% increase in the time participants spent processing each analogy. This suggests that Analogilead helped to reduce hasty dismissals of potential insights.

Our qualitative results complement these experimental results by revealing the potential mechanisms by which AnalogiLead might reduce premature dismissal by fostering playful engagement with analogies. Drawing on theories of playful engagement [57], we described how AnalogiLead's magnets and recombinations enabled participants to enter a state of immersed and curious engagement with analogies, often by iterating on and responding to generated recombination questions. A sense of inviting openness was associated with the system's features for generating suggested recombinations. And engagement with the magnets and recombinations enabled participants to manipulate their frame of focus to ignore irrelevant details, hone in on interesting alignments and concepts, and reframe the problem itself in novel ways in response to recombination questions.

Overall, our results point to the effectiveness of cognitive mechanisms of chunking and recombination for scaffolding playful recombination in initial encounters with analogies to reduce premature rejection. Because these mechanisms only require a source problem and a single possible analogy, and focus on fostering playful problem reformulation in addition to direct solution transfer, they are complementary to previous process-oriented approaches that are optimized for noticing and transferring specific solution components or relational mappings that are known in advance, such as including images or descriptions that highlight core solution schemas from the analogy [10, 17, 19, 29], or inducing schemas from analogical comparison of two analogs with the same key relational schema [29, 53, 80]. Our design work and empirical results also reinforce the value of — and provide one example of — systematic, theory-driven investigations into redesigning interaction paradigms in computational analogical innovation systems.

Beyond the particular problem of analogical innovation, our usage of LLMs to scaffold exploration of recombinations connects to broader discussions around human-AI interaction and co-creation patterns for creativity support. Here, we demonstrate the value of using generative AI not to produce or refine creative products, but to foster playful engagements with creative *materials* (in this case, analogies). In this way, we add to a growing body of design explorations for using generative AI to construct re-representations of information to facilitate sensemaking and reflection [43, 55] and search and learning [2, 46]. We are curious to see more explorations of this design space for human-AI co-creation, focusing not just on sensemaking and learning (as in past work) but also playful reframing and reformulation (as in our work), which could integrate into larger workflows, such as iterative cycles of ideation and reframing in design firms [66].

7.1 Limitations and Future Work

Our study has several limitations that must be considered when interpreting the results. First, the generalizability of our findings may be restricted due to our evaluation being conducted with a relatively small and homogeneous group of participants. This limited sample size — combined with the loss of complete video protocol data for 10 of our 23 participants due to technical difficulties — also constrained our ability to perform a comprehensive qualitative analysis and capture more nuanced insights. Second, the interface and task design in our study did not explicitly instruct participants to develop initial ideas into more mature concepts. Further, the relatively brief allotted duration for ideation — balancing our need for task authenticity with the need to minimize participant fatigue in a fairly long within-subjects design — was likely insufficient to fully develop ideas. This is a key limitation since the influence of novel inspirations, particularly from distant analogies, might only become apparent after several rounds of iteration and development [5, 13, 33]. The study design thus limits our analysis potential to fairly coarse process-based measures of divergent thinking, such as quantity and diversity of ideas. It is also unclear whether more output-focused measures of quality would be appropriate at this early stage of the ideation process [72].

A direct evaluation of the downstream implications of the changes in analogical screening behavior induced by our system is a critical next step. The ideation task in our study was primarily designed to provide an authentic context for selecting analogies and observing revisions in initial screening decisions—a potential indicator of premature rejection. However, it was not ideally suited to study impacts on ideation comprehensively. Future work should allow for and directly study the effects on idea iteration and development, such as providing longer timeframes for idea development and iteration, embedding the screening task and measures in a more authentic project arc, or including measures of influence, such as requests for reflections on the sources of ideas.

Another significant question concerns the potential alternative explanation that changes in behavior observed with our intervention were merely due to participants spending more time and effort. Our qualitative results challenge this explanation by identifying specific interface-driven actions, such as focusing on conceptual chunks and responding to generated recombinations, that plausibly connect to characteristics of playful engagement. Future research should develop more precise measures of these behaviors to explore their relative impact on decision-making processes. Such careful mechanistic analyses will be crucial as the playful engagements we observed can also occur in unscaffolded interactions, albeit perhaps more sporadically and effortfully: the core benefit of novel interaction paradigms would be to shift more behaviors, on the margin, towards playful (versus narrowly relevance-focused) engagement.

From a system design perspective, enhancing AI assistance for recombinations could be fruitful. Participants sometimes reported frustrations with occasional nonsensical or repetitive generations, likely due to our use of `text-davinci-002` with a lower temperature setting to control the model's outputs. However, lower temperature settings resulted in deterministic but less creative outputs. When we tested our exact prompts with later versions of GPT (GPT-3 and ChatGPT), the responses were more informative, intuitive, and proactive. The dialogue-like nature of ChatGPT could further enhance iterative recombination processes, for example, by using prior recombinations as starting points for new ones.

Relatedly, our system was anchored on representing and manipulating textual representations of problems and individual analogies. This design choice followed from our core design inspiration of magnet poetry, and lent itself well to the use of GPT to assist with exploring potential recombinations. Future work can explore how chunking and recombination might work for analogies in other mediums, such as visual designs [49], code examples [7], or other materials such as chemical or protein isomorphisms. Similarly, we are curious to more directly support recombinations and explorations *across* analogies, as observed in some prior work on "compound analogical mappings" [36]. Notably, while AnalogiLead did not explicitly allow for cross-analogical mappings with a target problem during the screening process, we found traces for this phenomena occurring in our observations. For instance, participants P07 and P23 added a custom magnet called *"sling"* that they identified as being relevant to the problem of designing a baby carrier, carrying them over across analogies to add a little bit of context from earlier analogies in their generated recombinations.

Finally, we are curious about how this playful interaction paradigm for screening analogies might generalize to other contexts and workflows. We are particularly interested in the "effect size" of interaction paradigm interventions relative to or in concert with other more structural and socio-technical factors, such as levels of socio-emotional support, metacognition, or stages of projects. For instance, how might our interaction mechanics fruitfully pair with increased openness to distant analogies during impasses in problem-solving [69, 74]? From a task and socio-technical context perspective, how might nudges towards playful engagement fit—or not—in higher-stakes problem situations? Research on the potential misalignment of "blue sky" design thinking trappings in community-based co-design with marginalized populations [35] suggests that careful design work is needed to create scaffolds for playful engagement that fit different socio-technical contexts. We believe the theoretical grounding of our prototype in cognitive mechanisms and conceptualizations of playful engagement, along with our qualitative results, will be helpful for informing this future design work.

8 CONCLUSION

In this paper, we investigated how we might design novel interaction paradigms that help creators more readily recognize potential inspiring analogies, especially from different domains. Our prototype system AnalogiLead, with its grounding in cognitive mechanisms of chunking and recombination and theoretical conceptualizations of play, illustrates one design path to answering this question: scaffolding playful engagement with analogies and problems in terms of recombinations of meaningful conceptual chunks. We call for more systematic exploration of novel interaction paradigms that can augment creators' ability to not only retrieve, but fully benefit from, analogical inspiration.

REFERENCES

[1] Diederik Aerts, Liane Gabora, and Sandro Sozzo. 2013. Concepts and Their Dynamics: A Quantum-Theoretic Modeling of Human Thought. *Topics in Cognitive Science* 5, 4 (2013), 737–772. https://doi.org/10.1111/tops.12042

[2] Tal August, Lucy Lu Wang, Jonathan Bragg, Marti A. Hearst, Andrew Head, and Kyle Lo. 2023. Paper Plain: Making Medical Research Papers Approachable to Healthcare Consumers with Natural Language Processing. *ACM Transactions on Computer-Human Interaction* (April 2023). https://doi.org/10.1145/3589955 Just Accepted.

[3] Marcia J. Bates. 1989. The design of browsing and berrypicking techniques for the online search interface. *Online Review* 13, 5 (Jan. 1989), 407–424. https://doi.org/10.1108/eb024320 Publisher: MCB UP Ltd.

[4] Wayne A. Baughman and Michael D. Mumford. 1995. Process-analytic models of creative capacities: Operations influencing the combination-and-reorganization process. *Creativity Research Journal* 8, 1 (1995), 37–62. https://doi.org/10.1207/s15326934crj0801_4

[5] Justin M. Berg. 2014. The primal mark: How the beginning shapes the end in the development of creative ideas. *Organizational Behavior and Human Decision Processes* 125, 1 (2014), 1–17. https://doi.org/10.1016/j.obhdp.2014.06.001 00056.

[6] Brian J. Birdsell. 2019. Creative Cognition: Conceptual Blending and Expansion in a Generative Exemplar Task. *IAFOR Journal of Psychology & the Behavioral Sciences* 5, si (Oct. 2019), 43–62. https://doi.org/10.22492/ijpbs.5.si.03 00002.

[7] Joel Brandt, Mira Dontcheva, Marcos Weskamp, and Scott R. Klemmer. 2010. Example-centric Programming: Integrating Web Search into the Development Environment. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. ACM, New York, NY, USA, 513–522. https://doi.org/10.1145/1753326.1753402

[8] Virginia Braun and Victoria Clarke. 2006. Using thematic analysis in psychology. *Qualitative Research in Psychology* 3, 2 (Jan. 2006), 77–101. https://doi.org/10.1191/1478088706qp063oa

[9] Tom B. Brown, Benjamin Mann, Nick Ryder, Melanie Subbiah, Jared Kaplan, Prafulla Dhariwal, Arvind Neelakantan, Pranav Shyam, Girish Sastry, Amanda Askell, Sandhini Agarwal, Ariel Herbert-Voss, Gretchen Krueger, Tom Henighan, Rewon Child, Aditya Ramesh, Daniel M. Ziegler, Jeffrey Wu, Clemens Winter, Christopher Hesse, Mark Chen, Eric Sigler, Mateusz Litwin, Scott Gray, Benjamin Chess, Jack Clark, Christopher Berner, Sam McCandlish, Alec Radford, Ilya Sutskever, and Dario Amodei. 2020. Language Models are Few-Shot Learners. *arXiv:2005.14165 [cs]* (Jun 2020). http://arxiv.org/abs/2005.14165 00030 arXiv: 2005.14165 Citation Key: brownLanguageModelsAre2020.

[10] R. Catrambone, D. L. Craig, and N. J. Nersessian. 2006. The role of perceptually represented structure in analogical problem solving. *Memory & Cognition* 34, 5 (2006), 1126–32. https://doi.org/10.3758/BF03193258

[11] Joel Chan, Joseph Chee Chang, Tom Hope, Dafna Shahaf, and Aniket Kittur. 2018. SOLVENT: A Mixed Initiative System for Finding Analogies between Research Papers. *Proceedings of ACM Human-Computer Interaction: CSCW* 2, CSCW (2018), 31. https://doi.org/10.1145/3274300

[12] Joel Chan and David Anthony Rudd. 2023. Supporting Exploration of Far-Domain Analogical Inspirations with Bridging Analogies. In *Proceedings of the 15th Conference on Creativity and Cognition (C&C '23)*. Association for Computing Machinery, New York, NY, USA, 293–297. https://doi.org/10.1145/3591196.3596829

[13] Joel Chan and Christian D. Schunn. 2015. The importance of iteration in creative conceptual combination. *Cognition* 145 (Dec. 2015), 104–115. https://doi.org/10.1016/j.cognition.2015.08.008

[14] William G. Chase and Herbert A. Simon. 1973. *The mind's eye in chess*. New York, NY, 215–281. 02662.

[15] Akshay Chaturvedi, Swarnadeep Bhar, Soumadeep Saha, U. Garain, and Nicholas M. Asher. [n. d.]. Analyzing Semantic Faithfulness of Language Models via Input Intervention on Conversational Question Answering.

[16] C.A. Clement, R. Mawby, and D.E. Giles. 1994. The Effects of Manifest Relational Similarity on Analog Retrieval. *Journal of Memory and Language* 33, 3 (June 1994), 396–420. https://doi.org/10.1006/jmla.1994.1019

[17] C. A. Clement. 1994. Effect of structural embedding on analogical transfer: Manifest versus latent analogs. *The American Journal of Psychology* 107, 1 (1994), 1–38. 00000.

[18] Catherine A. Clement and Dedre Gentner. 1991. Systematicity as a selection constraint in analogical mapping. *Cognitive Science* 15, 1 (Jan. 1991), 89–132. https://doi.org/10.1207/s15516709cog1501_3

[19] D. L. Craig, N. J. Nersessian, and R. Catrambone. 2002. The Role of Diagrams and Diagrammatic Affordances in Analogy. In *Proceedings of the 24th Annual Meeting of the Cognitive Science Society.*

[20] Mihaly Csikszentmihalyi. 1990. *Flow: the Psychology of Optimal Experience by Mihaly Csikszentmihalyi.* Harper & Row, New York, N.Y. Google-Books-ID: tSD3tgEACAAJ.

[21] Kees Dorst. 2015. *Frame Innovation: Create New Thinking by Design.* The MIT Press. 00435.

[22] Joost R. Duflou and Paul-Armand Verhaegen. 2011. Systematic innovation through patent based product aspect analysis. *CIRP Annals - Manufacturing Technology* 60, 1 (2011), 203–206.

[23] Karl Duncker. 1945. On problem-solving. *Psychological Monographs* 58, 5 (1945), i–113. https://doi.org/10.1037/h0093599 Citation Key: dunckerProblemsolving1945.

[24] C. Eckert and M. Stacey. 2003. Adaptation of Sources of Inspiration in Knitwear Design. *Creativity Research Journal* 15, 4 (2003), 355–384. 00000.

[25] Michael C Frank and Michael Ramscar. 2003. How do Presentation and Context Influence Representation for Functional Fixedness Tasks?. In *Proceedings of the Annual Meeting of the Cognitive Science Society.* Citation Key: frankHowPresentationContext2003.

[26] K. Fu, J. Cagan, K. Kotovsky, and K. L. Wood. 2013. Discovering Structure In Design Databases Through Functional And Surface Based Mapping. *Journal of Mechanical Design* 135 (2013), 031006.

[27] Dedre Gentner. 1983. Structure-Mapping: A Theoretical Framework for Analogy*. *Cognitive Science* 7, 2 (Apr 1983), 155–170. https://doi.org/10.1207/s15516709cog0702_3

[28] Dedre Gentner and Arthur B. Markman. 1997. Structure mapping in analogy and similarity. *American Psychologist* 52, 1 (Jan 1997), 45–56. https://doi.org/10.1037/0003-066X.52.1.45

[29] M. L. Gick and K. J. Holyoak. 1983. Schema induction and analogical transfer. *Cognitive Psychology* 15, 1 (1983), 1–38. https://doi.org/10.1016/0010-0285(83)90002-6 04045.

[30] Karni Gilon, Joel Chan, Felicia Y Ng, Hila Lifshitz Assaf, Aniket Kittur, and Dafna Shahaf. 2018. Analogy Mining for Specific Design Needs. In *Proceedings of the 2018 ACM SIGCHI Conference on Human Factors in Computing.* 00000.

[31] Sam Glucksberg. 1962. The influence of strength of drive on functional fixedness and perceptual recognition. *Journal of Experimental Psychology* 63, 1 (Jan 1962), 36–41. https://doi.org/10.1037/h0044683

[32] W. J. J. Gordon. 1961. *Synectics: The Development of Creative Capacity.* New York, NY. 00000.

[33] Howard E. Gruber and Paul H. Barrett. 1974. *Darwin on man: A psychological study of scientific creativity.* E. P. Dutton, New York, NY, England. Pages: xxv, 495.

[34] Andrew Hargadon and Robert I. Sutton. 1997. Technology Brokering and Innovation in a Product Development Firm. *Administrative Science Quarterly* 42, 4 (Dec 1997), 716. https://doi.org/10.2307/2393655

[35] Christina Harrington, Sheena Erete, and Anne Marie Piper. 2019. Deconstructing Community-Based Collaborative Design: Towards More Equitable Participatory Design Engagements. *Proceedings of the ACM on Human-Computer Interaction* 3, CSCW (Nov. 2019), 1–25. https://doi.org/10.1145/3359318

[36] M. E. Helms, S. Vattam, and A. K. Goel. 2008. Compound analogical design, or how to make a surfboard disappear. In *Proceedings of the 30th Annual Conference of the Cognitive Science Society.* 00013.

[37] Scarlett R. Herring, Chia-Chen Chang, Jesse Krantzler, and Brian P. Bailey. 2009. Getting inspired!: understanding how and why examples are used in creative design practice. In *Proceedings of the 27th international conference on Human factors in computing systems.* ACM, 87–96. https://doi.org/10.1145/1518701.1518717 Citation Key: herringGettingInspiredUnderstanding2009.

[38] Keith J. Holyoak and Kyunghee Koh. 1987. Surface and structural similarity in analogical transfer. *Memory & Cognition* 15, 4 (Jul 1987), 332–340. https://doi.org/10.3758/BF03197035

[39] Keith J. Holyoak and Paul Thagard. 1989. Analogical Mapping by Constraint Satisfaction. *Cognitive Science* 13, 3 (Jul 1989), 295–355. https://doi.org/10.1207/s15516709cog1303_1

[40] Tom Hope, Joel Chan, Aniket Kittur, and Dafna Shahaf. 2017. Accelerating Innovation Through Analogy Mining. In *Proceedings of the 23rd ACM SIGKDD*

International Conference on Knowledge Discovery and Data Mining (KDD '17). ACM, New York, NY, USA, 235–243. https://doi.org/10.1145/3097983.3098038

[41] Tom Hope, Ronen Tamari, Daniel Hershcovich, Hyeonsu B Kang, Joel Chan, Aniket Kittur, and Dafna Shahaf. 2022. Scaling Creative Inspiration with Fine-Grained Functional Aspects of Ideas. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (CHI '22)*. Association for Computing Machinery, New York, NY, USA, 1–15. https://doi.org/10.1145/3491102.3517434

[42] David G. Jansson and Steven M. Smith. 1991. Design fixation. *Design Studies* 12, 1 (1991), 3–11. https://doi.org/10.1016/0142-694X(91)90003-F

[43] Peiling Jiang, Jude Rayan, Steven P. Dow, and Haijun Xia. 2023. Graphologue: Exploring Large Language Model Responses with Interactive Diagrams. https://doi.org/10.1145/3586183.3606737 arXiv:2305.11473 [cs].

[44] Shuo Jiang, Jie Hu, Kristin L. Wood, and Jianxi Luo. 2021. Data-Driven Design-By-Analogy: State-of-the-Art and Future Directions. *Journal of Mechanical Design* 144, 2 (Sept. 2021). https://doi.org/10.1115/1.4051681

[45] Philip N. Johnson-Laird. 2005. Flying bicycles: How the Wright brothers invented the airplane. *Mind & Society* 4, 1 (June 2005), 27–48. https://doi.org/10.1007/s11299-005-0005-8

[46] Hyeonsu Kang, Joseph Chee Chang, Yongsung Kim, and Aniket Kittur. 2022. Threddy: An Interactive System for Personalized Thread-based Exploration and Organization of Scientific Literature. In *Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology (UIST '22)*. Association for Computing Machinery, New York, NY, USA, 1–15. https://doi.org/10.1145/3526113.3545660

[47] Hyeonsu B. Kang, Xin Qian, Tom Hope, Dafna Shahaf, Joel Chan, and Aniket Kittur. 2022. Augmenting Scientific Creativity with an Analogical Search Engine. *ACM Transactions on Computer-Human Interaction* (March 2022). https://doi.org/10.1145/3530013 Just Accepted.

[48] G. Knoblich, S. Ohlsson, H. Haider, and D. Rhenius. 1999. Constraint relaxation and chunk decomposition in insight problem solving. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 25, 6 (1999), 1534–1555. https://doi.org/10.1037/0278-7393.25.6.1534 00691 Citation Key: knoblichConstraintRelaxationChunk1999.

[49] Brian Lee, Savil Srivastava, Ranjitha Kumar, Ronen Brafman, and Scott R. Klemmer. 2010. Designing with Interactive Example Galleries. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '10)*. ACM, New York, NY, USA, 2257–2266. https://doi.org/10.1145/1753326.1753667

[50] Yuwen Li and Dongmei Li. 2009. Open-Ended Questions and Creativity Education in Mathematics.

[51] James Lin and James A. Landay. 2008. Employing patterns and layers for early-stage design and prototyping of cross-device user interfaces. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems (CHI '08)*. Association for Computing Machinery, Florence, Italy, 1313–1322. https://doi.org/10.1145/1357054.1357260 00000.

[52] J. Linsey, A. B. Markman, and K. L. Wood. 2008. WordTrees: A method for design-by-analogy. In *Proceedings of the 2008 ASEE Annual Conference*.

[53] J. Loewenstein. 2010. How One's Hook Is Baited Matters for Catching an Analogy. In *Psychology of Learning and Motivation*, B. H. Ross (Ed.). Vol. 53. San Diego, CA, 149–182.

[54] Andrés Lucero. 2012. Framing, aligning, paradoxing, abstracting, and directing: how design mood boards work. In *Proceedings of the Designing Interactive Systems Conference (DIS '12)*. Association for Computing Machinery, New York, NY, USA, 438–447. https://doi.org/10.1145/2317956.2318021

[55] Xiao Ma, Swaroop Mishra, Ariel Liu, Sophie Su, Jilin Chen, Chinmay Kulkarni, Heng-Tze Cheng, Quoc Le, and Ed Chi. 2023. Beyond ChatBots: ExploreLLM for Structured Thoughts and Personalized Model Responses. https://doi.org/10.48550/arXiv.2312.00763 arXiv:2312.00763 [cs].

[56] Stephen MacNeil, Zijian Ding, Kexin Quan, Thomas j Parashos, Yajie Sun, and Steven P. Dow. 2021. Framing Creative Work: Helping Novices Frame Better Problems through Interactive Scaffolding. In *Creativity and Cognition (C&C '21)*. Association for Computing Machinery, New York, NY, USA, 1–10. https://doi.org/10.1145/3450741.3465261 00000.

[57] Leland Masek and Jaakko Stenros. 2021. The Meaning of Playfulness: A Review of the Contemporary Definitions of the Concept across Disciplines. *Eludamos: Journal for Computer Game Culture* 12, 1 (Sep. 2021), 13–37. https://doi.org/10.7557/23.6361

[58] Mariano Mastrogiorgio and Victor Gilsing. 2016. Innovation through exaptation and its determinants: The role of technological complexity, analogy making & patent scope. *Research Policy* 45, 7 (Sep 2016), 1419–1435. https://doi.org/10.1016/j.respol.2016.04.003 Citation Key: mastrogiorgioInnovationExaptationIts2016.

[59] Tony McCaffrey. 2012. Innovation Relies on the Obscure: A Key to Overcoming the Classic Problem of Functional Fixedness. *Psychological Science* 23, 3 (Mar 2012), 215–218. https://doi.org/10.1177/0956797611429580

[60] D. Scott McCrickard, Shahtab Wahid, Stacy M. Branham, and Steve Harrison. 2013. *Achieving Both Creativity and Rationale: Reuse in Design with Images and Claims*. Springer London, 105–119. https://doi.org/10.1007/978-1-4471-4111-2_6 Citation Key: mccrickardAchievingBothCreativity2013.

[61] Martin G. Moehrle. 2005. What is TRIZ? From Conceptual Basics to a Framework for Research. *Creativity and Innovation Management* 14, 1 (2005), 3–13. https://doi.org/10.1111/j.1476-8691.2005.00320.x

[62] J. Moon and Y. Kim. 2001. Extending the TAM for a World-Wide-Web Context. *Information & Management* 38, 4 (2001), 217–230.

[63] Jeremy Murphy, Katherine Fu, Kevin Otto, Maria Yang, Dan Jensen, and Kristin Wood. 2014. Facilitating design-by-analogy: Development of a complete functional vocabulary and functional vector approach to analogical search. In *Proceedings of the ASME 2014 International Design Engineering Technical Conference & Computers and Information in Engineering Conference*.

[64] T. Okada, S. Yokochi, K. Ishibashi, and K. Ueda. 2009. Analogical modification in the creation of contemporary art. *Cognitive Systems Research* 10, 3 (2009), 189–203. 00032.

[65] Carole L. Palmer. 2001. *Work at the Boundaries of Science: Information and the Interdisciplinary Research Process*. Springer Science & Business Media. Google-Books-ID: P20cBQAAQBAJ.

[66] Bec Paton and Kees Dorst. 2011. Briefing and reframing: A situated practice. *Design Studies* 32, 6 (Nov. 2011), 573–587. https://doi.org/10.1016/j.destud.2011.07.002

[67] Jason Portenoy, Marissa Radensky, Jevin D West, Eric Horvitz, Daniel S Weld, and Tom Hope. 2022. Bursting Scientific Filter Bubbles: Boosting Innovation via Novel Author Discovery. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems (CHI '22)*. Association for Computing Machinery, New York, NY, USA, 1–13. https://doi.org/10.1145/3491102.3501905

[68] S. K. Reed, G. W. Ernst, and R. Banerji. 1974. The role of analogy in transfer between similar problem states. *Cognitive Psychology* 6 (1974), 436–450. https://doi.org/10.1016/0010-0285(74)90020-6

[69] Pao Siangliulue, Joel Chan, Krzysztof Gajos, and Steven P. Dow. 2015. Providing timely examples improves the quantity and quality of generated ideas. In *Proceedings of the ACM Conference on Creativity and Cognition.* https://doi.org/10.1145/2757226.2757230

[70] Dominik Siemon, Taras Rarog, and Susanne Robra-Bissantz. 2016. Semi-Automated Questions as a Cognitive Stimulus in Idea Generation. In *2016 49th Hawaii International Conference on System Sciences (HICSS)*. IEEE. https://doi.org/10.1109/hicss.2016.39

[71] Hyeonik Song and Katherine Fu. 2022. Design-by-Analogy: Effects of Exploration-Based Approach on Analogical Retrievals and Design Outcomes. *Journal of Mechanical Design* 144, 061401 (Feb. 2022). https://doi.org/10.1115/1.4053683

[72] Ricardo Sosa. 2019. Accretion theory of ideation: evaluation regimes for ideation stages. *Design Science* 5 (2019), e23. https://doi.org/10.1017/dsj.2019.22 00002.

[73] Toyin Tofade, Jamie Elsner, and Stuart T. Haines. 2013. Best Practice Strategies for Effective Use of Questions as a Teaching Tool. *American Journal of Pharmaceutical Education* 77, 7 (Sep 2013), 155. https://doi.org/10.5688/ajpe777155

[74] Ian Tseng, Jarrod Moss, Jonathan Cagan, and Kenneth Kotovsky. 2008. The role of timing and analogical similarity in the stimulation of idea generation in design. *Design Studies* 29, 3 (2008), 203–221. 00234 Citation Key: tsengRoleTimingAnalogical2008.

[75] Jian Wang, Reinhilde Veugelers, and Paula Stephan. 2017. Bias against novelty in science: A cautionary tale for users of bibliometric indicators. *Research Policy* 46, 8 (Oct. 2017), 1416–1436. https://doi.org/10.1016/j.respol.2017.06.006 00250.

[76] J. Wiley. 1998. Expertise as mental set: The effects of domain knowledge in creative problem solving. *Memory & Cognition* 26, 4 (1998), 716–730.

[77] M. J. Wilkenfeld and T. B. Ward. 2001. Similarity and Emergence in Conceptual Combination. *Journal of Memory and Language* 45, 1 (2001), 21–38. https://doi.org/10.1006/jmla.2000.2772 Citation Key: wilkenfeldSimilarityEmergenceConceptual2001.

[78] Edward J. Wisniewski. 1997. When concepts combine. *Psychonomic Bulletin & Review* 4, 2 (1997), 167–183. https://doi.org/10.3758/BF03209392

[79] Xiaofei Wu, Mei He, Yinglu Zhou, Jing Xiao, and Jing Luo. 2017. Decomposing a Chunk into Its Elements and Reorganizing Them As a New Chunk: The Two Different Sub-processes Underlying Insightful Chunk Decomposition. *Frontiers in Psychology* 8 (Nov. 2017), 2001. https://doi.org/10.3389/fpsyg.2017.02001

[80] Lixiu Yu, Aniket Kittur, and Robert E. Kraut. 2014. Searching for Analogical Ideas with Crowds. In *Proceedings of the 32Nd Annual ACM Conference on Human Factors in Computing Systems (CHI '14)*. ACM, New York, NY, USA, 1225–1234. https://doi.org/10.1145/2556288.2557378

[81] Lixiu Yu, Aniket Kittur, and Robert E. Kraut. 2016. Encouraging "Outside- The-Box" Thinking in Crowd Innovation Through Identifying Domains of Expertise. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing (CSCW '16)*. ACM, New York, NY, USA, 1214–1222. https://doi.org/10.1145/2818048.2820025 00000.

[82] Lixiu Yu, Robert E. Kraut, and Aniket Kittur. 2016. Distributed Analogical Idea Generation with Multiple Constraints. In *Proceedings of the 19th ACM Conference on Computer-Supported Cooperative Work & Social Computing (CSCW '16)*. ACM, New York, NY, USA, 1236–1245. https://doi.org/10.1145/2818048.2835201

[83] Pengyi Zhang and Dagobert Soergel. 2020. Cognitive mechanisms in sensemaking: A qualitative user study. *Journal of the Association for Information Science and Technology* 71, 2 (2020), 158–171. https://doi.org/10.1002/asi.24221 Citation

Key: zhangCognitiveMechanismsSensemaking2020.

A DETAILED DESCRIPTIONS OF TARGET ANALOGIES

Detailed descriptions of analogies used in our study (along with their functional component breakdowns) are shown in separate tables for the Baby Carrier problem (Table 6), Marine Environment problem (Table 7), and Weight Training problem (Table 8).

Table 6: Analogies for the "Baby Carrier" design problem

	Near Analogies		*Far Analogies*
Kangaroo Pouch Analogy		**Coral Reef Analogy**	
Description	Kangaroos that live in hostile open plains with arid climates need to constantly be on the move to keep cool in the arid climate. This can make it hard to protect their undeveloped offspring from predators and the elements. Kangaroos are able to overcome this problem because they have in-built pouches, called marsupiums, which they can use to carry their offspring with them.	*Description*	Coral reefs are an important part of the marine ecosystem. They provide a home and shelter for many different fish species and other marine life, including fish, crabs, and sea urchins. Coral reefs are constantly threatened by many factors, such as tidal waves, and marine predators. As they cannot move, they rely on their stinging cells, known as nematocysts, shooting tentacles and sturdy calcium-carbonate shells to defend themselves.
Stakeholder	kangaroo	*Stakeholder*	coral reefs
Context	in hostile open plains with arid climate	*Context*	along hostile ocean shorelines
Goal	protect their undeveloped offspring from predators and the elements	*Goal*	need protection from tidal waves and marine predators
Obstacle	need to constantly be on the move to keep cool in the arid climate	*Obstacle*	they cannot move
Solution	in-built pouches, called the marsupium, which they can use to carry their offspring with them.	*Solution*	stinging cells in the end of their tentacles, known as nematocysts, which shoot tentacles and sturdy calcium-carbonate shells to defend themselves
Mosquito Netting Analogy		**Military Missile Analogy**	
Description	Parents with young babies living in places with tropical climates often suffer from the surge of tropical insects during summertime. Some insects, like mosquitoes, act as disease-carrying vectors for malaria and other diseases. As it is quite easy for these insects to get in and out of houses, these parents use mosquito netting around beds can keep mosquitoes away from babies.	*Description*	Soldiers in the military stationed in a war-torn territory are duty-bound to protect the native people they serve. However, when the battlefield is open, land-locked, and offers little to no cover to the natives from debilitating attacks raining down from the sky, it becomes challenging for soldiers to defend themselves while protecting others simultaneously. To address this, the military uses ground-launched missiles designed to attack targets in the sky, thus offering soldiers a chance to aid the natives in protecting their lives, either by seeking refuge or helping them take cover.
Stakeholder	parents with young babies	*Stakeholder*	soldiers in the military
Context	hot tropical climates	*Context*	stationed in an open-field war-torn territory
Goal	protect their babies from malaria-carrying mosquitoes	*Goal*	need to protect natives from the invasion of harmful elements
Obstacle	it is quite easy for mosquitos to get in and out of houses	*Obstacle*	natives and their belongings are susceptible to a aerial bombardment
Solution	mosquito netting around beds can keep mosquitoes away from babies	*Solution*	ground-launched missile designed to attack targets in the sky
Baby Gates Analogy		**Convertible Car Analogy**	

Table 6 continued from previous page

Near Analogies		Far Analogies	
Description	Young parents with babies and kids working remotely from their homes often struggle to balance between work and monitoring their kids. This is especially true when they want to give their young children freedom and independence to play and roam in the house, as there will inevitably be areas around the house where safety can be a major cause of concern, like staircases, hot stoves, and cleaning chemicals installing baby gates that are easy for parents to open but hard for young children, thus keeping them safe from these dangerous areas with little supervision.	*Description*	Many car enthusiasts enjoy open-air driving experiences. However, in a city with varying weather patterns, this enjoyment can be hampered by rainy weather conditions. Convertible cars help solve this problem: when it rains, the driver can put up the convertible top to stay dry while driving.
Stakeholder	busy mothers	*Stakeholder*	a car enthusiast
Context	in a remote work environment	*Context*	in a city with varying weather patterns
Goal	give their young children freedom and independence to play and roam in the house	*Goal*	wants an open-air driving experience
Obstacle	there can be safety concerns with some areas of the house like staircases, hot stoves and cleaning chemicals	*Obstacle*	affected by rainy weather conditions
Solution	baby gates that are easy for parents to open but hard for young children to operate	*Solution*	convertible cars to put up the tops when it rains and put it down when it does not.

Table 7: Analogies for the "Marine Environment" design problem

Near Analogies		Far Analogies	
Shark Cages Analogy		**Immersive Technology Analogy**	
Description	Marine scientists and explorers often need to study sharks in their natural habitat, which can be dangerous since some sharks are territorial and hostile. To be able to do this safely, they use shark cages which prevent the sharks from making contact with the divers. This allows them to study the sharks in proximity without putting themselves in danger.	*Description*	Doctors in psychiatric care facilities have the goal of treating patients with psychological ailments. However, different illnesses require different interventions, which can be an obstacle. One The solution is to offer Virtual Reality and Immersive Technology treatments, which can be holistically tailored to the needs of an individual patient. VR and Immersive Technology can provide an immersive experience that can help patients feel more in control and can help to tailor the environment to their specific needs. For example, a patient with a social anxiety disorder may benefit from a VR program that allows them to practice social interactions in a safe and controlled environment.
Stakeholder	marine scientists and explorers	*Stakeholder*	doctors
Context	submerged in shark infested waters	*Context*	in a psychiatric care facility
Goal	study the sharks in proximity	*Goal*	treat patients with psychological ailments
Obstacle	some sharks are territorial and hostile	*Obstacle*	different illnesses require different interventions

Table 7 continued from previous page

	Near Analogies		*Far Analogies*
Solution	shark cages, which prevent sharks from making contact with divers	*Solution*	offer Virtual Reality and Immersive Technology treatments, which can provide an immersive experience that can help patients feel more in control and can help to tailor the environment to their specific needs. For example, a patient with a social anxiety disorder may benefit from a VR program that allows them to practice social interactions in a safe and controlled environment.
Lane Assist Analogy		**Dolphin Trainer Analogy**	
Description	Drivers swerve in and out of their lanes for many reasons: fatigue, inattention, visibility issues, etc., resulting in thousands of wrecks per year. In this era of distraction, cars equipped with lane assist technologies combat lane drifting by alerting drivers during an unintentional swerve and helping them keep and center their vehicle within the lane, thus making the roads significantly safer.	*Description*	The tourists at an open sea aquarium are always very enthusiastic about getting up close and personal with the dolphins. However, as these tourists are not trained to interact with dolphins properly, the dolphins can sometimes get stressed and exhibit aggressive behavior when they are forced to interact with these new faces. The solution is to have an expert dolphin trainer whom the dolphins are familiar with to assist by changing the requests of tourists into a series of commands that the dolphin can understand.
Stakeholder	car and truck drivers	*Stakeholder*	enthusiastic marine tourists
Context	during a long drive on the road	*Context*	in an open sea aquarium
Goal	help drivers swerve between lanes safely	*Goal*	get up close and personal with dolphins
Obstacle	fatigue, inattention and driving in low visibility conditions can cause lane drifting	*Obstacle*	tourists are not trained to interact with dolphins, and dolphins can exhibit aggressive behavior on forced interaction
Solution	Lane assist technologies that alert the drivers and help them keep and center within the lane	*Solution*	expert dolphin trainer whom the dolphins are familiar with to assist by changing the requests of tourists into a series of commands that the dolphin can understand
Negative Room Pressure Analogy		**Deep Sea Submersible Analogy**	
Description	Hospitalized patients who are ill are at risk of cross-contamination from other patients. Airborne transmission of disease is a major reason for this. Ventilation that generates negative room pressure can help to prevent the spread of disease. This solution allows air to enter a room but not escape, thus reducing the risk of cross-contamination. By keeping the air pressure in the room negative, it creates a barrier against air and contaminants flowing from areas of higher pressure, such as a hallway, into the room.	*Description*	Deep sea researchers and soldiers in the navy need to conduct exploration and surveillance in the depths of an ocean, but the deeper the depth, the greater the pressure. One solution is deep sea submersibles known as bathyscapes, which are designed to withstand high pressures and allow humans to explore depths that would otherwise be inaccessible using tethering as an apparatus for deep exploration.
Stakeholder	ill patients	*Stakeholder*	deep sea researchers and soldiers in the navy
Context	quarantined in hospitals	*Context*	in the depths of an ocean
Goal	prevent cross-contamination across rooms	*Goal*	conduct exploration and surveillance
Obstacle	disease spreads by airborne transmission	*Obstacle*	deeper the depth, greater the pressure

Table 7 continued from previous page

	Near Analogies		Far Analogies
Solution	ventilation that generates negative room pressure, so that air can enter a room but not escape. this creates a barrier against air and contaminants flowing from areas of higher pressure, such as a hallway, into the room	*Solution*	deep sea submersibles known as bathyscapes, which are are designed to withstand high pressures and allow humans to explore depths that would otherwise be inaccessible using a tethering apparatus

Table 8: Analogies for the "Weight Training" design problem

	Near Analogies		Far Analogies
Sandbag Analogy		**Popup House Analogy**	
Description	Professional boxers in a gym often want to practice moves to improve punching power, but cannot always find a sparring partner. One solution is to use a sandbag, which can be filled with sand or water to mimic real resistance.	*Description*	Cost-conscious people in suburbs who want to build their dream home often find that the initial capital required and recurring maintenance costs can be too high. Passively designed popup houses can be a great solution for this: they are energy efficient, environmentally friendly, and built using recyclable materials.
Stakeholder	professional boxers	*Stakeholder*	cost-conscious people
Context	in a gym	*Context*	in suburbs
Goal	practice moves to improve punching power	*Goal*	want to build a dream home
Obstacle	cannot always find a sparring partner	*Obstacle*	initial capital required and recurring maintenance costs can be too high
Solution	a sandbag: can be filled with sand or water to mimic real resistance	*Solution*	passively designed popup houses: energy efficient, environmentally friendly, and built using recyclable materials
Desk Cycle Analogy		**Protein Biosynthesis Analogy**	
Description	Some hobbyist cyclists who work at sedentary day jobs struggle to build up mileage and leg strength for a marathon because they don't have the space for a full bike or the time to move around during working hours. The desk cycle can be a great solution for this because they take up very little space and can be used during the workday without leaving the desk.	*Description*	As the cells within an organism age, they begin to lose cellular proteins that perform many critical functions as enzymes, structural proteins, or hormones due to constant degradation or export, leading to an overall decline that, if uncontrolled, can lead to a fatal loss of function. To prevent this, cells use a core biological process called protein biosynthesis, which balances the loss of cellular proteins by producing new proteins.
Stakeholder	a hobbyist cyclist	*Stakeholder*	cells
Context	working in a sedentary day job	*Context*	inside an organism
Goal	need to build up mileage and leg strength for a marathon	*Goal*	maintain the equilibrium of core biological processes
Obstacle	doesn't have the space for a full bike or the time to move around during working hours	*Obstacle*	loss of cellular proteins due to degradation and export
Solution	a desk cycle: takes up very little space and can be used during the workday without leaving the desk	*Solution*	make new proteins using protein biosynthesis to offset the deterioration of function in cells
Resistance Band Analogy		**Air Mattress Analogy**	

Table 8 continued from previous page

	Near Analogies		*Far Analogies*
Description	Amateur bodybuilders who are on the road for competitions often want to keep their muscles toned and in shape while on the road, but have limited access to gym equipment. Resistance bands or straps are a great solution: by attaching the bands to a door or other sturdy object, a bodybuilder can do a wide range of exercises to work every muscle group. The bands are also lightweight and portable, making them easy to take on the road.	*Description*	For elderly tourists, it is important to get a good night's sleep when away from home. This can help prevent bedsores and back injuries from occurring. However, many elderly couples cannot afford to customize a bed to their needs. A solution to this problem is a portable inflatable air mattress. This type of mattress can be adjusted to the desired level of firmness and flexibility by pumping air into it.
Stakeholder	amateur bodybuilders	*Stakeholder*	elderly tourists
Context	on the road for competitions	*Context*	need good sleep when away from home
Goal	keep their muscles toned and in shape	*Goal*	prevent bedsores and back injuries from occurring
Obstacle	limited access to gym equipment	*Obstacle*	cannot afford to customise a bed to their needs
Solution	resistance bands or straps: by attaching the bands to a door or other sturdy object, bodybuilder can do a wide range of exercises to work every muscle group. The bands are also lightweight and portable, making them easy to take on the road.	*Solution*	portable inflatable air mattresses: firmness and flexibility can be controlled by pumping air

B BASELINE AND INTERVENTION IDEATION TASK INTERFACES

Figures 7 and 8 show the baseline and intervention ideation interfaces used for the study.

C GLM MODELS PREDICTING IGNORE DECISIONS ON ANALOGIES

In this section, we report the GLM analyses for the predicting whether an individual Analogy is Ignored (Table 9), the results of this sequence of models, which are very similar to the GLMM analyses, are shown in Table 3.

Table 9: GLM models predicting whether an individual analogy received an "ignore" decision

	Null model	*Near Analogy as Predictor*	*Full Model: Near Analogy and Intervention as Predictors*
Fixed Effects			
Intercept	-2.05***(-2.43, -1.67)	-1.56***(-2.01, -1.11)	-1.02***(-1.55, -0.49)
Near Analogy	-	-1.32***(-2.20, -0.43)	-1.36***(-2.26, -0.46)
Intervention	-	-	-1.38***(-2.28, -0.48)
Model Fit Statistics			
Log Likelihood	-93.35	-88.37	-83.11
AIC	188.70	180.74	172.21
BIC	192.27	187.89	182.93

*p<0.1; **p<0.05; ***p<0.01; Confidence intervals for fixed effects are 95% confidence intervals; AIC = Akaike Information Criterion; BIC = Bayesian Information Criterion

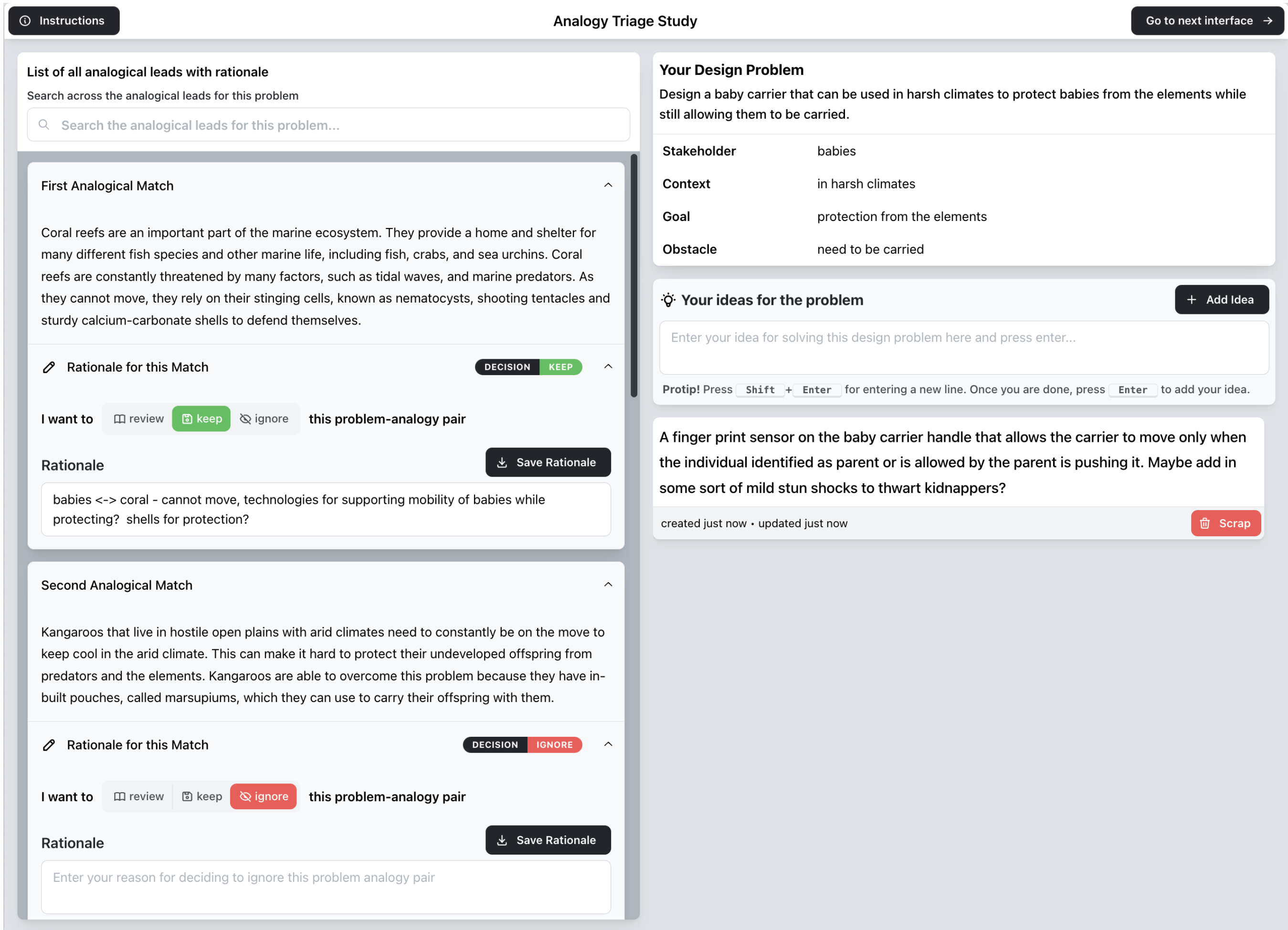

Figure 7: *Design of Ideation Task Interface for Baseline*. As discussed in Section 4.4, the interface is very similar to the intervention ideation interface (Fig. 8), with the key differences that selected analogies are presented as text descriptions, and there is no mechanism for revisiting the screening interface: instead, participants can revise their screening decisions in this interface, if desired, while generating ideas for the problem.

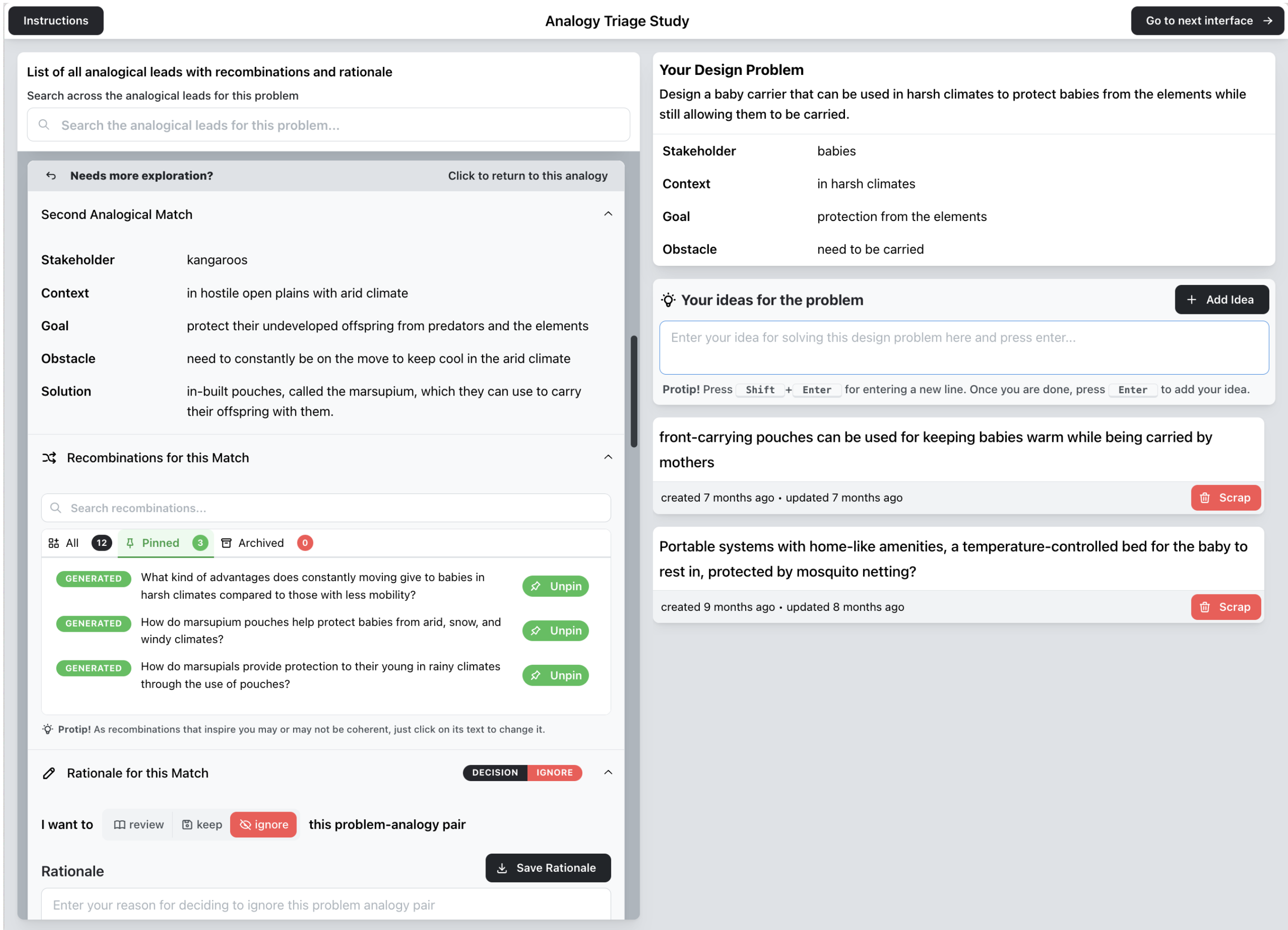

Figure 8: *Design of Ideation Task Interface for Intervention.* As discussed in Section 4.4, the interface enables users to scroll and search through the analogical leads they selected in the screening phase (left panel), while writing ideas for the design problem in the right panel. Each selected analogical lead is shown with its functional components and bookmarked recombinations, as well as the screening decision and rationale. Users can click on a button for each analogy to return to the screening interface to revisit their exploration of its potential value for the problem.