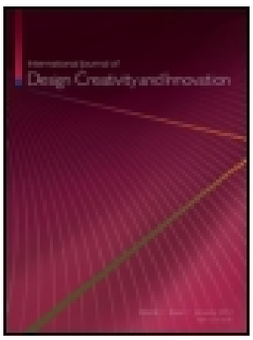

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The Ideation Compass: supporting interdisciplinary creative dialogues with real time visualization

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ABSTRACT

This study presents the potential of live topic visualization in supporting creative dialogs during remote idea generation. We developed a novel Creativity Support Tool (CST) to explore the effects of the live topic visualization. The tool emphasizes the interdisciplinary knowledge background of participants. Using Natural Language Processing (NLP) and topic modeling, the tool provides users with a live visual mapping of the domains and topics being orally discussed. To understand the tool's user perceived effects, we conducted evaluation sessions and interviews with participants (N = 10) from two different disciplinary backgrounds: design and bioscience. The findings show that live visualization of domains and topics supported self-reflection during individual and collaborative creativity and encouraged a balanced discussion, which can mitigate discipline-based fixation in ideation.

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Collaborative creativity; computational creativity; concept generation; creative cognition; idea generation; interdisciplinary ideation

1. Context and objective

This exploratory study is focusing on how discipline-based knowledge sharing and its visualizations in real time can aid creative interdisciplinary ideation. By applying theoretical findings in collective creativity and interdisciplinary ideation to the development of a Creativity Support Tool (CST), we aim to support the emergence of shared understanding (Kleinsmann & Valkenburg, 2008) in creative teams through topic visualizations. We propose to view team creativity through the lens of topic fixation. Creativity studies suggest that discipline-based topic visualizations will encourage teams to cover a wide spectrum of problem and solution spaces (Dorst, 2019; Reymen et al., 2009) and will thus mitigate discipline-based fixation in idea generation.

Additionally, interdisciplinary ideation can be supported by a *process*. Facilitation of interdisciplinary processes is challenging, because knowledge is not easily transferable (for example, between biology and engineering; Lobbe et al., 2021; Weidner et al., 2018). Practitioners perceive that they can better ideate when there is agreement in a team and a process to follow, however agreement on who leads the process and how the process is led is critical to success (Austin et al., 2001). In short, collaborative ideation sessions, such as design sprints and workshops, the process can be determined by a dominant lead or (external) facilitator. The role of facilitation principles and facilitation tools play an important role in creative team processes. For example, pro-active neutrality in creative facilitation can be a key mechanism in enhancing creativity and innovation in the workspace (Wróbel et al., 2020), suggesting interaction dynamics between creative practitioners and facilitation (tools and methods). Amabile's (1988) model of creativity and innovation in organizations highlights intrinsic motivation as a key construct in managing creative teams. As such, we are

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interested in triggering behaviors in idea generation that arise intrinsically through practitioner interactions with one another, and CSTs that are triggered by the practitioners themselves in real time. Implementing systems that analyze design dialog in real time have been suggested as a potential way to leverage creative outcomes (Casakin & Georgiev, 2021); therefore, we explore verbal communication in interdisciplinary creative ideation.

The objective of this exploratory study is to evaluate the user-perceived effects of visualized live feedback during interdisciplinary creative conversations in workshop settings with a novel CST. We aim to explore how topic-based interdisciplinary dialog visualization can support collaboration experience. We do this with a computational CST, which utilizes NLP and topic modeling. This study applies and expands existing theoretical constructs that describe the nature of interdisciplinary creative ideation, fixation, and shared understanding by contributing to the emerging field of AI-enabled tools for CSCW. The study is addressing the following question through the lens of reflective interviews post-cognitive activity:

RQ: In collective interdisciplinary ideation, how does topic visualization affect users' perception of their own creativity and fixation?

2. Theoretical foundations

2.1. Interdisciplinary creative ideation

An interdisciplinary paradigm requires interactions between highly specialized practitioners. These interactions and collaborations are needed for solving contemporary complex challenges, envisioning novel futures, as well as carrying out routine tasks where the aim is to innovate (Calvert & Schyfter, 2017; Ito, 2016; Sawa, 2016; Simons et al., 2011). This collaborative phase in designing can be described as a process in which actors from different disciplines share their knowledge about both the design process and the design content. They do that in order to create shared understanding on both aspects, to be able to integrate and explore their knowledge and to achieve the larger common objective: the new product to be designed. (Kleinsmann, 2006; Kleinsmann & Valkenburg, 2008)

Generating creative ideas (characterized as novel and useful) in interdisciplinary teams is challenging because of boundaries between practices and the difficulty of sharing knowledge and reaching mutual understanding (Simons et al., 2011).

Divergent thinking and consideration of multiple possibilities in early concept design is known to be supportive in ideation, particularly in fast paced collaborative settings such as workshops (Lee & Ostwald, 2022). Design tools and methods are shown to be effective in interdisciplinary short-term ideation workshops for new product development and innovation activities (Weidner et al., 2018). Various digital tools are known to impact convergent and divergent thinking in ideation (Frich et al., 2021); however, only a few use topic modeling to support shared understanding. Mechanisms and tools that support creative collaborative design through utilization of practitioners' tacit knowledge address challenges in interdisciplinary ideation. For example, the HiveMind Space model supports communication via mediated digital boundary objects (Zhu et al., 2010), which can alleviate the lack of shared formal language and communication difficulties in interdisciplinary teams (Driver et al., 2011).

In this study, we apply an approach whereby human creativity is divided into four quadrants – each representing a general discipline and knowledge that relates to it. The disciplines are Art, Engineering, Design, and Science (Oxman, 2016). This general characterization of disciplines enables exploration of interdisciplinary dialog because it provides a visual framework for raising discipline awareness. This awareness is a critical building block in team cognition, and it can be supported with computational tools (Gutwin & Greenberg, 2005). The key rationale for knowledge visualization is its ability to contextualize information, which makes it meaningful and actionable in collaborations (Bertschi et al., 2011).

2.2. Fixation in designing and shared understanding

Fixation can be described as an undesired cognitive effect in which an individual or group usually unconsciously focuses on certain aspects of an object or task while leaving (potentially more beneficial) alternatives aside (Vasconcelos & Crilly, 2016). Research into design fixation frames this psychological phenomenon as a negative occurrence and suggests that overcoming fixation will lead to more creative and innovative ideas. Interdisciplinary creative ideation benefits from an understanding of team-level creativity mechanisms that account for the diversity of team members and their disciplinary background (Kurtzberg & Amabile, 2001).

Structures of authority in creativity and innovation have been studied and found to play an important role in interactions between interdisciplinary generative individuals (Sosa & Gero, 2015). These structures create uneven hierarchies that can support dominant opinion leaders and influence the (asymmetric) roles performed by individual team members (Benony & Maudet, 2020; Välk et al., 2019). In interdisciplinary teams, this can manifest as topic fixation, which is based on the background or discipline of the dominating idea creator. Topic fixation hinders the creative potential of the team and may have a negative impact on team process and inclusivity. In this framing, topic fixation is a novel construct not previously addressed by the design research community.

As such, there is an opportunity to emphasize the interdisciplinary nature of practitioner backgrounds in creative collaborations, in which shared understanding (Cash et al., 2020) is critical yet challenging to develop. Visualizations of emerging themes aid the emergence of shared mental models (Dong et al., 2013).

2.3. CSTs for interdisciplinary ideation

Successful ideation is a critical part of design innovation processes and there are numerous physical tools that allow thinking through design, whereby the practitioners 'play around' with material objects without knowing what will come out of it. These interactions in design ideation are often facilitated by analog tools (Peters et al., 2020), which are of critical importance in collaborations that span different disciplines (Adamczyk et al., 2007). For example, cards are popular means of facilitating interdisciplinary ideation because they provide practitioners with inspirational materials and provide a guiding process (Haritaipan, 2019; Ocnarescu et al., 2011) but also externalize knowledge of individual practitioners to collaborators (Dalsgaard, 2017). Greater knowledge sharing is closely linked to increased shared understanding within the team (Cash et al., 2020). It is also generally acknowledged that team effectiveness will improve if team members have an adequate shared understanding of the team's objectives (Dong, 2005).

Computational creativity support tools (CSTs) aim at making more people more creative more often; however, more specific definitions are lacking and context-dependent (Frich et al., 2019). For example, CST classifications include defining which part of the creative process is being supported, whereas half of digital CSTs target idea generation and individual practitioners (Frich et al., 2019). Other types of computational CSTs provide retrospective summaries of meetings with the use of topic modeling (Chandrasegaran et al., 2019; Tur et al., 2010). Table 1 provides an overview of related CSTs for ideation and highlights their limitations.

Computational technology could be applied more extensively to explore and leverage interdisciplinary ideation, given its technical capabilities. For example, it can detect topics in conversations with natural language processing and use topic modeling in real time. Existing CSTs for ideation in CSCW currently lack features that create live topic visualization with verbal input. Hence, this study aims at exploring the effects of automatically generated visualizations, which inform users about the content of ongoing dialog. Spinneret (Bae et al., 2020) is a computational tool that aids mind mapping during ideation by providing suggestions based on a knowledge graph. The tool is

Table 1. Overview of existing CSTs that AIM at supporting ideation.

	Input	Output	Method	Limitation
Idea Expander (Wang et al., 2010)	Chatbox dialog (text)	Pictures (from database)	ML + Wizard of Oz + retrieval to prompt pictures	Constrained database and written text as input
Momentum (Bao et al., 2010)	Text and images from individuals	Summary visualization of inputs	Manual input before ideation	Supports preparation before ideation activity
IdeaHound (Siangliulue et al., 2016)	Text	Visual semantic model of solution space	Combines ML with human interactions	Prioritizes human–computer interaction
Semantic Collage (Koch et al., 2020)	Text, images	Semantic labels	Semantic labeling	Aids individual mood board creation
Spinneret (Bae et al., 2020)	Text	Graph with biased random suggestions	Node graph (for mind mapping)	Prioritizes human–computer interaction
Meeter (Huber et al., 2019)	Verbal	Statistical measures: word count, prosody features, and dialog act ratios	Sentence classification	Lack of user interface/ interaction in real time
Conversation Clock (Bergstrom & Karahalios, 2007)	Verbal	Live visualization	Speech tracking	Content awareness

programmed to reduce design fixation; however, it does not analyze dialog content from a discipline-based perspective, which could be useful for diverse teams.

Visualizing topic fixations within creative ideation could have significant implications for the design of computational CSTs, however this area is currently little investigated, despite inspirational examples emerging for *design ideation* (based on practitioners in a single discipline; Koch et al., 2019). Smart Meeting Systems and Group Support Systems have been developed with the aim to support collaborative work in creative meetings, but existing tools embody critical limitations and do not explicitly account for live feedback in idea generation.

Real-time tools that capture and visualize verbal content in meetings exist, but it is unclear as to what extent they can address topic fixation. For example, TalkTraces is a tool designed to address four main requirements: to aid historical recall, to provide a conceptual overview at a glance, to provide situational awareness of the current state of the meeting, and to provide an impetus for conversation (Chandrasegaran et al., 2019).

2.4. Research scope and objective

The literature shows the following:

- Interdisciplinary ideation poses challenges for participants. These challenges could be addressed with CSTs that support knowledge sharing and facilitate emergence of shared understanding
- Discipline-based topic fixation can hinder collaborative ideation
- Existing computational CSTs for ideation lack features that analyze content of interdisciplinary dialog and provide visualizations as live feedback

The objective of this study is to explore how visualizing emerging themes within a discipline-based framework can help ideation workshop participants with the mitigation of disciplinary fixation. This suggests that CSTs and CSCW tools have the capability to utilize theory on shared

understanding and knowledge sharing to support collaborative ideation, however this potential is underexplored.

This study adopts an approach whereby practitioner's awareness of common ground in creative dialog is critical for team creative process and proposes that team cognition can be supported by computational support tools (Gutwin & Greenberg, 2005). Similarly to how automatic key phrase extraction can be seen as a useful means for abstracting large amounts of data into high-level segments (Frank et al., 1999), our approach is to develop a tool that performs conversation transcription and transcript analysis in real time. Topic modeling as a rapidly developing statistical technique for text mining has been proven to allow for successful analysis of semantic structures (Kherwa & Bansal, 2019). Semantic structures in collaborative idea generation are important subjects of study in team cognition and creativity, informing the development of novel AI-based CSTs that reveal hidden topical patterns (Barde & Bainwad, 2017). Our study follows guidelines for the development of CSTs that propose appropriateness of multimodal stimuli (Borgianni et al., 2020), including team members, facilitation, and visualization tools.

We are interested in studying interdisciplinary creativity from a combinational perspective, where unfamiliar connections and domain knowledge is visualized for practitioners to aid their creative process (Bhowmik et al., 2015). Our approach is to apply natural language processing and topic modeling to create the visualizations since this technique has previously proven useful for addressing real-world issues and diverse segments of information (Hagen, 2019; Hagen et al., 2015; Kherwa & Bansal, 2019). However, its potential in speech processing is underexplored, albeit NLP's increasing uptake in practice interested in Requirements Engineering (Ferrari, 2018).

3. Development of The Ideation Compass

3.1. Overview of The Ideation Compass web-app

We developed The Ideation Compass, a web-based application for use in online collaborative ideation, alongside existing tools (video calls, whiteboards). The Ideation Compass analyses the content of the oral conversations between practitioners (i.e., voice inputs) through topic modeling and generates visualizations of the topics and themes in the conversation on a discipline-based radar chart informed by the Krebs Cycle of Creativity (KCC; Oxman, 2016). This visualization aids contextualization of knowledge shared by participants. Table 3 shows the positioning of The Ideation Compass in comparison to CSTs in Table 1. In this paper, we refer to the radar chart when discussing the interactive visualization that is visible to the users of the larger system called The Ideation Compass.

The app works by using speech in dialog as input for creating a visual output (Figure 1).

The data processing flow (Figure 2) consists of the following phases: dialog is recorded through microphones and speech is transcribed into text document, which is simultaneously analyzed to produce a similarity measure-based visualization.

3.2. Computational model and implementation

We formulated the task as a term-similarity measure between disciplines and a conversation. The system uses text data from the transcription. Pairs of keywords were selected from the KCC framework.

Next, words are processed along the pipeline in vectors obtained from GloVe (Pennington et al., 2014). The average vectors are used to represent disciplines. We assume that a discussion about an idea is a mixture of disciplines and each word used in ideation is attributed to one of the disciplines. Therefore, we use a topic modeling technique, Latent Dirichlet Allocation (LDA; Blei et al., 2002), to detect keywords in four disciplines. The conversation is treated as a set of documents, where each utterance is a single document, and input to the model. We exploited LDA to statistically nominate keywords that manifest underlying topics or disciplines in the dialog. The tool then calculates the

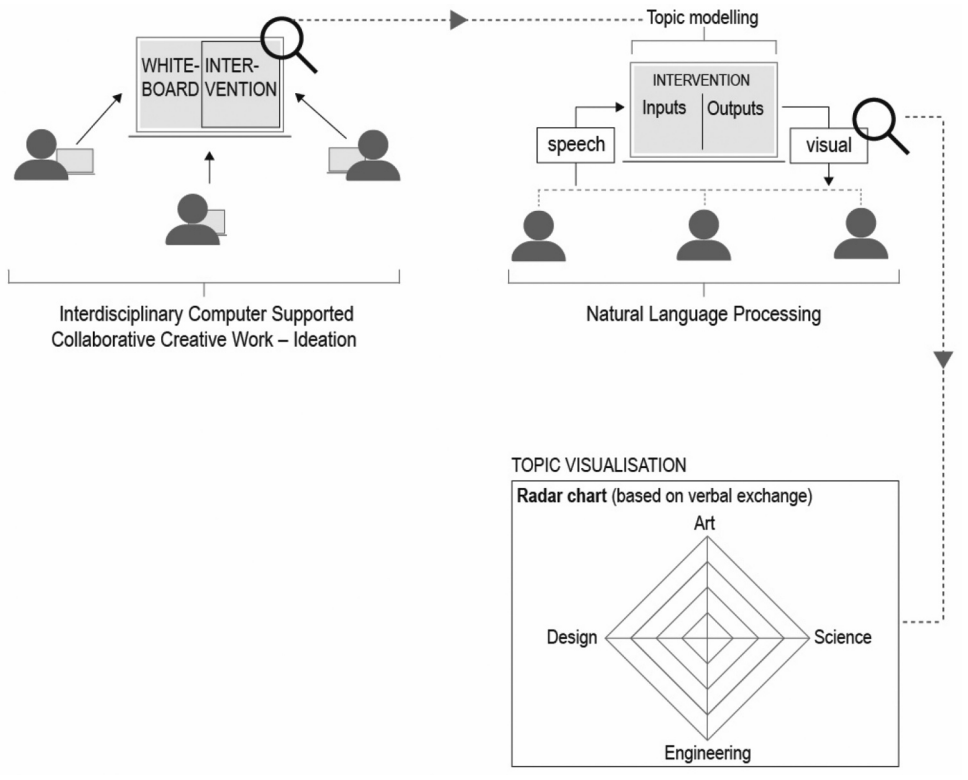

Figure 1. Overview of The Ideation Compass, showing its use and processes for generating live visualizations.

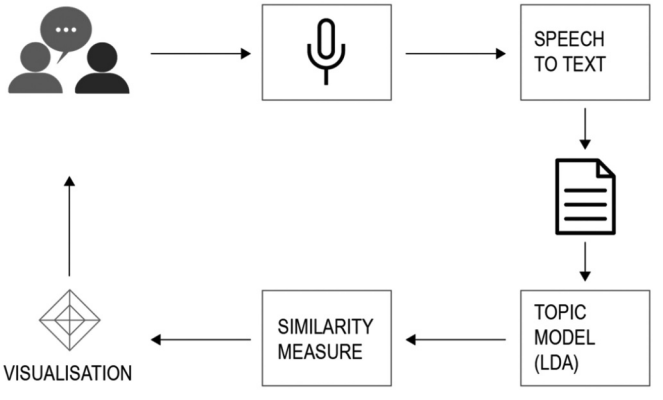

Figure 2. Data processing flow of The Ideation Compass.

similarity between each word and the disciplines using cosine similarity. Since the similarity scores are slightly different between disciplines, we scale the scores using min-max normalization to foster the polarities of words.

$$\cos(A, B) = \frac{\mathrm{A} \cdot \mathrm{B}}{\|A\|\|B\|} = \frac{\sum_{i=1}^{n} A_i B_i}{\sqrt{\sum_{i=1}^{n} A_i^2}\sqrt{\sum_{i=1}^{n} B_i^2}}$$

The data processing pipeline is implemented using Python with SpaCy library for natural language processing. The interface of The Ideation Compass is built with React, Chart.js, and Apexcharts.

The tool was validated by measuring its real-time transcription accuracy. We used thematic podcasts from four disciplines as voice inputs to calculate word error rate (WER; Table 2). Overall, the transcription achieved a WER around 0.3 which is acceptable for an exploratory study.

Table 2. WER results.

Domain	WER	Word count
Art	0.306	1070
Science	0.301	1647
Engineering	0.395	1228
Design	0.333	1373

Table 3. The Ideation Compass overview.

	Input	Output	Method	Limitation
The Ideation Compass	Verbal	Live visualization	Automatic	Discipline based

This computational model allows us to visualize a radar chart that displays cumulative similarity scores for each discipline. This visualization informs participants about the content of ongoing dialog (utterances) and each participant's individual contribution.

4. Evaluation of The Ideation Compass with users

4.1. Objective and protocol

We conducted an empirical evaluation with human subjects to better understand the perceived effects of The Ideation Compass on interdisciplinary collaborative ideation. Given the barriers in interdisciplinary collaboration and the emergence of shared understanding, we are interested in understanding how practitioner perceptions of disciplines influence creativity. In this exploratory study, we focus on user experience (Kuniavsky, 2003) and use interview data as a preliminary source for validation of live topic modeling in creative dialogs. We use thematic interviews because the method is established for analyzing design cognition retrospectively after practitioner immersion in the cognitive activity (Cross, 2002).

The sessions were in English, held online, and consisted of:

- A workshop (30 minutes) where participants would use The Ideation Compass during idea generation activities
- post-workshop semi-guided interviews (30 minutes) where participants would provide feedback on their perception of The Ideation Compass

5. Workshop

In the idea generation workshop, 5 pairs made of a bioscientist and a designer were given a brief (Propose a novel intervention for the Future City or Home (2050 and beyond)) and were asked to orally discuss their ideas on the topic. Participants used The Ideation Compass in addition to other conventional tools for online collaboration (video calls, group chats and virtual white board), which they all claimed to be familiar with, given the nature of work during the pandemic.

6. Interviews

Following their participation in the workshop, participants were asked to reflect on their experience of collaboration with the use of The Ideation Compass. The interviews consisted of open-ended questions on the breadth of topics discussed, reflections on problem and solution space co-evolution, effects of topics visualized in real time, interactions triggered by The Ideation Compass, functionalities of The Ideation Compass (existing and potentially useful in the future), the tool's (potential) impact on creativity, perception of user behavior with The Ideation Compass, arguments for and against the tool, and how to better build shared understanding in interdisciplinary teams.

We used reflective semi-structured interviews with practitioners after they had participated in the collaborative ideation (Koch et al., 2019). This approach elicits co-discovery and effective data retrieval in qualitative assessment (Zimmerman et al., 2007).

Our interviews followed the self-confrontation approach, where pairs of participants were interviewed jointly to elicit reciprocal reflections and enquire about the dialog dynamics (Baker et al., 2020).

Each participant was given the opportunity to answer all questions. The interviews for data collection (Byrne, 2001) followed guidelines for qualitative analysis: extensive familiarity with the topic, multidisciplinary approach, attention to interviewee behavior, resilience and lack of judgment, and heightened sense of empathy and objectivity (Miles et al., 2020). To reduce bias in the data gathering process, the interviews were conducted by the first author who has prior experience in qualitative research and had no direct involvement in the development of the intervention. Participants were made aware of this and informed that the aim of the research was to evaluate the effects of real-time visualization and critical comments are welcome. The interviews were audio and video recorded with consent from participants.

6.1. Participants

Participants (N = 10) were English-speaking: five students in Bioscience at Master or PhD level from Imperial College London (name code Sx) and five students in Design at Master level from the same university (name code Dx). The motivation for conducting the study with these participants is their ability to form interdisciplinary pairs of diverse backgrounds and perspectives. The pairs (three mixed and two of the same gender participants) were formed randomly, and none of the participants had been previously acquainted.

6.2. Interview coding and analysis

The analysis consisted in (1) transcribing the interviews and (2) highlighting relevant sections and then coding based on predetermined open-ended interview questions. Audio recordings were manually transcribed into segments, and all segments were later clustered based on their content. The transcripts and clusters were analyzed through directed qualitative content analysis – an approach established for validating and extending the existing theoretical frameworks (Hsieh & Shannon, 2005). The coding of interview data was done by two researchers – the first author and an external researcher experienced with interview coding – who followed the coding scheme described by Stompff et al. (2016). Interview data was divided into 98 segments of which 50% (N = 49) were selected randomly for assessing the inter-rater agreement score. Segments were coded into categories, then coding was compared and discussed. Forty-four segments out of 49 were assigned to the same category, resulting in 90% inter-rater agreement score. The calculation approach and inter-rater agreement score were judged acceptable in the context of the study.

7. Results

The following themes that emerged from the interviews analysis and clustering are reported in this section, with quotes from the interviews:

(1) diversity of topics
(2) effects of real-time topic visualization on perceived creative behaviors
(3) visualization's potential to leverage creativity
(4) further directions and ideas

7.1. Diversity of topics

Participants expressed different views when reporting on the Idea Compass's potential to encourage diverse topics in ideation. S2 suggested that their discussion revolved around the environment from the inception, because it is an area 'we can both comment on and it's not overly science-y, where I would take the lead.' According to S1, their ideation mainly covered social and psychological topics, such as mental health and well-being, but D1 also covered some engineering and technology aspects, such as building taller infrastructure. D2 highlighted the importance of investigating the future when ideating but suggested she 'quickly settled on water and self-sufficiency by the use of decontaminants and sensors.' S3 suggested that different stakeholders related to the ideas were covered, however noted that this did not fully enable to incorporate maximum diversity in idea generation. D3 added that they missed an opportunity to explore Engineering: 'We could've gone to more depth, so we could've covered selling or manufacturing. Perhaps it was narrow in that sense.' D5 stated that the topic visualizations were a useful prompt to suggest which area to explore next and D4 found that the visualizations assured her of team topic fluency. S4 added that they did not feel the need to cover broader topics because the visualizations covered ¾ of the compass quadrants.

Figure 3 shows a screenshot from a user evaluation session (names randomized) whereby engineering discipline has received least attention during the idea generation process and the participants have been expressing verbal content similarly regarding design, art, and science.

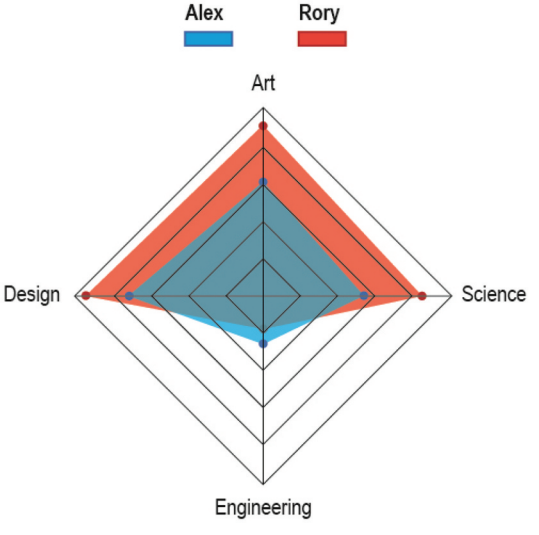

Figure 3. The Ideation Compass visualizing topics relatively in real time: new visualization provided cumulatively and updated every 3s.

7.2. Effects of real-time topic visualization

Participants noticed and acknowledged various effects that The Ideation Compass can have given its function to visualize emerging topics in real time.

According to S5, the compass allowed him to compare himself to other collaborators, which provided a useful overview. S1 reported that the visualizations will prevent ideators from narrow thinking: '*If it starts peaking you can take action.*' D1 added:

> I agree. Often people forget about the other side. The compass made me aware of what I'm not talking about. I looked at it briefly and I saw a peak in one area and then I considered talking about the other area, because I think this would be useful in interdisciplinary collaboration . . . so that you know you've covered all areas.

S1 further added that if only one branch was visualized, it would mean that not all possible options have been considered. D1 added that when the compass is significantly pointing in one direction, it makes him conscious about what he is saying: 'It makes me think that I'm perhaps thinking only in one aspect. So, . . . it forces me to consider other sides. In a good way, promotes a different direction of thinking about the same thing'.

S3 suggested his interpretation about how The Ideation Compass could have maximum impact:

> Ideally, you'd want the mapping to be as overlapping as possible. This shows that you're on the same page – at least not talking about too technical stuff from their field but trying to reach a common ground everyone can relate to.

It was later added that the tool supported him in trying to steer the conversation to something both parties could relate to, often by simply leaving out jargon. S5 said that seeing the topics in real time made him want to talk without jargon to make sure his ideas were clearly communicated. D2 echoed similar experiences, stating that it would make her want to try to increase the overlap and collaborate meaningfully: 'Obviously everyone has their expertise, but it would be the right thing to do to get involved and build the overlap'. S2 suggested that it was interesting to see where each participant was contributing: 'Every time I looked, we seemed to overlap a lot and I didn't speak about the science all the time and D2 didn't talk about the design all the time'. She then further implied that if there had been very small overlap between her and her partner's topic visualizations, she would have tried to change how she discussed the ideas, but since there was a large overlap, this was not needed. However she later revealed: 'I think I lowered down on science and I don't know if that was supposed to happen. So, it did change a bit how I expressed myself'. D3 said that the compass seemed accurate because the conversation was mostly about design, and this was reflected with the topic visualizations. D3 suggested that this was encouraging as it allowed deciding which quadrant of the compass to explore next, for improving the idea. S3 added: 'We could have the compass as a reminder to move towards another focus. It's also interesting to see how both parties have differing ideas within different scales. This is useful for reflecting on individual backgrounds'. D5 found that The Ideation Compass made her more aware about what she said, which was appreciated, however acknowledged that this awareness might be restricting to others.

D1 suggested that a potentially unwanted effect of live topic visualizations is its ability to make users overcompensate for areas that are not discussed. It was implied that overcompensated ideas would potentially not be *'as good or genuine.*' S3 commented that the effects of the topic visualizations would be more significant if the participants could customize The Ideation Compass with their own keywords. He then added that this would make the ideation session's expectations clearer. One of the key impacts of The Ideation Compass for D4 was that the tool encouraged her to *'up my game and catch up with how much I talk in the ideation.*' Similarly, S4 found that the tool made him talk more and raised awareness about the turn taking and balancing of the discussion.

7.3. The Ideation Compass's potential to leverage individual and collaborative creativity

Participants expressed different views when talking about The Ideation Compass's potential to support creativity. D1 found that the tool helps to come up with new ideas, because it visualizes areas that are not discussed:

> When you're seeing which areas you're not hitting, it makes you think about those. That improves creativity. Because when you're looking at things from different perspectives, that helps to come up with new ideas. First you can come up with ideas in one area but later you can also combine them. So, when there's a train of thought about design, I can also think how to combine it with Engineering.

D2 had similar experience, stating that the chart could encourage creativity because it invites users to cover all areas of the chart, which provides a source of inspiration. According to S5 the tool has the potential to support creativity because it provides a broad spectrum for emergence of ideas. D5 agreed and suggested that exploring all spectrums (Art, Science, Design and Engineering) would offer a great basis for ideas when merged in later stages of idea generation.

S3 thought that the compass is useful for tracking participation in meetings because it visualizes who is talking. He later suggested that tracking participation may have encouraging effects on people who take part in creative meetings and allow managers to change their innovation strategies. According to D3, the tool supports creativity because it informs meeting participants about the skills and interests of people who form the group: 'The compass provides a better understanding; it makes sure everyone is on the same page.' She also went on to suggest that the visualizations could boost creativity retrospectively. For example, looking back at the topic visualizations could help generate more ideas after the meeting, when working alone. D4 found that generally she thinks the tool supports creativity, because when it shows ideation topics merely in one or two domains, she would feel that other areas are neglected, and she would try to improve the diversity.

The Ideation Compass also received critical comments. S1 suggested that it can be distracting in a meeting: 'Perhaps instead of us, the head of the meeting could keep an eye on this tool, and they could direct the discussion.' S2 added that users who do not speak freely might feel that the compass inhibits their creativity because 'you cannot allow to say stupid things freely, but if you knew how the system works, then it wouldn't be an issue'.

7.4. Perception of users' behaviors

According to D3, The Ideation Compass has a good potential to change the way she communicates in collaborative ideation and suggested it is a fun tool which makes her more enthusiastic about ideation: 'Understanding other areas would mean that I'm more likely to come up with new ideas or concepts.' D1 echoed similar ideas, stating that

> I think it would change the way I share information … often when people talk, they share only what they understand, but someone else might interpret it differently. For me it would be really useful when I knew that if I was looking at a science idea but it didn't come across like that so I could rephrase that to be more science centered. It would help make communication a bit clearer.'

D4 did not think her communication was significantly affected by The Ideation Compass but suggested it most likely would have been if she had not been 'on the same page' with her partner during the meeting: 'If we were miles apart, I would make efforts to bring us closer together.' S4 agreed and added that he would feel fostered to be more creative given how gently the compass sends prompts to users. He later added that the tool would have more significant impact in larger teams, which are more challenging to manage and be part of.

S3 suggested that the changes in his behavior might become more apparent after a longer period of use: 'This could be really interesting for your own personal growth and understanding of your own biases, retrospectively.' He later added that the tool would show where the user is usually

shifting toward in a conversation, and this could encourage to explore other alternatives and challenge assumptions. Similarly, D2 revealed that after the first use of the compass, she did not change the way she usually communicates and collaborates:

> I didn't take a role that I should or could talk about design or engineering. It didn't affect me, but if I was to use it again for my own project, I would try to get the topics a bit more balanced.'

S2 acknowledged that she did change the way she communicated to some degree, when using The Ideation Compass:

> We were mostly on the same page but when I saw it was leaning towards Science, I changed a bit. I started thinking differently about how my knowledge could feed into other areas. How could science contribute to other areas . . .'

Similarly, D2 suggested that since it was their first time using the the tool, the focus was on identifying what it can do, but with more experience, it would help her to go beyond the usual comfort zone.

7.5. Potential future directions

Participants envisioned ways in which The Ideation Compass could be further improved, based on their projections for future collaborative projects.

D4 suggested that the breath of interdisciplinary CSTs could be further explored, proposing that such tools could consider multiple inputs: 'It only understands the speech, but I made sketches which the system didn't take into account.' Participants also made several comments about the customizability of the compass, suggesting that the framework of Science, Art, Design, and Engineering could be adapted to organization and/or meeting-specific framework to support team process. For example, D4 said that the compass could be useful outside the ideation context, in which case the organizer or manager of the meeting could customize the framework. D1 had similar comments: 'In different projects it would be great if you could have specialized disciplines.' He also suggested that the design of the tool should consider the long-term effects of its use: 'Long term effect could be that you develop an appreciation for other domains or disciplines. If it's used consistently, it would make you used with the practice of considering other disciplines' points of view.' Users also expressed some concerns about the transparency of The Ideation Compass, suggesting that it was not clear to them what is the 'exact logic' behind the quadrants of the compass, implying that users would find it valuable to know which semantic constructs form each of the disciplines. Users also experienced a competitive element when interacting with The Ideation Compass. D5 and S5 found that the compass indicates a score that should be as high as possible as this would reflect the quality of the collaboration.

8. Discussion

8.1. Effects of topic visualization on creativity and fixation

We found that live topic visualizations facilitated by The Ideation Compass enabled effective knowledge sharing (Hutchins, 1995) by supporting team building. Our findings are complementary to CSTs such as Momentum and Idea Expander that highlight the importance of visual summaries in ideation (Bao et al., 2010; Wang et al., 2010). A manifestation of this new way of knowledge sharing was user data that shows that topic visualizations made users aware of jargon related to their own professional practice. Users reported that the compass reminded them to avoid jargon and domain-specific terminology. They found that the collaboration outcomes in creative ideation can be supported by abstaining from complex terminology, because it improves collaborative awareness of team skills, expertise, and interests. This may have implications for empathy building in interdisciplinary collaborations, related to team

alignment and creativity. These phenomena have previously been studied and supported by tools that visualize users' participation in meetings in real time. This highlights the emergence of groupware tools for creative collaboration (Bergstrom & Karahalios, 2007).

We found that the topic visualizations highlighted areas that have not been fully discussed by the users (in relation to the framework provided). This meant that the compass acted as a prompt for users to consider a wider set of alternatives, which is a key characteristic of the divergent and convergent nature of creativity, in parallel with establishing a balance between the problem and solution space (Dorst, 2019). In other words, the live topic visualizations provided a source of inspiration that helped users to avoid fixation (Vasconcelos & Crilly, 2016) and encouraged to leave the path of least resistance in the creative process.

We found that The Ideation Compass can change behavior by subtly nudging users toward creative trajectories. The topic modeling visualizations has the potential to change the way users communicate in a creative collaboration. User data shows that they were inclined to share their ideas and knowledge clearly and therefore effectively establish a common ground for generating new ideas. The long-term effects of live topic visualizations on user behavior remain unknown. On the one hand, participants suggested that once they became more accustomed to the tool, they experienced it as more useful. On the other hand, once the novelty effect expires, users may discard the visualizations from their process. In general, we found that users were inclined toward more creative behaviors when using The Ideation Compass. This manifested with participant perceptions.

8.2. Team collaborative process

Our non-explicit assumption was that users would start their discussions from widely diverging perspectives (for example, a bio-scientist's topic visualizations would be displayed in the Science quadrant and designer's topic in the Design quadrant of the compass). We expected the compass to achieve its effect gradually during the idea generation process, by showing how topics move closer together. According to the interviews, this was not necessarily the case, because users understood the intent behind the compass from the early stages of the discussion and projected their ideas in the broadest possible manner from inception. However, it was acknowledged by the users and observed by the authors, that the topic visualizations were an important factor for maintaining the diversity of ideas proposed and generated. The user data shows that the compass played an important role in assuring participants about the team process. As such, The Ideation Compass encouraged users to engage actively, which is particularly useful when people with little previous ideation experience take part in creative tasks. We found that interdisciplinary ideation can benefit from live topic visualizations, due to its ability to support and maintain shared understanding (Cash et al., 2020) in CSCW.

Our findings have implications for the future research and development of CSTs. We have demonstrated one way to apply NLP and topic modeling in an exploratory study that aims at supporting the creative team process during ideation. In addition, the user data suggests that this technology also has the potential to leverage team processes outside idea generation settings. The interviews show that participants acknowledge challenges in interdisciplinary collaboration. The Ideation Compass performed an important role in facilitating reflection in action (Schön, 1991) which alleviated some of the challenges. This shows that the potential of existing and future CSTs could be leveraged through their ability to visualize and externalize (parts of) the team cognitive process. This visualization can then act as a boundary object (Star & Griesemer, 1989) that incites reflection and supports social creativity by making cognition and knowledge sharing observable (Bila-Deroussy et al., 2017). Similar findings have been reported for CSTs that address the preparation phase of ideation (Bao et al., 2010).

8.3. Limitations of the study

One of the limitations of the study is that The Ideation Compass was at prototype stage during the user evaluation sessions. The main manifestation of this was the occasional errors with the software. The errors meant that users were asked to refresh the web app that facilitated The Ideation Compass. On the one hand, the prototype fidelity may have made participants biased in providing too positive comments when evaluating the tool and its effects (despite the interviewer explicitly asking for critical reflections about the use of the compass). On the other hand, they may not have experienced the full intent behind the tool because the prototype fidelity had not been maximized. For example, the UI received only little refinement before it was presented to users. Our interviews were limited to exploring the effects of real-time visualization using the intervention and did not evaluate commitment of use.

The study replicated a real-life scenario of interdisciplinary collaboration where participants are relatively loosely tied by an educational institution. As such, the findings and participant experiences are limited to the experimental setting. Further research in an organizational setting with functioning teams and established organizational hierarchies would alleviate this limitation and allow the scope of this research to expand. A limitation that was acknowledged by the participants was the limited duration of the study. It was noted that a longer use period would render additional insights. We found that gaining a longitudinal perspective on the effects of live topic visualization would be an important next step in the development of our tool and other CSTs in CSCW that address interdisciplinary idea generation. With the next iteration of the compass, we would be interested in carrying out research in meetings that have more than two active participants that present more than two disciplines.

Distraction from computer-mediated human–human interaction is a potential side effect from using the tool, which calls for further exploration. Our results omit the possibility that the participant dialog was subject to gender balance. Although this has not been observed in the data, there is an opportunity to explore the effects of live topic visualization from a gender perspective.

8.4. Implications for future developments in live topic visualization

Our study looked at the participant perception regarding exposure to live topic visualization, which is based on a discipline-based framework for creativity. The qualitative findings of this study can inform follow-up studies that could quantitatively assess the effects of live topic visualization in ideation, for example, by focusing on the number of ideas generated, the quality of ideas generated, or the evaluation of practitioners' shared mental models (Goldschmidt, 2007).

Based on the user feedback, the framework of Science, Art, Design, and Engineering could be refined to make the interaction more transparent in terms of communicating the semantic constructs that formulate each quadrant of the compass. The user evaluation sessions highlighted that a customizable compass would allow for greater flexibility and suitability in real-life context, which would potentially leverage the creative potential of ideation.

Several participants indicated either directly or indirectly that they perceived the compass to inhibit an element of competitiveness. The competition was seen to take place between the collaborating participants or with oneself (e.g., improving one's performance score). There was no explicit intention in the design of The Ideation Compass to facilitate competitive interactions, but we suggest that gamification strategies (Deterding, 2012) could be applicable in the development of CSTs that use live topic visualization in ideation.

9. Conclusion

This exploratory study presented a novel CST for interdisciplinary creative idea generation – The Ideation Compass. The tool aimed at supporting interdisciplinary CSCW during ideation by

presenting a discipline-based live topic visualization. We interviewed users of the tool, comprising bioscientists and design engineers, to understand their perception on visualization generated by The Ideation Compass. Our findings show that real time discipline-based topic visualization can support creative idea generation across disciplines through:

- its ability to *incite self-reflection* among idea generators
- enabling emergence of *shared understanding*
- *prevention of discipline-based fixation* and raised awareness about knowledge sharing in dialog

Based on the findings, we suggest future work to explore how live dialog visualization could be used to facilitate interdisciplinary collaborations that tackle complex societal problems or aim at producing innovations (for example, to address United Nation's sustainable development goals).

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