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The Group Folding Effect: The Role of Collaborative Process Structuring and Social Interaction in Group Work

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Group work involves a myriad of complex processes encompassing social, perceptual, cognitive, and contextual factors. However, there is a lack of empirical research on computer-supported *group work processes* and their impact on outcomes at different stages of group work, especially when creativity and quality of outcomes are significant. Group work processes can interfere and hinder productivity, which we refer to as the “*group folding effect*.” We designed a three-stage *process structuring* to enhance group work productivity. In a field study, we examined how process structuring shapes productivity in two sub-studies: design and peer feedback, each with 40 participants ($N = 40$). The results revealed that process structuring significantly improved both the quantity and quality of productivity. Additionally, process structuring appeared to reduce inhibitory effects of group work, such as negative priming, fixation on familiar ideas, and social comparison. We discuss the implications of this research in supporting productive group work processes in collaborative tools and insights into a pattern of the group folding effect.

CCS Concepts: • **Human-centered computing** → **Empirical studies in collaborative and social computing**; **Field studies**.

Additional Key Words and Phrases: collaboration, group work, process structuring, group productivity, social interaction, design conception, peer feedback

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1 INTRODUCTION

Many people around the globe are working in small groups on shared activities, for personal and professional life, and in various societal sectors, ranging from schools [e.g., 69] to research communities [e.g., 52, 94] to corporate departments [e.g., 38, 59], and in a variety of areas, such as learning [2], writing [97], creativity [56, 87], problem-solving [37], to name a few. Their collaborations and interactions rely on productive idea exchange [5, 44, 75], which involves complex social, perceptual, and cognitive processes [27, 35, 63, 64].

While human intuition might suggest that creative group work, such as brainstorming and design problem-solving, should be effective, research has shown that group members suffer productivity loss due to various inhibitory factors, such as social loafing [42], social matching [24, 56], evaluation apprehension [27, 63], production blocking [65], negative priming [89], and fixation [73], among

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others (see related work). Careful considerations of contextual, social, perceptual, and cognitive *processes' interference* in group work can catalyze productivity. However, little empirical research has been devoted to examining *how* they might do so. Existing approaches rely on limiting direct and immediate interactions among group members to reduce inhibitory effects of the group, such as writing ideas rather than exchanging them verbally [45, 72], and sharing ideas through a computer asynchronously and anonymously [22]. Other approaches rely on problem reduction techniques, such as task-decomposition [21] to direct group members to explore subcategories of the problem [47]. A primary limitation of decomposition is that it is task-dependent and requires expert knowledge about the group and the situation at hand. Other strategies rely on hybrid alternation of individual and group work, either individual-to-group or group-to-individual. Two studies found that individual-to-group is beneficial [6, 34]. A follow-up study found that group-to-individual is rather beneficial [45]. Existing studies in this area are limited in number and consensus, suggesting that more work is needed.

We build on previous research and examine the role of *process structuring* in group work. We seek to provide a better understanding of the socio-cognitive processes of humans' shared and mediated interactions as well as design recommendations for technological mediation and intervention. We differ from previous work in four main ways. First, we articulate three sub-processes for creative group work in design problem-solving: idea generation (problem space), idea association and evaluation (evaluation space), and idea mapping (solution space). Second, structuring the process rather than the task [e.g., 21] removes the need for expert knowledge underlying decomposition and removes any task-decomposition bias (cf. expert-novice paradigm [60]). Third, previous studies have focused on idea generation [6, 21, 34, 45, 72]. Instead, we examine a comprehensive problem-solving process. In real-world situations, group members usually need to generate ideas, discuss, associate, and evaluate their ideas, and map out a representation that communicates the collective outcome. And finally, existing studies involved either group members discussing ideas verbally (face-to-face) [6, 34], writing ideas on slips of papers individually and passing them to each other [45, 72], or sharing ideas remotely through a computer [21–23, 74]. Instead, we leverage the possibilities of face-to-face and a shared online whiteboard [41, 92]. Face-to-face can offer group members affordances of spontaneity, sense of humor, and synergy. A shared whiteboard can offer group members affordances of immediacy and simultaneity to offload ideas at will, reducing production blocking. Additionally, it creates a shared repository of ideas accessible for individuals with cognitive ease, thus reducing the cognitive demand of maintaining an internal representation of ongoing group work [78].

Although it might seem evident that the three sub-processes mentioned above are essential for collaborative work, combining them effectively is challenging because of inhibitory interference of contextual, social, perceptual, and cognitive group processes (we refer to this as the group folding effect). We hypothesize that making a process salient during another process can affect group work productivity.

We conducted a field study with 40 participants ($N = 40$) and examined how processes structuring shaped group work productivity, comparing two conditions (process structuring versus structure-free) across two design-related sub-studies. In sub-study #1, we engaged participants in an intellectual and generative activity of a conception of a design. In sub-study #2, we engaged participants in an evaluative and goal-directed activity (in addition to being intellectual and generative) of peer feedback on design solutions (results of study #1). The results showed a main effect of process structuring on group work compared to a structure-free condition. We found that dyad teams were as productive as triad teams. We found that process structuring produced similar emotional experience and cognitive load compared to a structure-free condition. The results show that process structuring yields greater productivity in design and peer feedback sub-studies

in terms of fluency (effect size_{design} $r = .702$), originality (effect size_{design} $r^{averaged} = .744$, effect size_{feedback} $r = .573$), and flexibility of ideas (effect size_{design} $r = .599$, effect size_{feedback} $r = .643$). Fluency of feedback was smaller ($r^{averaged}_{feedback} = .177$). The process structuring yields greater socio-affect language i.e., motivational and emotional (effect size $d = 2.304$), level of feedback, i.e., formative and summative (effect size $d = .744$). We found that a goal-directed activity (e.g., producing a target number of ideas) performed in a shorter timeframe can hinder group work productivity in terms of quantity (e.g., fluency) but not quality (e.g., originality, flexibility, as well as socio-affect and focus in feedback). The results show that process structuring attenuates inhibitory effects of group work, namely negative priming, fixation on familiar ideas, and social comparison. In light of our results and previous research, we discuss implications of our research to support group work productive processes and insights into a pattern of the group folding effect.

The main contributions of this work are:

- A review of social, perceptual, cognitive, contextual, and technological factors influencing small group work processes in problem-solving, creative work, and concept generation.
- A process of individual idea generation, collaborative idea association and evaluation, and collaborative idea mapping to support and catalyze group work productivity.
- A field study of the effects of process structuring on group work productivity shows that structure can be beneficial and offset the inhibitory effects of group work.
- Design recommendations to support small group work productivity through process structuring.

2 BACKGROUND AND RELATED WORK

A group of two or more members working together on a shared activity constitutes a fabric embedded in a context of social, perceptual, and cognitive interactions. There has been a concerted effort to examine factors that enhance or inhibit collaborative work productivity. We review relevant research in this area and focus on how *processes structuring* might shape collaborative work.

2.1 Productivity and Productivity Loss In Collaborative Work

Productivity of labor and intellectual work can be seen as “*ratios of value created to effort expended*” and are often related to producing unanticipated or exceptionally higher outcomes [19, p. 15]. Research into collaborative processes and outcomes underlines formidable challenges. Productivity loss is a common threat to group work [23, 74]. The outcome of group members working together might not be effective compared to the sum of the individuals [63]. Repeated studies have reported several reasons and conditions (see following sections) of productivity loss in group work [22].

Research in this area covers at least three overlapping strands. One strand takes a situational approach, focusing on contextual factors of group dynamics as a whole, such as team diversity [93], level of structure [e.g., 41], group size [38], collaboration duration [59], and medium of collaboration [22]. Another strand takes an individual perspective, focusing on group members’ social, perceptual, and cognitive factors [16, 27], individuals’ need for structure [77], intuitive or systematic work strategies [e.g., 43, 82], and training [6]. And finally, a third strand takes a socio-technological approach, focusing on collaborative computational infrastructures and tools [e.g., 30, 52, 86].

Productivity measures are commonly adopted to quantify group work outcomes. Early research, building upon Osborn’s (1953) famous technique of group-brainstorming as a tool of problem-solving, creativity, and concept generation, has largely quantified group work productivity as the number of ideas generated by groups —also known as “*group fluency*” [68, p. 298], e.g., [23, 45]. Follow-up research has shown that focusing only on the number of ideas generated by groups is too

narrow [76]. Other productivity factors are essential, such as the quality, feasibility, and implementation of ideas. A contemporary approach to quantifying group work productivity is the number of units produced times the values of their units [19]. Unit values are proxied through their contextual properties, such as greater accuracy, speed [90], emotional experience [30], germane/cognitive load [17], originality [e.g., 45], among others. Comprehensive approaches that combine various ways to proxy work productivity are desirable.

Primary measures of group productivity are fluency, originality, and flexibility. Fluency is the degree of ease in processing an input (e.g., reading a problem) or producing an output (e.g., generating ideas or solutions) [90]. In group work, fluency is widely quantified as the number of ideas generated for a given situation. Originality captures the pertinence, novelty and rarity of ideas. Flexibility captures the conceptual categories and shifts in thinking underlying ideas, and indicates various heuristics and strategies adopted when approaching a problem or a challenge. Together, fluency, originality, and flexibility provide qualitative and quantitative insight into productivity. Research has shown a strong positive correlation between the quantity (e.g., fluency) and quality (e.g., originality) of ideas generated for a given situation [e.g., 45].

One main finding of this review reveals that much research focuses on group productivity in one process, namely idea generation. Our approach is unique because we scaffold the group work process through three main processes: (1) idea generation, (2) ideas association and evaluation, and (3) ideas mapping, which cover the main stages of problem-solving¹. We quantify the effect of process structuring on group work in two different design-related sub-studies: design and peer feedback. We combine both qualitative and quantitative approaches and quantify three cross-measures: fluency, originality, and flexibility for both sub-studies. Additionally, we quantify activity-dependent measures for the peer feedback activity. We do so to assess the effectiveness and generalizability of process structuring on group work productivity.

2.2 Socio-motivational and Socio-emotional Factors of Collaborative Work

Collaborative work has a pronounced social component. We naturally tend to desire a positive evaluation from others. As a result, the presence of others (e.g., collaborators) amplifies our mental attention to perceptions of self in others' eyes, i.e., evaluation apprehension [63]. Individuals with a higher evaluation apprehension feel anxious and unsafe about sharing their ideas because of potential negative evaluation, judgment, or embarrassment, resulting in productivity loss. In some cases, evaluation apprehension can positively affect individuals, e.g., encouraging self-awareness, self-reflection, self-regulation; however, it is detrimental to group work productivity [27].

Human tend to naturally engage in social comparison [24]. Comparison with one another can thus be unavoidable. Upward comparison with higher-performing members can improve members' effort [56]. In contrast, and somewhat counterintuitive, downward comparison with lower-performance group members tends to be detrimental. Higher-performing group members tend to lower their effort to match lower-performing members' productivity (i.e., social matching), resulting in productivity loss. Conflicting results with social matching were observed among students studying online in semi-formal groups. Highly motivated students had higher levels of germane load, as they compensated for the lack of effort of less intrinsically motivated students [17].

Individuals tend to take advantage of a given situation to conserve mental and physical effort [1], which could be explained by resources-rational bias [8], detrimental to group work. Individuals working together might not internalize (intrinsic motivation) the benefit of their contributions to

¹In the following sections, we elaborate on interferences between these three processes and how separating them can be beneficial.

the group. Group work members tend to minimize their effort and relatively lean to free ride (social loafing) on the collective effort of others, resulting in productivity loss [23, 42]. Social dilemmas can manifest among group members working together, resulting in members' unwillingness to collaborate, e.g., unwillingness to share information and knowledge, resulting in productivity loss [59]. Group emotional awareness, namely members' ability to perceive, identify and understand emotions, can moderate group interactions and productivity. In a field study of videoconferencing learning environments, teachers' formative and affective feedback reports for learners increased as their level of awareness of learners' emotional state increased [30].

Although several studies reported social effects through comparative conditions and variables induced by researchers, remedies to enhance social factors of group work have not been extensively examined, especially not in ecological settings. Existing approaches limit direct and immediate interactions among group members to attenuate social inhibitory effects. It was shown that group writing [6, 45, 72] and sharing ideas through a computer asynchronously and anonymously [22] have supported productivity. Writing ideas rather than expressing them verbally can lower evaluation apprehension. Researchers also have reduced social loafing by increasing accountability, such as having each person write ideas using a differently colored pen [45, 72], telling group members that they would be tested for their memory [72] or that their performance will be evaluated [6]. Leveraging individual and collaborative work can enhance social interactions and productivity. We can assume that the group would benefit from a hybrid structure that combines individual and group work, either group-to-individual or individual-to-group. Two studies found that individual-to-group is beneficial because individuals are freed from social constraints and can generate ideas at will, which are elevated during group work [6, 34]. However, in both studies, participants in the group condition discussed ideas verbally, while in the individual condition, participants wrote their ideas. The difference in the technique is a confounding factor and could account for the productivity gain among conditions. One study found that hearing each other's ideas made little difference in group brainstorming [23]. Controlling for the technique and using only the writing, another study found that a hybrid structure is beneficial; however, the group seems to benefit from group-to-individual rather than individual-to-group in terms of fluency and flexibility of ideas [45].

Existing studies in this area are limited in number and consensus, suggesting that more work is needed. We extend previous research in two ways. First, previous studies focused either on discussing ideas verbally [6, 34], writing ideas [45, 72], or sharing ideas remotely through a computer [21–23, 74]. Following insights from [41], we can assume that it is possible to leverage the possibilities of two worlds: face-to-face and online whiteboard-mediated interactions. Individuals might benefit from face-to-face spontaneity, a sense of humor, and synergies while having a whiteboard to type their ideas at will without the need to take turns (immediacy and simultaneity). This structure follows hybrid modern group work interactions, such as nowadays meetings. However, its social effects on group work processes are not known yet. Second, previous studies focused on one main task, namely idea generation. We instead focus on a comprehensive perspective of problem exploration, namely three main stages of idea generation, idea association and evaluation, and idea mapping. However, the effects of combining these processes effectively at both the individual and group level are hard to predict. For example, one could assume that making idea association/evaluation salient during idea generation will heighten evaluation apprehension and hinder individuals' productivity. However, following a social perspective, one could assume that separating idea generation and idea association/evaluation will prevent individuals from stimulating each other with ideas (e.g., social facilitation [68, p. 300]). It might limit group synergy and persistence, resulting in productivity loss. Furthermore, suppose individuals engage with idea generation alone. In that case, they might become emotionally attached to their initial ideas and fixate on them, negatively affecting both

individuals and the group. Because of the potential interference, the benefit of a particular structure of individual and group work through the problem-solving processes is still not clear.

2.3 Perceptual and Cognitive Factors of Collaborative Work

A considerable part of group collaboration engages members in performing mental operations, e.g., coordination, sharing, processing, integrating, and generating information. Various perceptual and cognitive factors come into play. The quality and amount of communication and coordination among group members is vital to the collaborative process [e.g., 52, 86]. Group members' attention to each others' ideas is crucial for productivity. Prior knowledge, information accessible in memory, is usually helpful for productive collaboration. Group members need to understand meanings, create, integrate, and share their relevant knowledge in the context of group collective knowledge [72]. However, prior knowledge can interfere with generating adequate information, especially when readily accessible information is less relevant to the current context, cf., fixation [73], expert-novice paradigm [60].

Group members stimulate one another with their shared knowledge, which is often helpful because they can positively prime their ideas [27]. Shared knowledge among group work creates a semantic context and chain of thinking reactions. Recently evoked ideas and concepts spark new ideas. However, negative priming can also occur. Shared ideas can affect members' divergent thinking and evoke memory blockers that hinder members from producing unique and relevant knowledge (i.e., memory-biased retrieval set) [89]. As collaborators interact more with a set of ideas, they increase the likelihood of failing in retrieving additional ideas. Group fluency of idea generation seems to decline over time [e.g., 45]. Rather than tapping into less accessible ideas, collaborators tend to fixate on initial ideas and think within bounded, familiar, and narrow sets of ideas, resulting in productivity loss [21, 84]. Readily accessible information is usually less relevant to creative problem-solving [33, 50, 88]. Further, group members face the illusion of group productivity, i.e., a feeling of satisfaction with their performance even if their collective productivity is suboptimal, e.g., compared to individuals working alone [74].

Another source of collaborative productivity loss is production blocking [65]. Collaborators need to express their ideas spontaneously or immediately after ideas come to mind. Technological or instructional "blockers," e.g., taking turns to speak or express ideas, can negatively affect group productivity. While waiting for their turn, collaborators may forget or even over-premeditate their ideas and decide against sharing them with the group.

The main finding in this area is that group productivity might benefit from perceptual and cognitive stimulation. One strategy to support perceptual and cognitive stimulation of group work relies on reduction techniques, specifically, problem decomposition [47]. Decomposition encourages individuals to explore (and focus on) subcategories of the problem. One study has shown that group task decomposition, i.e., asking the participants three questions, one at a time, yielded greater productivity compared to one all-encompassing question [21]. Not related to group work, examination of task structure and individuals' cognitive style of personal need for structure has shown that task structure can stimulate and inhibit creative work [77]. In the same view, examination of the interplay between task structuring and individuals' systematic or intuitive cognitive styles has shown that structure supported creative work but inhibited intuitive individuals' productivity [82]. Examination of individuals' implicit and explicit task decomposition in design idea generation, i.e., without deliberate analysis (implicit) or with deliberate analysis (explicit), found that novice designers did not deploy explicit problem decomposition [47]. Thus, a primary limitation of decomposition is that it is task-dependent and requires expert knowledge about both the group and the situation: "[...] to divide a problem, something must be known about it" [21, p. 275]. Another strategy is to leverage both individual and group work, either individual-to-group or

group-to-individual. Two studies found that individual-to-group is beneficial [6, 34]. A follow-up study found evidence supporting group-to-individual [45]. The conflicting results underscore that more research is needed.

We build on previous work in two ways. First, as mentioned earlier, we leverage face-to-face and online whiteboard-mediated interactions and compare process structuring (combining individual and group work) to a structure-free condition. This setup is different from previous studies where individuals either engaged in brainstorming [6, 34] or brainwriting [45, 72]. Second, we structure group processes through three main stages of problem-solving exploration: idea generation, idea association and evaluation, and idea mapping, which is different from previous studies on idea generation [e.g., 6, 21, 34, 45, 72]. Stimulating effects of structuring the processes mentioned above on group work are not apparent. We can assume that conducting individual work, such as idea generation, can be beneficial because it might reduce production blocking, reduce negative priming, and support divergent thinking. We can also assume a carry-over (if not a boost) of individuals' work productivity during a follow-up collaborative work. However, we can also think that group work can be more beneficial because individuals can stimulate one another with shared ideas and benefit from group synergy and persistence. One could assume that the number of ideas can be higher in individual-to-group but perhaps not the quality; the opposite can be true for groups with process structuring. And finally, one could argue that a whiteboard might support individuals in cognitive offloading [78] because it might foster attention, support information processing, and reduce production blocking. However, one could also argue that such a structure might pose higher cognitive demand on individuals because they need to attend to (listen, read, and process) one another's ideas in addition to generating and writing their ideas. A shared whiteboard might make ideas contextually salient to the participants, resulting in fixation and preventing members from divergent thinking. The main effects of process structuring with cognitive offloading are still not apparent.

2.4 Contextual Factors of Collaborative Work

Contextual factors are essential to group work outcomes. One factor is group size. One could assume that as the size of a group increases, it might become harder for group members to coordinate, share successfully, and process information (e.g., resources, responsibilities). Lack of coordination and information sharing might leave more room for counterproductive social, perceptual, and cognitive effects to take place, such as nonparticipating members, social loafing, production blocking. One study found that smaller groups are better, and productivity seems to decrease as the size of the group increases [38]. However, decreasing group size might also decrease group exchange synergy, thus reducing social, perceptual, and cognitive stimulation. A meta-analysis of idea generation in digital brainstorming found a somewhat larger group size of 8 or greater that drastically outperformed individuals working online [22].

Similar to group size, the duration of the collaboration is essential. One could assume that a shorter length of collaboration time can be better. Collective information sharing seems to decline over time. On one side, the decline of ideas over time perhaps is a cause of social dilemmas; in the long run, collaborators tend to value a reciprocal and equal exchange, even at the expense of the quality of the collaboration [59]. On another side, given the biased memory retrieval set, idea production fluency in brainstorming sessions seems to decline over time [45].

In salient aspects, group members' diversity, such as backgrounds, perspectives, socio-cultural factors, gender, skills, can promote group work's qualities and outcomes. One study found demographic diversity attributes can significantly impact the group's results, compared to group

members with similar "thinking styles" (e.g., from the same country) [93]. Gender diversity can impact group work [7]. Individual differences and epistemic needs are also shown to affect individuals' productivity [77].

This paper assumes that careful manipulations of contextual factors are crucial to examining process structuring effects. Because of the wide range of contextual factors of group collaboration, it can be hard to draw an optimal group size. Findings from organization settings regarding 58 software development projects showed that the top five teams in terms of teamwork quality were, on average, around four members; the bottom five teams were around seven members [38]. We opted for triads and dyads because we felt adequate for our settings. Finding an optimal group size of about 8 in online brainstorming makes sense because the focus was on idea generation [22]. Instead, in this paper, we are interested in a comprehensive group problem-solving process from idea generation to idea association and evaluation to idea mapping. Group members need to generate ideas, discuss them, and create a meaningful solution representation. One study observed little difference between dyads and group of four [64].

Similarly, it can be hard to draw an optimal duration for collaboration. While a shorter timeframe is recommended, e.g., for brainstorming sessions [81], it is worth noting that group members can feel pressure to produce rapid results, leading to suboptimal convergence and production [57]. We opted for a reasonable duration for one activity that enables individuals to maintain focus and gives them enough time to perform the activity. We reduced the timeframe by more than half in a second different activity. By doing so, we aim to examine the effectiveness of the process scaffold on two different timeframes. Furthermore, diversified group members can facilitate productive interactions. However, it is worth noting that heterogeneous group members can also lead to less cohesiveness, conflict, and discomfort among group members. We, therefore, opted for homogeneous group members to carefully examine process structuring effects on group productivity. And finally, we designed two different sub-studies varying in complexity. Both sub-studies are intellectual and generative. Additionally, one activity is evaluative and goal-directed. Both sub-studies engage individuals in group brainstorming and group brainwriting as means of problem-solving using both face-to-face and an online whiteboard. The effects of our contextual settings on group work processes structure have not been examined yet.

3 MOTIVATION AND POSITIONING: PROCESS STRUCTURING IN HCI AND CSCW

Our work aims at providing empirical insights into collaborative and social interaction, especially in small-group work productivity. Specifically, we seek to illuminate socio-cognitive processes of humans' shared interactions and mediated interactions (through external tools, artifacts, and representations). Examination of core processes in collaboration can provide a foundation for technological mediation and intervention. We motivate and position our work from four main perspectives that we introduce below.

3.1 M1: Need for Collaborative Process Models

Many studies in HCI and CSCW have been conducted to support collaborative work. A main focus of such research was devoted to supporting coordination and communication among group members using novel computational tools. Synchronous and asynchronous tools can allow users to coordinate distant and co-located actions [e.g., 52, 92]. Infrastructures for auditory and visual communication can foster feeling of presence [e.g., 83], support socio-emotional interactions [e.g., 30], and provide shared spaces and displays [e.g., 86, 94]. Other studies have examined the impact of existing tools on collaborative work [25] and uncovered users' practices, challenges, and possibilities [e.g., 4, 41, 49, 97]. A few studies have designed processes, mainly to automate part of collaborative work, such as designing a series of steps for collaborative crowdsourcing work [e.g., 3, 48].

So far, most research into collaborative work in HCI and CSCW has focused on (i) supporting coordination and communication using novel technologies, (ii) studying the impact of existing technologies, or (iii) automating parts of work processes. There is less research on collaborative processes. Models, such as iterative process [62], double diamond [18], and design thinking [12], are known examples of process models. Such models have several values [79] – they provide explicit language of coordinated actions to perform a work, they abstract variability and generalize to rich work processes and tasks, and they illuminate psychological processes of humans’ shared interactions as well as their interactions with external representations (e.g., computer, artifacts). Research has found evidence supporting process models in collaborative design work, such as double diamond [41] and iterative process [31]. However, given the challenges of collaborative work, group members are often subject to social, cognitive, and contextual challenges (see related work 2). One study [41] found instances of “*unexpected problems*” during collaborative design process, mainly due to collaborators’ (i) overusing and underusing certain communication channels (e.g., verbal versus textual) and (i) challenge in managing and combining group work productions. While previous research suggests that careful considerations of process iterations can support group work, it remains unknown how process decomposition and structuring might do so. Identifying suitable sub-processes, combinations and sequences involved in collaborative work has not been studied systematically. While common sense might suggest that known process models can support group work, such models are mainly adopted by designers and researchers and require professional training [e.g., 31, 66]. Instead, we aim to design and empirically analyze process structuring to support everyday collaborative work, not only professional workers, such as designers.

3.2 M2: Identifying Suitable Group Work Sub-processes, Their Combinations and Sequences

Research into group creative work has identified several sub-processes that can catalyze productivity, such as idea generation [e.g., 6], idea selection [76], idea combination [44], and idea evaluation [75]. Much research in this area examines one or two key sub-processes [e.g., 6, 34, 45, 72]. Such research is vital because of two main reasons. First, processes might manifest simultaneously and in linear and non-linear forms. Second, it is becoming clear that each sub-process involves complex social, perceptual, and cognitive constructs.

In the view of process model approaches, even if human work might not appear as linear and sequential, we often scaffold our work through a series of steps. A widely adopted strategy is the problem reduction technique, where a problem is divided into sub-problems or sub-goals [21, 47]. For example, one can decompose an idea generation task into three questions to be performed in a sequence [21]. However, this decomposition approach has three limitations. First, a problem decomposition requires domain knowledge about both the group and the situation at hand, referred to as: “knowledge underlies decomposition” [21]. Second, it can be hard to find an optimal decomposition for a problem. And finally, not all group work problems are decomposable. Denis et al., (1996) concluded in their work: “*more research is also clearly needed on process decomposition, given its significant effects on performance*” [21, p. 274]. While previous research has revealed several key sub-processes, identifying suitable combinations and sequences has not been subject to empirical research – currently it is mostly based on human intuition. In addition, most sub-processes have been contributed by the cognitive / social sciences. Examining work processes from an HCI-CSCW point of view is therefore relevant and important. Furthermore, famous processes in HCI and CSCW are rather designed for trained professional [12, 18, 31, 62, 66]. Other workflows have been designed, however, they aim to automate part of group work for a given context (e.g., crowdsourcing), and rely on salient technological component [e.g., 3, 48]. Collaborators can not use such workflows for everyday work. We aim at extending this space by examining *how* process

structuring might shape group work. Ultimately, we hope to cast important light on implications for collaborative technologies.

3.3 M3: Threats of Group Work Sub-processes Interference

Although it might seem evident that the processes mentioned above are essential for collaborative work, combining them effectively is challenging. The sequence of processes through which group members engage will have a prominent effect on individuals' productivity. This paper takes a closer look at three main processes of creative group work in design problem-solving: idea generation (problem space), idea association and evaluation (evaluation space), and idea mapping (solution space). We hypothesize that making a process salient during another process can affect group work strategies, experiences, and outcomes. To have a productive idea generation, individuals should not feel any fear or pressure of judgment (i.e., evaluation apprehension). Thus, idea generation (e.g., generating potential ideas from long-term memory) will be productive without interference from idea evaluation. Similarly, individuals discussing and associating their ideas with one another will block the process of idea generation (i.e., production blocking). Thus, idea generation will be productive if separated from idea association and evaluation. Further, group work members often fixate on embellishing their initial ideas and overlook exploring problem space, considering alternatives, and discussing all relevant information. Thus, idea generation and idea evaluation will be productive if separated from idea mapping, where a solution representation is shaped.

In this paper, we examine process structuring by comparing it to a structure-free work process for two main reasons. First, previous studies focused on idea generation and have found conflicting results for hybrid alternation of a group and individual work [6, 21, 34, 45, 72]. Instead, we were interested in a comprehensive group work process (idea generation, idea association and evaluation, and idea mapping). Second, previous studies have limited direct and immediate interactions among group members to reduce inhibitory effects of the group (e.g., writing ideas rather than discussing them verbally, or sharing ideas through a computer asynchronously and anonymously) [6, 22, 45, 72]. In contrast, we leverage face-to-face and online whiteboard [41, 92]. Because we introduced a new process structuring for small group collaboration along with the use of co-located and computer-mediated interactions (that we examined through two different studies), we felt it adequate to set up a baseline for process structuring by comparing it against an intuitive work process, such as structure-free.

3.4 M4: Need for Shared Mapping of Group Work Processes

Previous studies focused on the process of group idea generation, where participants were tasked to list ideas on slips of paper [6, 34, 45, 72]. However, in ecological settings, collaborators need to generate ideas, discuss, associate, evaluate, and map out their collective outcome. Further, collaborators can find it challenging to manage and combine their shared productions [41]. Thus, in the present study, we directed the participants to create a meaningful representation to communicate their ideas instead of just listing them. Visualizations of interrelated ideas and concepts, commonly known as *concept mapping* are being reported among the most successful techniques for knowledge inquiry in design education and practices [36, 69], creativity [87], and collaborative sense-making [52]. A study of spontaneous drawings on whiteboards—for brainstorming, communication, and problem-solving, found that more than 50% percent of drawings were concept maps alike [92]. Concept maps are node-link visuospatial representations, where nodes represent concepts (or ideas, people, places, events, and such) and links, either implicit or explicit, represent relationships among concepts [70]. In a study of idea generation stimulated through external contextual conversational keywords, users showed interest into displaying “connections” between keywords (rather than a cluster of abstract keywords) [86, p. 600]. Spatial, visual, and conceptual externalization of ideas

can support limitations of our working memory [51]. Externalization can make it easier for us to offload, scaffold, and capture thinking [91]. Such representations can directly communicate literal and metaphoric contents, structures, and relationships. Externalized ideas can prime one another and generate new ideas through associations [55].

4 GROUP PROCESS STRUCTURING: FROM INDIVIDUAL IDEA GENERATION TO IDEA ASSOCIATION AND EVALUATION TO IDEA MAPPING

We propose a new process structuring (M1) that includes three sub-processes (M2). This new structuring is unique because it is based on a theoretical foundation that helps: (1) decrease inhibitory processes interference during group work, leading to increased productivity for everyday collaboration (M3) and (2) support group members in mapping out collective outcomes (M4).

4.1 Individual Idea Generation

Research underlines the importance of divergent thinking for creative and productive group collaboration [71]. However, group work might facilitate counterproductive biases (M3). Group work can have inhibitory effects on members' divergent thinking and evoke "blockers," constraining members from tacking unique and relevant perspectives. Members' shared ideas can negatively prime collaborators [73]. The dynamics of group work can place members under the pressure of seeking common premature consensus, cf., conformity effect [57]. Members might tend to fixate on familiar ideas and commit to a narrow set of ideas by seeking uniformity. Consequently, exploring alternatives (problem space) and less accessible ideas might not be straightforward for group work, resulting in productivity loss. Group members face the illusion of group productivity. Group members tend to feel more satisfied with their performance even if their collective productivity is sub-optimal than individuals working alone [74]. Group members tend to focus on contextually salient information and overlook information not evoked by the context.

Individual idea generation can be a valuable tool to help emerge diverse and unique perspectives, alternatives, thoughts, and interactions in group collaboration. We hypothesize that individual idea generation (before group work) will facilitate divergent thinking, and thus improve group work productivity. Individual idea generation can support group members in overcoming negative priming when each individual alone —not the group, brainstorm to generate their ideas first. Individual idea generation will free individuals from group social constraints. It may reduce evaluation apprehension because members can not premeditate immediate reactions from collaborators. It may reduce initial downward social comparison because individuals will be initially blind to the performance of each other. It may minimize production blocking because individuals can generate ideas at will without taking turns to express their initial ideas. And finally, it may help reduce free-riding because individuals might feel a need to contribute to the group.

4.2 Collaborative Idea Association and Evaluation

While individual idea generation can catalyze group members to explore unique perspectives and ideas, it comes at three expenses (M3). First, it prevents members from benefiting from group social synergies and persistence. Second, it prevents individuals from benefiting from exchanging and positively priming each other with ideas in a chain of thinking reactions. Third, ideas emanating from individual idea generation may vary substantially from one individual to another [20]. Members need to collectively discuss, connect, evaluate, and refine their ideas. Research underlines that successful creative group work is a combination of generating and evaluating ideas [75].

Idea association and evaluation can support convergent thinking, primarily when ideas are already generated and need to be discussed, associated, and refined before developing a solution. Idea collision in an associative-transformative manner is crucial for a collaborative creative outcome

to occur [55]. Such a process includes individuals stimulating each other with unique, similar, and different ideas and elaborations on the initial ideas, selections, combinations, modifications of ideas, and even rejections of less promising ideas. However, such a process requires complex social, perceptual, and cognitive skills, which can be challenging for individuals. Individuals need to engage in analytical heuristics, participatory negotiation, and decision-making strategies to appraise and assess the qualities of ideas. Individuals need to listen, think, and react to one another's ideas, which can be mentally taxing. Our capacity to allocate information in the working memory for active cognitive processing is limited to a very few items at a time [51]. Shared and external scaffolding and offloading of idea association - evaluation can be an effective tool to augment memory and ease information processing of group work. Group members can create external visuospatial representations to make information salient to be more easily identified, processed, and interpreted by the members. In the view of the extended mind hypothesis, external representations interact with and are intrinsic to human perceptual and cognitive processes [78]. External representations can activate congruent internal representations, senses, abilities, and knowledge. Individuals can interact with external representations as resources of dialogue. We hypothesize that idea association and evaluation supported by external representation can enhance group productivity.

Collaborative idea association and evaluation might elevate ideas generated individually. However, the evaluation process should be separated from generating alternatives or implementing a solution. A threat to group work is focusing too much on embellishing initial ideas and not considering alternatives or discussing all relevant information. Problem-solving research has found that individuals have difficulty creating a complete set of alternatives. Individuals typically overestimate (and underestimate) how they exhaust a problem's space, leading them to generate and consider a few alternatives [33, 50, 88]. Thus, idea mapping where a solution is formulated should not interfere with considering all relevant alternatives, associating, and evaluating ideas.

4.3 Collaborative Idea Mapping

Group work requires generating, associating, and evaluating ideas, leading to a meaningful solution or a creation that takes an external representation, such as a model, diagram, or writing (M4). Once group members identify promising ideas, they collectively create a common solution. Members might make a meaningful conceptual solution through visuospatial mapping and linking of ideas. Idea mapping can be an effective tool for group members to identify, categorize, organize, and communicate a mental image underlying their ideas, namely literal and metaphoric content, structures, and relationships directly. Through idea mapping, group members can co-locate contents (e.g., similarity, proximity), show hierarchical structures of contents (e.g., trees), and show relationships between contents (e.g., connectedness).

Research into problem-solving suggests that most people engage in mental representations of problem space [40]. This includes activating appropriate models (e.g., expert in a subject area) or actively constructing and adjusting appropriate representations toward a solution. Individuals constantly manipulate meta-reasoning resources to envisage and assert possibilities during such a process. Entertaining quasi-states of problem space in memory is challenging and prone to errors because of the limitation of our working memory [51]. Idea mapping can ease and preserve thinking processes when creating a solution [e.g., 52]. We hypothesize that the practice of idea mapping, namely the process of collective mapping ideas, the gain through mapping ideas, and the outcome of mapping—the end artifact, will support group work. By mapping ideas, individuals collectively create representations that connect ideas in ways that make sense, elicit discussions, and help instantiate and reflect on a solution. Such a process is less prone to error, cognitive load, and distortion than mental representations. The observational and artifactual nature of idea mapping

can allow individuals to constantly see content, structures, and relationships and ease reasoning about their work [61, 92].

5 FIELD STUDY DESIGN

We conducted a field study to examine the impact of PROCESS STRUCTURING on collaborative work in two design-related sub-studies. We used mixed methods analysis and followed an overall 2x2x2 factorial design with the following factors and levels:

- CONDITION: WITH & WITHOUT PROCESS STRUCTURING
- SUB-STUDY: DESIGN & peer FEEDBACK
- SURVEY: PRE-SURVEY (*a priori*) & POST-SURVEY (*post-hoc*)

The CONDITION was a randomized between-subject factor. The SUB-STUDY was a within-subject factor. We ran the two sub-studies at two different points in time. The SURVEY was a within-subject factor. We designed the PRE-SURVEY to capture the participants' demographics and the participants' perceptions toward visuospatial LITERACY, COLLABORATION, CREATIVITY, and giving and receiving FEEDBACK. We designed the POST-SURVEY to capture the participants' EMOTION and COGNITIVE LOAD. Apart from the participants' demographics, we handled the SURVEY responses as five-points Likert scales, i.e., items, treated as ordinal data.

We quantified three cross-measures for both SUB-STUDY, namely (1) FLUENCY, (2) ORIGINALITY, and (3) FLEXIBILITY of ideas. Additionally, for the peer FEEDBACK sub-study, we quantified specific conceptual categories of feedback ideas (utterances) with nested levels, namely (1) SOCIO-AFFECT language: motivational and emotional, (2) FOCUS of feedback: summative, formative, (3) TARGET of feedback: content, structure, and relation, and (4) NATURE of feedback: correction, evaluation, brainstorming, interpretation, recommendation, and reflection.

5.1 Study Hypotheses

We examine four primary hypotheses:

- **H1:** In the design sub-study, process structuring will yield greater productivity in fluency, flexibility, and originality than in the structure-free condition. From a social perspective (e.g., group synergy, persistence, idea sharing, upward comparison), the group in process structuring might initially suffer productivity loss (i.e., during individual idea generation). However, we hypothesize that the gain of process structuring will be higher from cognitive (e.g., divergent thinking, lower negative priming, lower production blocking) and social perspectives (e.g., lower free riding, lower evaluation apprehension).
- **H2:** In the feedback sub-study, process structuring will yield greater productivity in quality (e.g., flexibility and originality) but perhaps not quantity (e.g., fluency) than the structure-free condition. If group work processes set a clear fixed goal (e.g., producing a specific number of ideas), the members will likely aim for the specified goal, constraining their fluency.
- **H3:** Process structuring will attenuate negative priming, fixation on familiar ideas, and social comparison, resulting in productivity gain. Process structuring leverages cognitive scaffolding and divergent thinking, which are likely to facilitate relevant perspectives, unique ideas, and deeper exploration. Process structuring will likely prevent group members from seeking premature (sociocognitive) convergences, consensus, and conformity.
- **H4:** Process structuring will yield greater productivity without taxing collaborators cognitively or emotionally.

In the design sub-study, collaborators engaged in a generative conception of a design **H1** —generative in the sense that, apart from the structuring, there was no other external constraint on the work process and the outcome. In the feedback sub-study, collaborators engaged in a goal-directed

activity **H2** —goal-directed in the sense that they needed to (1) write a feedback report about a design solution produced by a peer group (2) in a shorter timeframe. By comparing structuring to structure-free (section 3, **M1**), we can obtain informed results about if and how a suitable sequence of group work processes (**M2**) can support group productivity (**M3**) in these two types of collaborative work. Further, **H3** examines why process structuring might be superior to a structure-free and more importantly what factors might contribute to such superiority, in part, sub-processes interference (**M3**). At first, we might think that process structuring can tax collaborators cognitively or emotionally, but we hypothesize that it will not (**H4**), mainly because the sequence of sub-processes is designed to facilitate a shared mapping of group work (**M4**). And finally, currently, to the best of our knowledge, there is no baseline to compare processes structuring against (with a comparable design). Therefore, we opted for a structure-free as a control condition to obtain a precise estimate of the effects of process structuring.

5.2 Study Setting and Sample

We designed and planned the study in early 2021. We conducted the study between September and November at an engineering school, in the context of the course “Information Systems Modeling.” The course was administered and taught by the second author of the paper. Because of the Covid-19 pandemic, the teacher has begun blending design thinking [9, 69] and educational technologies to improve classroom experiences and outcomes.

Two classes enrolled in the course participated in the study. Each class had two sessions of collaborative work. Each session lasted for two hours. Both classes gave us a reasonable sample size of 40 participants ($N = 40$) and a total of approximately eight hours of collaborative work split over four sessions.

The institution’s research coordinator approved the study. We took several measures to avoid conflicts of interest. First, the activities of the study were carefully designed to align with the course objectives and topics, ensuring that they were relevant and meaningful within the context of the class curriculum. This integration allowed us to collect data in a natural and authentic setting, capturing the participants’ genuine responses and interactions, thereby benefiting both the students and the research outcomes. Second, we informed the participants about collecting and anonymously analyzing their collaborative work data and possibly withdrawing their data from the study at any time. We told participants about the possibility of reporting snippets of their work anonymously for research. All the participants consented to collecting and analyzing their data. We made it clear to the participants that they had the option to opt-out without any negative consequences. Attendance in the study did not affect their grading or academic standing in any way. Furthermore, the co-authors separately analyzed the data to ensure objectivity and minimize bias.

5.3 Participants

The participants were 40 third-year graduate students, of two classes of 21 and 19 students ($N = 40$), enrolled in the course “Information Systems Modeling”, (gender: [$M = 38, F = 2$], age: [$<20 = 6, 20-25 = 33, >25 = 1$]). All the participants were French native speakers. They voluntarily participated in the study as part of the course. We did not give a compensation/gift to the participants. We report on the main effects of demographics in the results section 6.

5.4 Activities and Materials

We designed two main collaborative activities, a pre-survey, and a post-survey.

5.4.1 DESIGN Sub-study. We aimed to provide participants with meaningful archetypes for their collaborative work, using engaging and narrative scenarios for design exploration [9]. The collaborative DESIGN activity focused on the conception of a DESIGN, specifically on three main stages: problem exploration, generation, and representation of a solution. From an instructional perspective, we designed two identical DESIGN activities in terms of experiences, materials, and level of difficulty, but with two slightly different problem statements (subject), one for each group. We slightly changed the problem statement. We ensured that participants get a new problem statement in each condition. We formulated two similar design problems: “Classroom 2.0” and “Hybrid Meeting Room”, one for each group. Below is the wording used for both problems.

Your mission: Collaborative Conception of a Design

Imagine that you work for a [name of a city]-based company that is looking to offer a [“new learning experience to schools” OR “new hybrid meeting room service to businesses”]. The new offer named [“Classroom 2.0” OR “Hybrid Meeting Room”] is based on the experience of [“learning with” OR “meeting using”] new technologies.

Your mission is to design the [“Classroom 2.0” OR “Hybrid Meeting Room”] offer with one or two colleagues. Your company offers you nine concepts to stimulate your thinking [we placed nine initial concepts on the starter Miro boards that we had created for each team, see procedure below (section 5.6)]. You do not have to limit yourself to the proposed concepts. You can modify them and/or add to them as you wish. You can use images and illustrations to communicate your ideas.

5.4.2 Peer FEEDBACK Activity. The second activity focused on participants’ peer FEEDBACK on design solutions, specifically the participants’ results of the DESIGN activity. We motivated the activity of (peer) feedback to the participants. We create a narrative scenario [9] for participants to collaboratively analyze and reflect on a design solution of their peers and consequently write a feedback report to their peers (see appendix B for the statement used).

We decided to use peer feedback activity for two main reasons. First, peer feedback is a precious tool in design thinking practices [15, 85]. Second, peer feedback is uniquely different from the design activity. In addition to being intellectual and generative, it is evaluative, which gave us a unique setting. Specifically, we leverage the evaluative aspect of peer feedback with social information (participants shared results) to evaluate the moderating effects of process structuring on social comparison (see procedure - section 5.6.4). We made the activity more goal-directed by asking the participants to produce at least 200 words feedback reports. We also allocated a shorter timeframe, about half of the DESIGN sub-study. We did so to gather empirical data about the effectiveness and generalizability of process structuring on group work productivity.

5.4.3 Pre-survey. We designed the PRE-SURVEY to gather participants’ perceptions regarding four factors relevant to our work: Visuospatial LITERACY, COLLABORATION, FEEDBACK, and CREATIVITY (see appendix D). Visuospatial LITERACY involves a set of perceptual and cognitive skills of manipulating visuospatial attributes of objects through space-time [54, 61]. Being a fundamental competence, not only for designerly practices, but for all aspect of learning for life and work, various arguments advocate leveraging visuospatial thinking for knowledge inquiry in a variety of areas, such as creativity [87], design [36, 69], brainstorming and problem-solving [92]. Specifically, we collected participants perceptions towards interpreting, understanding, appreciating, and producing meanings through visuospatial representations. We gathered participants’ perceptions towards collaboration, namely working alone and in group. Similarly, we gathered participants’ perceptions towards giving and receiving feedback, drawing on ideas from [46, p. 63:9]. And finally, we collected participants’ perceptions towards creative thought, drawing on ideas from [26, p. 6].

Visuospatial literacy, collaboration, feedback, and creativity are important factors to account for, for both sub-studies: conception of a DESIGN and peer FEEDBACK on design solutions. We wanted to make sure that participants in the both conditions have relatively similar backgrounds.

5.4.4 Post-survey. Drawing on ideas from [53], we designed two small POST-SURVEY to gather participants' self-reported emotion and cognitive load (i.e., effort) after the DESIGN and peer FEEDBACK sub-studies (appendix E).

5.5 Apparatus

We used three apparatus: a classroom, an online collaborative whiteboard, and pens and papers.

5.5.1 Classroom Setup. The study took place in two identical school classrooms (one for each group). The two classrooms facilitate group work using round tables in the form of islands (Figure 1). The classroom has four tables. Each table can host up to five persons. Each person has two monitors stacked vertically. The primary monitor directly faces the person. The secondary monitor on top of the primary one. Both classrooms have a noise reduction carpet.



Fig. 1. Overview of the classroom setup.

5.5.2 Online Collaborative Whiteboard. We used the web-based Miro whiteboard [58], with an educational account. Miro is a raising collaborative whiteboard with several academic and collaborative features. At the time of this writing, they advertise their product as: “The online collaborative whiteboard platform to bring teams together, anytime, anywhere” with “over 25 million users” [58]. The whiteboard is relatively intuitive. We can create an unlimited number of boards with an educational account and invite others to join boards (or share boards using links). A Miro board shows real-time cursors of the collaborators with unique colors and names. Also, Miro displays real-time highlights of the contents when edited by collaborators.

5.5.3 Pens and Papers. In the first stage of the DESIGN and peer FEEDBACK activity, i.e., individual idea generation, the participants in the CONDITION WITH PROCESS STRUCTURING have first to note their ideas on sheets of papers as part of the process.

5.6 Procedure

The procedure consists of five main stages: (1) opening, (2) group formation, (3) collaborative design sub-study, (4) collaborative peer feedback sub-study, and (5) closing. We conducted all activities in the participants' first language (French).

5.6.1 Opening. We told the participants about the activities of the sub-studies in the second week of the course without disclosing the conditions of the study. We administered the PRE-SURVEY to gather participants' demographics, backgrounds, and consent. All participants completed the pre-survey two weeks following the opening.

5.6.2 Teams Formation. We randomly create teams for the two conditions. CONDITION WITH PROCESS STRUCTURING had eight teams, five triads, and three dyads ($N = 21$, $N_{Teams} = 8$, $N_{Triads} = 5$, $N_{Dyads} = 3$) for both DESIGN and FEEDBACK sub-studies. The CONDITION WITHOUT PROCESS STRUCTURING had seven teams four triads, and three dyads ($N = 18$, $N_{Teams} = 7$, $N_{Triads} = 4$, $N_{Dyads} = 3$) for the DESIGN activity and five triads and two dyads ($N = 19$, $N_{Teams} = 7$, $N_{Triads} = 5$, $N_{Dyads} = 2$) for the FEEDBACK activity (one participant was absent during the DESIGN activity).

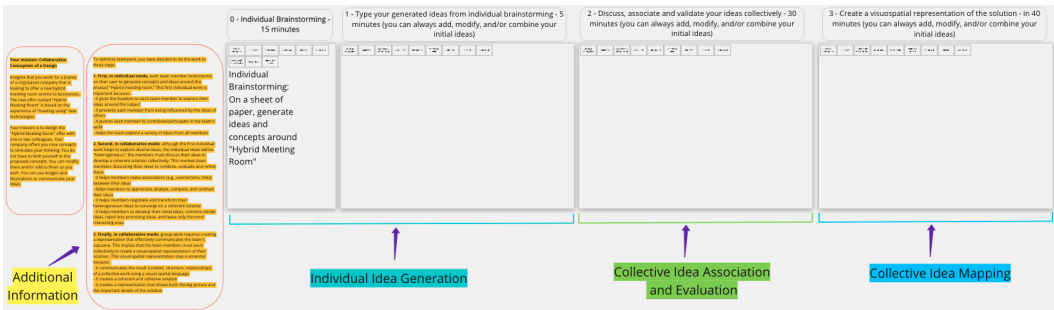


Fig. 2. The starter Miro board that the group WITH PROCESS STRUCTURING received for DESIGN activity. Left is the activity description. Next to it is the additional bullet points that participants in this condition received, highlighting why structuring their collaborative work in three steps might be important (see appendix A). Then, we have three main Miro frames, one for each stage of the process: idea generation, idea association and evaluation, and idea mapping. We placed in each frame the nine initial ideas that we provided participants for stimulation ("Artificial Intelligence", "Audience", "Smartphone", "Video Wall", "Internet", "Audiovisual", "Augmented / Virtual Reality", "Visual Tools", "Immersive Rooms", see small boxes). In the first stage, participants were asked to generate ideas on sheets of papers (in 15 minutes) before typing them on Miro. We mentioned to the participants in the Miro Frames: "you can always add, modify, and/or combine your initial ideas". Participants in the group WITHOUT PROCESS STRUCTURING received the same board without the additional information and with only one frame entitled: "Conception of a Design of the "Classroom 2.0" - 90 minutes" with nine initial ideas ("Augmented Reality", "Internet", "Data Collection", "3D Printing", "Visual Tools", "Classroom as Laboratory", "Smartphone", "Collaboration Between Classes", "Immersive Courses and Classrooms").

As noted earlier in related work (section 2.4), we opted for triads and dyads for three reasons. One reason was to increase the number of groups for statistical analysis. The second reason was to optimize group work. Smaller teams are generally better because of the nonparticipating effect that increases as the size of the team increase [38]. One study found less difference between group of four and dyads in idea generation [64]. Third, we felt triads and dyads are adequate to our objective of examining a comprehensive process structuring of group work problem-solving (not only idea generation, e.g., [45]).

5.6.3 *Sub-study #1: Collaborative DESIGN Activity.* We create starter Miro boards the week before each activity, one board for each team. We made seven identical boards for CONDITION WITHOUT and eight identical boards for CONDITION WITH PROCESS STRUCTURING. To help structure Teams' collaborative work on Miro boards, we used Miro frames. A frame creates a boundary for a space of work. Collaborators can locate their shared work and cursors within a frame on the canvas and work together. Figure 2 presents the starter Miro board that teams received in the CONDITION WITH PROCESS STRUCTURING.

In the fourth week of the course, we conducted the design activity with the participants in both conditions: WITHOUT and WITH PROCESS STRUCTURING, respectively. We randomly assigned the participants in the CONDITION WITHOUT PROCESS STRUCTURING to work on the design activity "Classroom 2.0." They received the description of the activity reported in section 5.4, with no additional instructions. The participants in the CONDITION WITH PROCESS STRUCTURING worked on the "Hybrid Meeting Room" activity. Similarly, they received the description reported in section 5.4. Additionally, teams in this condition, received bullet points highlighting why structuring their work in three steps might be beneficial (see appendix A).

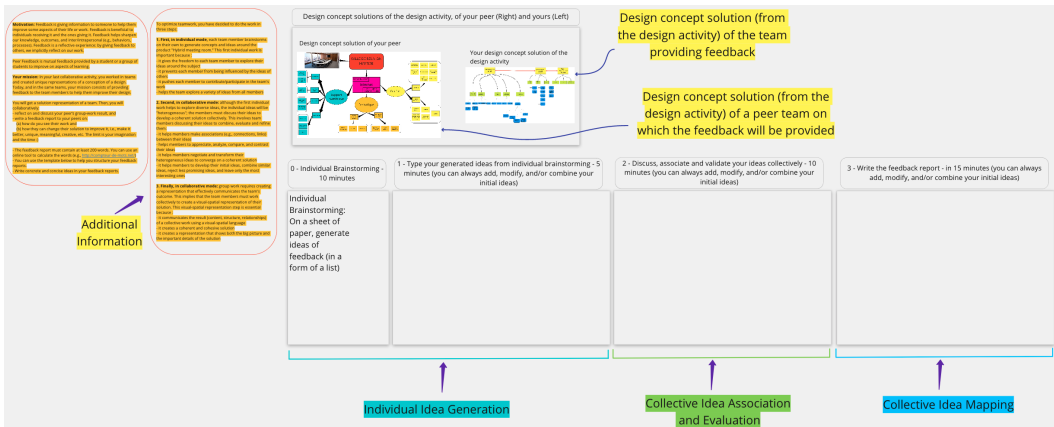


Fig. 3. The starter Miro board that the group WITH PROCESS STRUCTURING received for FEEDBACK activity. Left is the activity description. Next to it is the same additional information provided in DESIGN activity (see appendix A). Then, we have three main Miro frames, one for each stage of the process. Above the three frames, we placed the design solution of the peer team (subject to feedback) and the design solution of the team providing the feedback. In the first stage, participants were asked to generate ideas on sheets of papers (in 10 minutes) before typing them on Miro. Participants in the group WITHOUT PROCESS STRUCTURING received the same board without the additional information and with only one frame entitled: “Your feedback report - 40 minutes”.

We introduced the activity to the participants. We briefly explained the user interface and functionalities of the Miro board. We showed the layout of the started Miro board that we created for the teams. We asked the participants in the condition WITH PROCESS STRUCTURING to preserve their work in the three frames along the three stages of the process (see Figure 2). Specifically, when the participants finished a stage, they copied/pasted the results into the subsequent frame, and so on. We then disclosed and formed the teams accordingly in the classroom. We shared with the members of each team the link to the starter board that we have created for them beforehand. And, we let participants work on the activity for 90 minutes.

5.6.4 Sub-study #2: Collaborative Peer FEEDBACK Activity. Similarly, we create starter Miro boards the week before the peer feedback activity, one board for each team. Figure 3 presents the Miro board that teams received as a starter in the CONDITION WITH PROCESS STRUCTURING. The started board had three frames, one for each stage of the process. Also, it had the design solution of the peer team subject to the feedback and the design solution of the team providing the feedback. The participants in both conditions received the instructions as reported in section 5.4. The participants in the CONDITION WITHOUT PROCESS STRUCTURING received the same starter board without the additional information (see Figure 3) and with only one frame entitled: “Feedback report - 40 minutes”. We randomly distributed design solutions among teams for peer feedback in each condition – eight design solutions for the treatment and seven design solutions for control (see data collection, section 5.7).

In the eighth week of the course, we conducted the feedback activity with participants in both conditions: WITHOUT and WITH PROCESS STRUCTURING, respectively. We introduced the activity to the participants. We asked the participants in the condition WITH PROCESS STRUCTURING to preserve their work in the three frames along the three stages of the process (see Figure 3). We formed the same teams as in the design activity in the classroom. We shared with the members of

each team the link to the starter board that we have created for them beforehand. And, we let the participants work on the activity for 40 minutes .

5.6.5 *Closing*. After each SUB-STUDY: DESIGN and FEEDBACK, we administered a small POST-SURVEY to collect participants' EMOTION and COGNITIVE LOAD.

5.7 Overview of Data Collection and Analysis

In both studies, we had 8 teams in the process structuring condition and 7 teams in the structure-free condition.

- We collected the participants' results from the DESIGN and peer FEEDBACK sub-studies (Miro boards). We collected 15 design solutions (sub-study #1) and 15 feedback reports (sub-study #2).
- We collected the participants' self-reports, 40 responses to the PRE-SURVEY (*a priori*, sub-study #1-2), 39 responses to the post-survey of DESIGN activity (*post-hoc*, sub-study #1), and 38 responses to the post-survey of FEEDBACK activity (*post-hoc*, sub-study #2). Three participants did not complete the post-surveys (sub-study #1-2). However, having 38 responses was representative for descriptive and statistical analysis.

5.7.1 *Coding Ideas*. We coded FLUENCY, ORIGINALITY, and FLEXIBILITY of ideas using the following definitions:

- **FLUENCY**: refers to the level of ease or proficiency in processing inputs and producing outputs [90]. It encompasses input fluency and output fluency. In this paper, we focus on output fluency, which represents someone's capacity to produce a large number of creative or relevant ideas in response to a specific situation or problem.
- **ORIGINALITY**: refers to the pertinence, novelty, and rarity of ideas [75]. It quantifies the uniqueness and cleverness of ideas, emphasizing their less frequent occurrence while still being valuable and relevant to the subject. Original ideas stand out from existing or conventional ideas, offering fresh perspectives or approaches.
- **FLEXIBILITY**: relates to the conceptual categories and shifts in thinking underlying ideas or solutions [75]. It indicates an individual's capacity to think, adapt, and explore different perspectives, approaches, or solutions. It demonstrates a departure from conventional or rigid thinking for a given problem or situation, highlighting the ability to embrace new thinking strategies.

Coding DESIGN Ideas:

We extracted all design ideas from the solutions on the Miro boards (for each team). We checked all ideas for validity. We removed duplicate ideas and corrected spelling issues. We found that some participants spelled some words, while others abbreviated them. We, therefore, spelled abbreviations. We used Hunspell spell checker to perform a dictionary-based check of ideas' spelling in **R** [67]. We tagged the ten initial ideas that we provided participants for stimulation (nine design concepts plus the main idea "Classroom 2.0" or "Hybrid meeting room"). Then, we coded fluency, originality, and flexibility of design ideas using a similar approach to [e.g., 13, 21, 45, 72].

– *Fluency*: all generated ideas without duplicate and ten initial ideas.

– *Originality*: We qualified original ideas in two ways: qualitatively and quantitatively. First, we qualitatively coded original ideas through novelty, uniqueness, or rarity of ideas. Second, we used Natural Language Processing (NLP) approaches to quantify the rarity scores of ideas. We quantified the originality of ideas by computing a rarity score as the sum of the frequency of each idea's stem words. After cleaning up misspellings and abbreviations, we tokenized each idea using 1-gram (one word). We removed stop-words. In NLP, stop-words are common words of a language, such as articles and prepositions. We used Hunspell to perform a dictionary-based stemming of each idea's

words [67]. Stemming unifies the wording used for ideas. Next, we computed the frequency of each stem word in each condition. We then categorized the frequency scores into three categories using a similar approach to [13]. Stem words of a frequency between [1, 3] had a score of 5 (i.e., highly rare). Stem words of a frequency between [4, 5] had a score of 3 (i.e., rare). Stem words of a frequency between [6, 8] had a score of 1 (i.e., frequent). And finally, we computed the rarity score of each idea as the sum of the frequency scores of its stem words.

– *Flexibility*: We coded conceptual categories of generated ideas, indicating shifts in thinking underlying ideas. Specifically, we piled ideas into conceptual categories using thematic analysis [11]. Examples of categories include: “Category ‘user feedback’ derived from ideas: ‘student feedback’, ‘parent feedback’, ‘teacher feedback’ –C2G1”; “category ‘software’ derived from ideas: ‘Powerpoint’, ‘Excel’, ‘presentation software’, ‘software’ –C1G5”. “category ‘automation’ derived from ideas: ‘smart thermostats’, ‘motion sensor’, ‘connected light bulb’, ‘home automation’ –C1G7” “category ‘connectivity’ derived from ideas: ‘RJ45’, ‘HDMI cables’, ‘Multi plugs’, ‘Bluetooth’, ‘connectivity’, ‘WIFI Router’, ‘WIFI network’, ‘connected glasses’ –C1G4”. “category ‘gamified learning’ derived from ideas: ‘playful learning’, ‘coding games’ –C2G3”.

– *Inter-Rater Agreement* : We discussed and applied the coding scheme on a few DESIGN solutions. Then, the two authors coded separately all the collected DESIGN data. We found a percent agreement (PA) = 100% in the fluency, PA = 96,31% for originality, and an PA = 74,17% for flexibility. Then, we discussed disagreements to reach a consensus.

Coding Peer FEEDBACK Ideas:

We extracted all feedback ideas from the feedback reports written by participants for their peers on the Miro board. We checked all ideas for validity. We corrected spelling and minor punctuation issues. Then, we coded fluency, originality, and flexibility of feedback ideas, using a similar approach to [e.g., 21, 45, 72].

To capture the FLEXIBILITY of the FEEDBACK (sub-study #2), we analyzed the principles for representing information that participants highlighted as necessary in their peer feedback. These principles include hierarchy, centrality, categorization, visual appeal, and color.

In addition, we used a similar approach to [30, 46], and coded feedback units (utterances) into four categories, namely SOCIO-AFFECT (motivational or emotional), the level of FOCUS (summative or formative), the TARGET of the feedback (content, structure, relation), and the NATURE of the feedback (correction, evaluation, brainstorming, interpretation, recommendation, or reflection). We developed feedback categories, in particular, the TARGET and NATURE through a bottom-up thematic analysis [11]. When exploring the feedback reports, we found that the participants highlighted aspects of contents, structures, and relationships – we named this category TARGET of feedback. *Content* captures elements, parts, and components of group outcome. *Structure* captures how the elements of an outcome are organized. *Relation* captures how different elements are related or connected to one another. Similarly, we found that the participants *corrected* aspects of the outcome of their peers, *evaluated* aspects of the outcome, *brainstormed* about new ideas, *interpreted* what they saw, *recommended* new ideas, or *reflected* on aspects of the outcome –we named this category NATURE of feedback.

– *Fluency*: First, we qualitatively coded fluency of feedback through the units or utterances of feedback. We considered a unit as the smallest sentence piece with a clear ending (or pause) [30, p. 9]. Second, we quantitatively quantified fluency of feedback ideas as the count of words in each feedback report. We considered both feedback report with and without stop-words.

– *Originality*: We coded original ideas through each feedback unit’s novelty, uniqueness, or rarity (utterance).

– *Flexibility*: We coded conceptual categories of generated ideas indicating shifts in thinking underlying ideas.

• First, we coded information mapping principles that participants indicated in their peer feedback ideas, such as organization, categorization, relations, hierarchy, color, shape, size, similarity, salience, visual appeal, imagery, and readability. Below are examples of this coding.

- *Hierarchy*: “The first thing that stands out are the colors, they separate the different depths of the diagram well. –C2G4”, “The idea of setting up a hierarchy in this diagram could be a good improvement for our representation. –C2G1”;

- *Centrality*: “The most important elements are well highlighted. –C2G6” “[...] although the hierarchy shows ideas better, the diagram lacks a central point, an original idea that is developed. –C1G2”

- *Categorization*: “A more organized arrangement according to categories rather than free space is necessary for a better visualization of the diagram. - C1G8”, “Several ideas can certainly be grouped in larger categories [...] –C2G2”

- *Visual appeal*: “The use of images is a good plus and makes the reading more pleasant –C2G6”, “The graphical aspect should be reviewed because the ideas are good but poorly displayed graphically. –C2G4”.

- *Color*: “A more visual representation would have been possible with more shapes and colors. –C1G5”, “The shapes and colors are similar, they improve the understanding of the diagram and make salient the visual hierarchy. - C2G1”

• Second, we coded SOCIO-AFFECT, FOCUS, TARGET, and NATURE of feedback. Below are examples of this coding.

- *Affect*: We coded feedback ideas with a salient motivational (e.g., “It’s a complete work that we think could have benefited from a few minor tweaks. –C1G6”) or emotional “This one is attractive, colorful and looks complete. –C2G6” statement.

- *Focus*: We coded specificity of feedback ideas, highlighting general aspects (summative, e.g., “Some concepts could have been developed further. –C2G3”) or explaining specific aspects (formative, e.g., “Information about different learning methods is missing, for example, for the different types of classes. –C2G7”).

- *Target*: We coded the target of feedback ideas, namely parts or components of the outcomes (content, e.g., “It would be interesting to evoke for example the use of artificial intelligence, new methods of learning and research. –C2G1”), organizations of various parts (structure, e.g., “This good hierarchy thus helps the general understanding of the topic. –C2G1”), or relationships between various parts (relation, e.g., “The links are not very meaningful, they should better explain what is implied (rather than a simple keyword, sentences would be better). –C2G5”).

- *Nature*: We coded the nature of feedback ideas, namely statements about good ways to do something (correction, e.g., “Categories should be grouped together: Internet, Smartphones, AI, Audiovisual are all similar. –C1G1”), statements about what was done correctly or incorrectly (evaluation, e.g., “The content is precise and very complete, although the general organization does not emphasize it. –C1G8”), statements about new possibilities (brainstorming, e.g., “Several ideas can most certainly be grouped into a larger category, containing all of the ideas [...]. –C2G2”), statements about making sense (interpretation, e.g., “We understand that ‘Internet’ is at the center of the schema, so it is at the center of the ‘Classroom 2.’ –C2G3”), statements about suggestions (recommendation, e.g., “Similarly, for ‘learning tools’, it is too vague, it could be detailed a little more. –C2G7”), and statements where participants reflect on their work or the work of their peers (reflection, e.g., “They have come up with a lot of interesting ideas that can be implemented in a hybrid meeting room. –C1G7”).

– *Inter-Rater Agreement*: We discussed and applied the coding scheme on a few feedback reports. Then, the two authors coded separately all the reports. We found a percentage agreement (PA) = 94,64% for fluency, PA = 97,17% for originality, PA = 52,94% for flexibility, PA = 100% for affect, PA = 95,41% for focus, PA = 86,77% for target, and PA = 86,32% for nature of feedback ideas. Then, we discussed disagreements to reach a consensus.

6 RESULTS

We report and interpret our results using both p-values for statistical significance and effect sizes for quantifying the main difference between groups (*small*: < .3, *moderate*: .3 - .5, *large*: > .5), with a 95% confidence interval [14, 80]. We planned most analyses before the study. We report boxplots with the median, 1st quartile (25%), 3rd quartile (75%), the minimum and maximum (whiskers), and outliers. We used a nonparametric Mann–Whitney U test for two-way analyses of count data [96]. The count data analysis is summarized over each team, i.e., a between-subject design. Thus, observations are independent, appropriate for Mann–Whitney U test. We used the Generalized Linear Mixed-effects Model (GLMM) for factorial analyses of count data [10]. We used nonparametric factorial analyses of variance of participants’ Likert ratings using the Aligned Rank Transform (ART) [95]. Study materials, including the collected data and a notebook of analyses (in R), are available as supplementary material to this submission (see: [28, 29]).

6.1 The Participants’ Demographics, Backgrounds, and Team Sizes

6.1.1 Demographics. A total of 40 (N = 40) participants participated in the study (Table 1). We administered a PRE-SURVEY (*a priori*) to quantify participants’ DEMOGRAPHICS and BACKGROUND in terms of visuospatial LITERACY, COLLABORATION, CREATIVITY, as well as giving and receiving FEEDBACK. Questions were handled on five-points Likert scales (see pre-survey in appendix D). All participants answered the pre-survey.

We conduct nonparametric factorial analyses of variance of participants’ ratings using the Aligned Rank Transform (ART) procedure [95]. We used CONDITION and BACKGROUND as fixed effects. We used the participant as a random effect. A 2x2 analysis of the Likert scores (dependent variable) with respect to the CONDITION and GENDER (independent variables) showed that there is no main difference of Likert scores in both the CONDITION ($F_{1,36} = 2.883, p = .098$) and the GENDER ($F_{1,36} = .134, p = .715$). Similarly, the results showed that there is no main difference of Likert scores in both the CONDITION ($F_{1,35} = 1.588, p = .215$) and the AGE ($F_{2,35} = .764, p = .473$). We conclude the participants in both conditions were similar in their backgrounds with respect to both age and gender.

6.1.2 Backgrounds. We conducted a 2x4 analysis of the Likert scores with respect to CONDITION and the BACKGROUND (Figure 4). The results showed that there is a main difference of Likert scores in both the CONDITION ($F_{1,42} = 3.762, p = .059$) and the BACKGROUND ($F_{3,554} = 7.315, p < .001$). We conducted post-hoc pairwise comparisons, using Holm-Bonferroni for adjustments [39]. The results showed no significant difference in the CONDITION for LITERACY ($p = n.s$), and FEEDBACK ($p = n.s$), CREATIVITY ($p = n.s$). However, participants in the WITH PROCESS STRUCTURING rater

Table 1. Demographic Comparison Between Participants in Both Conditions and Sub-studies .

Factor	Level	Proc. Structuring	
		WITHOUT	WITH
Gender	Female	1	1
	Male	18	20
Age	>25	0	1
	20-25	16	17
	<20	3	3
Sub-study	Design	18*	21
	Feedback	19	21

*One participant (Male) was absent during the DESIGN activity in the WITHOUT CONDITION.

significantly lower in their perceptions toward COLLABORATION level (Estimate = -95.16, SE = 29.6, $t = -3.218, p = .037$), as demonstrated by Figure 4.

In sum, the only significant difference in participants' backgrounds was in collaborative perceptions, which happened to be "interesting" for our study because the group who rated higher was the group in the structure-free condition. Background in COLLABORATION will not be a confounding factor if the PROCESS STRUCTURING condition yields higher group work productivity.

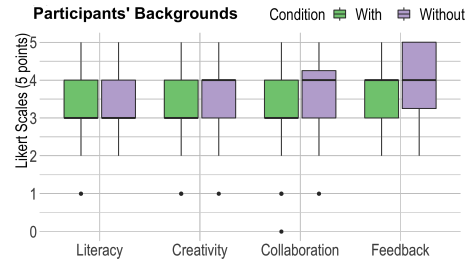


Fig. 4. A boxplot comparison between participants' self-reported (*a priori*) backgrounds.

6.1.3 Team Sizes. We conducted a two-way analysis of the relationship between the participants' TEAM SIZE and their FLUENCY of ideas, across both sub-studies DESIGN and FEEDBACK (Figure 5). The independent variable was the TEAM SIZE, with two levels: DYAD and TRIAD. The dependent variable was participants' FLUENCY of ideas (DESIGN + FEEDBACK). Mann-Whitney U test showed that there is no significant difference between DYAD and TRIAD ($p = .870$). The r effect size showed a small difference ($r = .054, 95\% \text{ CI of } [-.445, .552]$). As Figure 5 demonstrates, looking at the median, overall, dyads were as productive as triads in terms of FLUENCY of ideas. Looking at the upper interquartile range, overall, FLUENCY of ideas of dyads seems to be higher than triads. A percentile test showed no significant difference in 25% ($p = n.s$), 50% ($p = n.s$), 75% ($p = n.s$) percentiles between DYAD and TRIAD.

6.2 H1: PROCESS STRUCTURING Yields Greater Productivity in FLUENCY, FLEXIBILITY, and ORIGINALITY in DESIGN Activity

We conduct a two-way analysis to examine the main effect of the CONDITION: WITH and WITHOUT on participants' FLUENCY, FLEXIBILITY, and ORIGINALITY of DESIGN ideas.

6.2.1 Similarity of DESIGN Ideas Between Conditions. We analyzed similarity of DESIGN ideas between CONDITION: WITH and WITHOUT. To better capture similarities, we analyzed ideas' stem words with and without stem words of the 10 initial ideas. The results using Pearson correlation coefficient [14] and Holm-Bonferroni for adjustments [39], showed small effect sizes: with initial ideas ($r = 0.216, p < .0001, 95\% \text{ CI of } [.122, 0.305]$) and without ($r = 0.169, p < .0001, 95\% \text{ CI of } [.074, .260]$). These results suggest that DESIGN ideas between treatment and control groups were not highly correlated. The smaller correlation is quite normal given the semantic similarity between the subjects "Classroom 2.0" and "Hybrid Meeting Room."

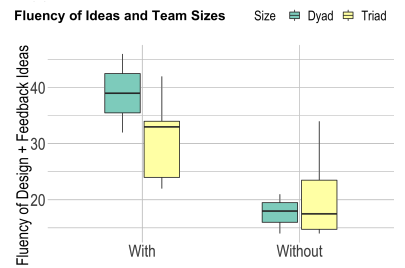


Fig. 5. A boxplot comparison between dyads' and triads' FLUENCY of ideas.

6.2.2 FLUENCY of DESIGN Ideas. We analyzed the count of new ideas generate by each team in both conditions (Figure 6-A). As reported in section 5.7, new ideas are all generated ideas except (1) duplicate ideas + (2) ten initial ideas that we provided participants for elicitation.

We analyzed the number of new ideas using Mann-Whitney U test. The results showed that there is a significant difference ($p = .007$) in the FLUENCY of DESIGN ideas between the CONDITION's levels: WITHOUT and WITH PROCESS STRUCTURE. We calculated the common effect size r for Mann-Whitney U test to quantify the amount of difference between the two conditions. The effect size r is the

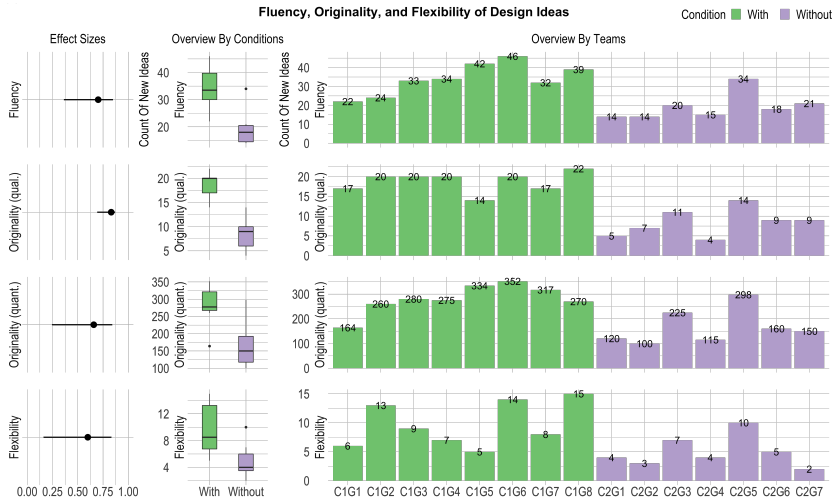


Fig. 6. A comparison between teams' FLUENCY, ORIGINALITY (qualitative and quantitative), and FLEXIBILITY of DESIGN ideas in both conditions: WITHOUT and WITH PROCESS STRUCTURING. Left is the r effect size for Mann–Whitney U test. The middle boxplot compares CONDITION's levels. The right barplot compares teams.

standardized test statistic (from the test) divided by the total number of observations. The results showed a large effect size ($r = .702$, 95% CI of $[.325, .849]$).

6.2.3 ORIGINALITY of DESIGN Ideas. We analyzed the count of *original ideas* generated by each team in both conditions (Figure 6-B). As reported in section 5.7, we qualified original ideas in two ways: qualitatively and quantitatively. First, we qualitatively coded *original ideas* through novelty, uniqueness, or rarity in each CONDITION. Second, we quantitatively quantified *original ideas* by computing a rarity score as the sum of the frequency of each idea's stem words.

The results of Mann–Whitney U test showed that there is a significant difference ($p = .001$) in the ORIGINALITY of DESIGN ideas qualitative quantified between the two conditions and a large effect size ($r = .831$, 95% CI of $[.674, .868]$). Similarly, the results showed that there is a significant difference ($p = .009$) in the ORIGINALITY of DESIGN ideas quantitatively quantified and large effect size ($r = .658$, 95% CI of $[.244, .844]$). A meta-analysis of both qualitative and quantitative ORIGINALITY shows a large effect size ($r^{averaged} = .744$).

6.2.4 FLEXIBILITY of DESIGN Ideas. We analyzed the count of *conceptual categories* of ideas generated by the teams (Figure 6-B). As reported in section 5.7, conceptual categories indicate the number of shifts in thinking underlying ideas.

The results of Mann–Whitney U test showed that there is a significant difference ($p = .023$) in the FLEXIBILITY of DESIGN ideas between the two conditions and a large effect size ($r = .599$, 95% CI of $[.133, .831]$).

6.3 H2: PROCESS STRUCTURING Yields Greater Productivity In Quality of FEEDBACK Ideas (i.e., ORIGINALITY, FLEXIBILITY, SOCIO-AFFECT, FOCUS, TARGET, and NATURE) but not in Quantity (i.e., FLUENCY)

We conduct a two-way analysis to examine the main effect of the CONDITION on participants' FEEDBACK ideas.

6.3.1 FLUENCY of FEEDBACK Ideas. As reported in section 5.7, we qualified FLUENCY of FEEDBACK ideas in two ways: qualitatively and quantitatively (Figure 7). First, we qualitatively coded *feedback units* for each team’s peer feedback report. We coded a feedback unit as an utterance, i.e., the smallest piece of a sentence with a clear ending (or pause) and full meaning [30, p. 9]. Second, we qualitatively quantified FLUENCY of FEEDBACK ideas as the count of words in each team’s feedback report. We considered both: with and without stop-words.

The results of Mann–Whitney U test showed that there is no significant difference ($p = n.s.$), for the three measures: (1) the count of feedback units (utterances), (2) the count of words, and the count of terms (without stop-words). The results showed a small (negative) effect size for the count of feedback utterances ($r = -.106$, 95% CI of $[-.643, .429]$), a small effect size for the count of terms ($r = .21$, 95% CI of $[-.338, .617]$), and a moderate effect size of the count of words ($r = .387$, 95% CI of $[-.121, .767]$) and small effect size of the count of terms ($r = .25$, 95% CI of $[-.307, .615]$).

We found that the participants in process-structuring made longer argumentative feedback ideas (see the number of words in Figure 7-A); however, this resulted in fewer feedback units (utterances) compared to the structure-free condition. Thus, comparing the length of feedback reports (i.e., number of words) reflects more accurately the feedback fluency between the two conditions, especially when the FEEDBACK activity was (1) goal-directed (i.e., we asked participants to produce at least 200 words) and (2) conducted in a shorter timeframe compared to the DESIGN activity. A meta-analysis of both qualitative and quantitative FLUENCY shows a small effect size ($r^{averaged} = .177$).

6.3.2 ORIGINALITY of FEEDBACK Ideas. We analyzed the count of *original ideas* of feedback generate by each team in both conditions (Figure 7-D). As reported in section 5.7, we qualitatively coded original ideas through the novelty, uniqueness, or rarity of each feedback unit (utterance), in each CONDITION.

The results of Mann–Whitney U test showed that there is a significant difference ($p = .030$) in the ORIGINALITY of FEEDBACK ideas between the two conditions. The results showed a large effect size ($r = .573$, 95% CI of $[.095, .837]$).

6.3.3 FLEXIBILITY of FEEDBACK Ideas. We analyzed the count of *conceptual categories* of feedback ideas generated by each team in both conditions (Figure 7-E). As reported in section 5.7, we qualitatively coded information mapping principles that participants indicated in their peer feedback ideas, in each CONDITION.

The results Mann–Whitney U test showed that there is a significant difference ($p = .015$) in the FLEXIBILITY of FEEDBACK ideas between the two conditions. The results showed a large effect size ($r = .643$, 95% CI of $[.271, .842]$).

6.3.4 SOCIO-AFFECT, FOCUS, TARGET, and NATURE of FEEDBACK Ideas. We conduct a 2×4 factorial analysis to examine the main effect of the CONDITION on participants’ peer FEEDBACK CATEGORY (Figure 8). As reported in section 5.7, we qualitatively coded feedback units (utterances) into four categories, namely SOCIO-AFFECT (motivational, emotional), FOCUS (summative, formative), TARGET (content, structure, relation), and NATURE (correction, evaluation, brainstorming, interpretation, recommendation, and reflection).

We analyzed the number of feedback ideas using a Generalized Linear Mixed-effects Model (GLMM) analysis [10], with two fixed effects: CONDITION and FEEDBACK CATEGORY. We used a TEAM as a random effect. GLMM does not require the normality assumptions of data. GLMM handles the

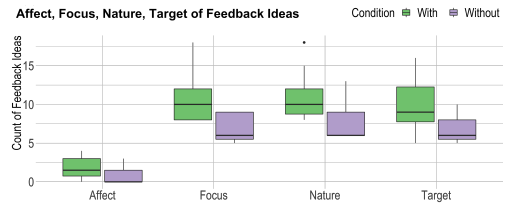


Fig. 8. A boxplot comparison between participants’ FEEDBACK ideas in terms of SOCIO-AFFECT, FOCUS, TARGET, and NATURE.

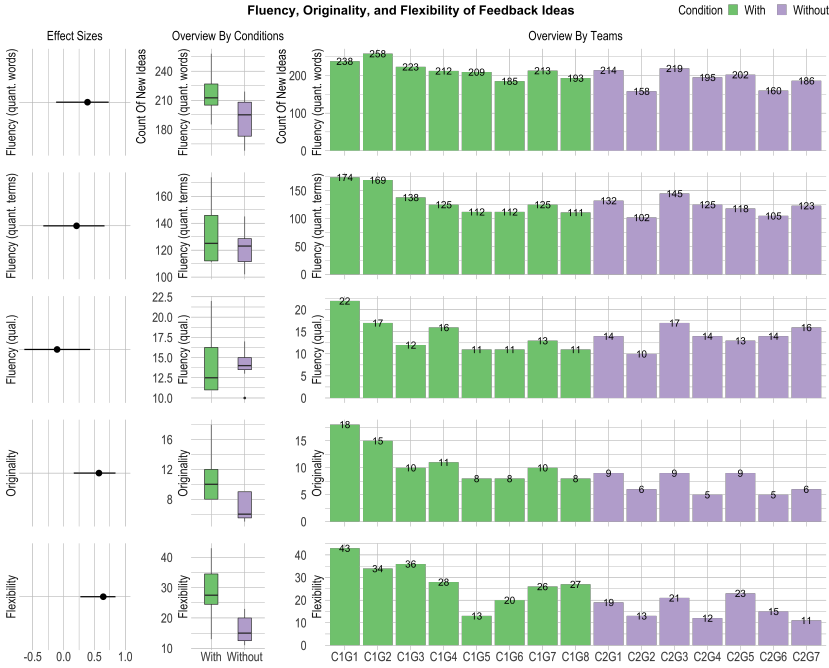


Fig. 7. A comparison between teams’ FLUENCY (quantitative and qualitative), ORIGINALITY, and FLEXIBILITY of FEEDBACK ideas in both conditions: WITHOUT and WITH PROCESS STRUCTURING. Left is the r effect size for Mann–Whitney U test. The middle boxplot compares CONDITION’s levels. The right barplot compares teams.

dependencies of the data within subjects (i.e., teams). We verified the five assumptions required to validate the good fit of a GLMM model [10].

The results showed a significant effect of Condition ($\chi^2(1) = 7.958, p = .004$) and a significant effect of FEEDBACK CATEGORY ($\chi^2(3) = 51.216, p < .001$) on number of feedback ideas. The interaction between CONDITION and FEEDBACK was significant ($\chi^2(3) = 7.717, p = .052$). We conducted post-hoc pairwise comparisons to compare the number of feedback ideas per CATEGORY in both conditions. We used Holm-Bonferroni for adjustments [39]. The results showed that PROCESS STRUCTURING yields significantly more SOCIO-AFFECT language feedback (Estimate = 1.663, SE = .589, $z = 2.822, p = .004$) and FOCUS feedback (Estimate = .537, SE = .247, $z = 2.173, p = .029$) compared to structure-free process condition. The results showed that there is no significant difference in the TARGET (Estimate = .195, SE = .249, $z = 2.173, p = .433$) and the NATURE (Estimate = .226, SE = .236, $z = .960, p = .336$) of the feedback.

As demonstrated in Figure 9, we calculated Cohen’s d, the standardized mean difference [14] by dividing estimated differences by the residual standard deviation suggested as effect size [32]. The results showed a large difference for SOCIO-AFFECT language ($d = 2.304$), a large difference for FOCUS feedback ($d = .744$), moderate difference for NATURE of feedback ($d = .314$), and small difference for TARGET ($d = .270$).

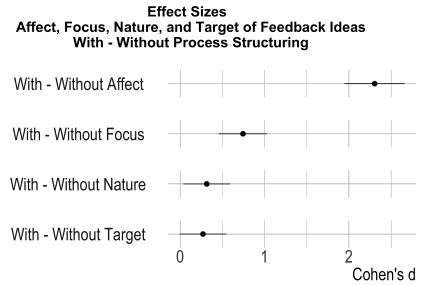


Fig. 9. Cohen’s d effect sizes of difference in FEEDBACK categories in both conditions WITH - WITHOUT PROCESS STRUCTURING.

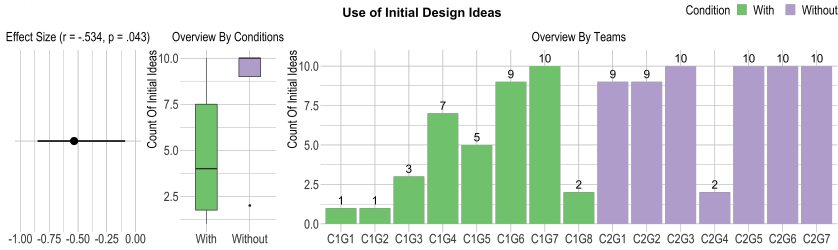


Fig. 10. A comparison between teams’ PRIMING of initial ideas in both conditions: WITHOUT and WITH PROCESS STRUCTURING. Left is r effect size for Mann–Whitney U test. The results showed a significant difference between levels of CONDITION ($p = .043$) and large effect size ($r = -.534$). The middle boxplot compares CONDITION’s levels. The right barplot compares teams.

6.4 H3: PROCESS STRUCTURING Attenuates Negative Priming, Fixation, and Social Comparison, Resulting in Productivity Gain

6.4.1 *Extrinsic Social Comparison.* We analyzed the relationship between the ORIGINALITY of FEEDBACK ideas and FLUENCY of DESIGN ideas of peers (Figure 11). As reported in section 5, participants wrote feedback reports about their peer teams’ design solutions. The results of correlation, using Pearson coefficient [14] and Holm-Bonferroni for adjustments [39], showed that the ORIGINALITY of FEEDBACK ideas was significantly correlated to the FLUENCY of DESIGN ideas with a large effect size ($r = .627, p = .012, 95\% \text{ CI of } [.169, .862]$). As demonstrated by Figure 11, the correlation was negatively moderated for the group with structure-free process and positively moderated for the group with process structuring.

6.4.2 *Negative Priming and Fixation on Familiar Ideas.* We conduct a two-way analysis to examine the main effect of the CONDITION on participants’ use of initial ideas that we provided them for stimulation in the DESIGN activity (Figure 10).

The results of Mann–Whitney U test showed that there is a significant difference in the PRIMING ($p = .043$) and a large (negative) effect size ($r = -.534, 95\% \text{ CI of } [-.855, -.093]$).

We analyzed the relationship between the PRIMING and ORIGINALITY of ideas (Figure 12). The results of correlation, using Pearson coefficient [14] and Holm-Bonferroni for adjustments [39], showed a strong negative correlation between using initial ideas (priming) and the ORIGINALITY of DESIGN ideas, with a large effect size ($r = -.625, p = .016, \text{ with } 95\% \text{ CI of } [-.867, -.141]$). The correlation is mainly due to the significant difference in using initial ideas between the participants

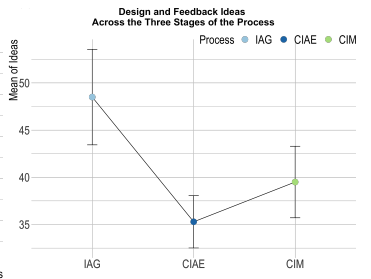
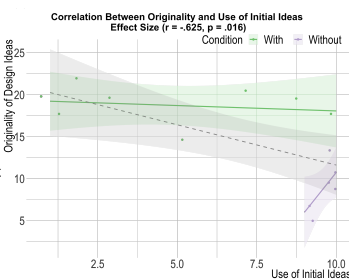
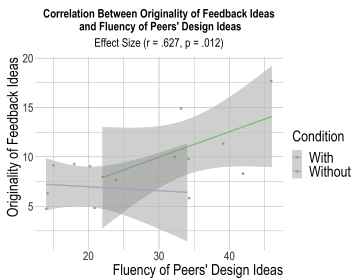


Fig. 11. Linear regression comparison between ORIGINALITY of FEEDBACK ideas and FLUENCY of peers’ design ideas.

Fig. 12. Linear regression comparison between PRIMING of initial ideas and ORIGINALITY of ideas, without C2G4 outlier (Figure 10).

Fig. 13. Comparison between participants’ ideas across the three stages of process structuring (IAG (N = 8), CIAE (N = 7), CIM (N = 8)).

in both conditions. As demonstrated by Figure 12, the originality of DESIGN ideas was not moderated by the priming of initial ideas in the WITH PROCESS STRUCTURING condition; the opposite was true for the WITHOUT PROCESS STRUCTURING condition.

We analyzed the number of ideas generated by the participants across the three stages of the process: individual idea generation (IAG), collaborative idea association and evaluation (CIAE), and collaborative idea mapping (CIM) (Figure 13). As reported in the procedure (section 5.6.3), in the CONDITION WITH PROCESS STRUCTURING, the participants used three separate Miro frames, one for each stage of the process (on the same whiteboard, see Figure 2). One team (C1G6) continued working on the Miro frame of IAG during CIAE. Four teams dropped ideas during CIAE, the number of dropped ideas was: 66% (C1G3), 49% (C1G2), 34% (C1G5), 33% (C1G4). Three teams added ideas during CIAE, the number of added ideas was: 32% (C1G8), 14% (C1G7), and 3% (C1G1).

We conducted a factorial analysis to examine the main effect of the process stages. We analyzed the number of DESIGN ideas using a Generalized Linear Mixed-effects Model (GLMM) analysis [10], with a fixed effect of PROCESS with three levels: IAG, CIAE, CIM. We used the TEAM as random effect. The results showed a main effect of the PROCESS factor ($\chi^2(2) = 14.392, p < .001$). We conducted post-hoc pairwise comparisons to compare the difference in the number of DESIGN ideas between stages. We used Holm-Bonferroni for adjustments [39]. The results showed a significant difference between IAG - CIAE (Estimate = .292, SE = .082, $z = 3.535, p = .001$), a significant difference between IAG - CIM (Estimate = .205, SE = .075, $z = 2.708, p = .013$). There was no significant difference between CIAE - CIM (Estimate = -.087, SE = .086, $z = -1.010, p = .312$). Thus, in the PROCESS STRUCTURING condition, the participants did not fixate on ideas, especially, between individual idea generation and the two subsequent processes.

6.5 H4: PROCESS STRUCTURING Does Not Tax Collaborators Cognitively and Emotionally

We conduct a nonparametric factorial analysis of variance of participants' post-hoc self-report ratings (Figure 14) using the Aligned Rank Transform (ART) [95]. The analysis was a 2x2 analysis of the Likert scores with respect to (1) CONDITION (fixed effect) with two levels (WITH and WITHOUT PROCESS STRUCTURING) and (2) POST-SURVEY CATEGORY (fixed effect) with two levels: EMOTION and COGNITIVE LOAD. We used the subject (participant) as a random effect.

The results showed no significant difference of Likert scores in the CONDITION ($F_{1,43} = 1.341, p = .253$). The results showed a significant difference of Likert scores in POST-SURVEY CATEGORY ($F_{1,227} = 44.857, p < .0001$). The interaction between the CONDITION and POST-SURVEY CATEGORY was not significant ($F_{1,227} = 0.537, p = .464$). We conducted post-hoc pairwise comparisons, using Holm-Bonferroni for adjustments [39]. The results showed no significant difference between conditions (WITH - WITHOUT PROCESS STRUCTURING) for EMOTION (Estimate = -24.2, SE = 14.3, $t = -1.694, p = .290$) and COGNITIVE LOAD (Estimate = -20.9, SE = 17.8, $t = -1.171, p = .413$).

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7 DISCUSSION

We first summarize our results on the main effects of collaborative process structuring. In light of our results, we discuss insight into the group folding effect and introduce implications and

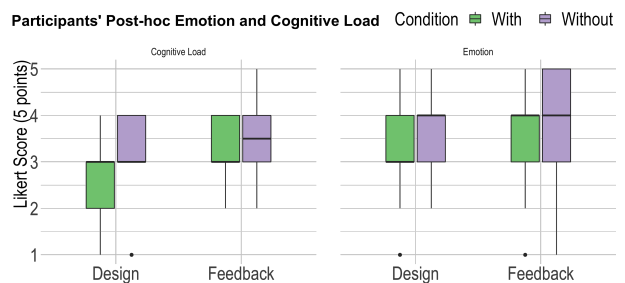


Fig. 14. A boxplot comparison between participants' post-hoc self-report of cognitive load and emotion collected after each activity.

design recommendations for collaborative tools. We then reflect on the confounding factors and limitations of the present study as well as suggestions for future work.

7.1 Effects of Collaborative Process Structuring

The results indicate that process structuring has a substantial effect on group work compared to the structure-free condition. Process structuring yields greater productivity in both design and peer feedback sub-studies. We designed both sub-studies to be generative and intellective in collaborative design problem-solving. For the design sub-study, the difference between process structuring and the structure-free condition was significant for fluency, originality, and flexibility of ideas. effect sizes were large for fluency, originality (quantitatively and quantitative), and flexibility. Such results validate the hypothesis **H1**.

We designed the feedback activity to be evaluative and goal-directed (in addition to being generative and intellective). The difference in participants' feedback fluency was not significant. As predicted, participants aimed for the number of words we asked them for in their feedback reports, constraining their fluency. Additionally, the time we provided the participants for the peer feedback activity was half of the time provided for the design activity, also constraining participants' fluency. We found that participants in the process structuring group made higher elaboration in their feedback ideas (utterances or units), resulting in longer argumentative feedback ideas than the structure-free group. The number of words and terms (stop-words excluded) was higher for the participants in the process structuring condition; however, the count of their feedback units was lower. The main difference in the originality and flexibility of feedback ideas was significant between conditions, with a large effect size. The level of focus in feedback reports (summative and formative) and the socio-affect language were significantly higher in the process structuring condition. Although the target and the nature of feedback ideas were higher (moderate and small effect sizes, respectively) in the process structuring condition compared to the structure-free one, the differences were not significant. These findings suggest that goal-directed tasks performed in shorter timeframes can hinder group work quantity (e.g., number of ideas or fluency) but not quality (e.g., originality, flexibility, level of focus, and socio-affect in feedback), which validates the hypothesis **H2**.

The results show that participants benefit from individual idea generation followed by collaborative idea association and evaluation, subsequently followed by idea mapping, compared to working on the activities in a structure-free manner. Related to our work, our results support and extend two previous studies that showed that a hybrid form of individual-to-group was productive for idea generation [6, 34].

We found that dyads were as productive as triads. There was no significant difference between both team sizes, supporting the previous finding of a more negligible difference between groups of four and dyads [64].

A promising result of our work relates to priming and fixation on initial ideas. The groups in the process structuring used less the initial ideas that we provided them for cognitive elicitation. The originality of their ideas was not moderated by the use of initial ideas in the process structuring condition, while the opposite was true in the structure-free condition. It seems like individual idea generation (first process's stage) fostered divergent thinking, preventing group members from focusing on a narrow set of familiar ideas. We recognize that fixation, sometimes, can be desirable; for example, a teacher might want learners to fixate on specific ideas. However, fixation is detrimental to brainstorming, design problem-solving, and creativity [73].

Another promising result of our work relates to social comparison. We found a negative effect of what we call *extrinsic upward comparison*. Research highlights that it can benefit individuals to compare themselves to higher-performing individuals [24, 56]. However, the social comparison

was not self-driven but induced in the peer feedback activity by our setting. Each team had both their design solution and the solution of their peer on the whiteboard when providing the feedback (see Figure 3). We found a correlation between the originality of feedback ideas and the fluency of peers' design ideas. The correlation was positively moderated in the process structuring condition and negatively moderated in the structure-free condition. One interpretation is that as the fluency of the peers' design solution increased, the participants in the structure-free condition found less or had more difficulty coming up with original ideas for their peer feedback report. Another interpretation could be that the participants in the structure-free condition were more intimidated by the fluency of their peers' design solutions, preventing them from a deeper exploration and resulting in productivity loss. While these findings support the hypothesis **H3**, more research is needed to pin down negative priming and social comparison in computer-supported group work, especially given the nuanced interactions and complexities in group work.

At first, one could argue that process structuring can yield higher productivity, but at the expense of the emotional experience and cognitive load. We found no significant difference between the participants' post-hoc self-reported emotional or cognitive load in both conditions and sub-studies. These findings validate the hypothesis **H4**.

7.2 Folding Effect in Group Work Processes

Our findings show that groups with process structuring yields greater productivity, the group without process structuring (at least) suffers process loss. Our observations combined with the post-hoc survey indicate that the participants in both conditions were equally satisfied with their performance (emotional satisfaction). They also showed equal cognitive load. However, groups in process structuring were more productive in fluency, originality, and flexibility. Such a result might point to what is known as the illusion of group productivity [74]. To a great extent, group members are blind to their productivity (e.g., blind spot effect [60]). When asked to do so retrospectively, what processes lead group members to feel confident of their performance, whether accurate or not?

One could argue that perhaps the processes were not goal-directed (e.g., producing a fixed number of ideas), in which case individuals might indeed feel appropriately happy with their performance regardless of the achievements. There might be an interplay between generative and strategic group work processes (a systematic examination of this is beyond the scope of this paper). However, it might not be practical or desirable to set a clear fixed goal (e.g., creative work, brainstorming, problem-solving). Additionally, in many domains of knowledge, the process of exploring a problem space might be as crucial as a result. Setting a goal could have an inhibitor effect on the group work, which was the case for the participants' fluency in the peer feedback activity (sub-study #2).

Another explanation could be that group members' metacognitive processes, i.e., "*thinking about thinking*" for evaluating and regulating mental processes, fall short in accurately monitoring group productivity. Limitations of our working memory can hinder metacognitive operations [51]. However, the more likely explanation is what is known as *fluency bias* [90]. At a metacognitive level, when individuals feel at ease of processing information or that information is readily accessible in their memory, they feel confident evaluating their knowledge and performance, even if inaccurate.

A third explanation is what we refer to as the folding effect: When work processes leverage contextual, social, perceptual, and cognitive processes with interferences, individuals unwittingly anchor on contextually salient and accessible information, overlooking other relevant but less accessible information. In this view, the sociocognitive interferences and convergences in group work processes can be seen as (meta)-cognitive filters that need to be reduced to a greater degree, especially in the generative processes of group work (e.g., individual idea generation) to enable a carry-over of group work productivity. Structuring group work processes can refocus individuals'

attention on sub-processes, support managing processes' time, reduce sociocognitive interferences, and reduce sociocognitive premature convergences.

7.3 Implications and Design Recommendations for Collaborative Tools

Our research has practical implications and recommendations for HCI and CSCW research that we introduce below.

7.3.1 Promote hybrid alternations of individual and group work to stimulate collaborators socio-cognitively. At a higher level of process structuring, design and feedback sub-studies support structuring scaffolds that alternate individual and group work. In our study, we manually designed different structuring scaffolds using Miro whiteboards to support such an alternation. We asked the participants to write their ideas on sheets of paper during individual work before typing their ideas for collaborative work. Our results suggest that individual work freed members from negative priming, fixation, downward comparison, production blocking, and potentially evaluation apprehension and free-riding. Collaborative work fostered group synergy, persistence, upward comparison, and convergent thinking. In addition, our results support a positive cost-benefit of such an alternation. While members might not benefit from group idea exchange during individual work, the overall productivity gain can be higher due to a carry-over and an elevation of productivity with alterations.

We recommend that designers provide flexible and customizable interfaces so that users can design scaffolds for different alternations of individual and collaborative work. Our scaffolds using Micro were adhoc because Miro does not support alternating individual and collaborative work. Tools should, as far as possible, provide ways to fine-tune alterations depending on the context and the constraints at hand. For example, collaborative tools can allow users to allocate varying time-frames for individual and collaborative work which can enable collaborators to deepen their work individually and/or collaboratively. Advanced technological scaffolds might work best if designed to strategically alternate and orchestrate individual and collaborative work, such as listening, speaking, sharing, thinking with and about each other's ideas, and producing shared ideas.

7.3.2 Promote process structuring scaffolds that prevent socio-cognitive interferences. At a sub-process level of process structuring, our results show that group members typically underperform when multiple sub-processes were induced simultaneously (e.g., evaluation apprehension, production blocking, social comparison), which was the case for both design and peer feedback sub-studies. Our results show that a shared online whiteboard did not compensate for higher-level productivity in the structure-free condition because collaborators can type ideas at will, suggesting that productivity loss in this condition is mainly due to socio-cognitive processes' interference. Once a member in the structure-free group generated an idea, reactions from other members occurred. Individuals needed to listen, speak, and think of a narrow set of ideas, making it harder to explore the problem deeply and resulting in sub-optimal productivity. While listening and waiting to interact, individuals might reevaluate or even forget their ideas, resulting in productivity loss [23]. On the other hand, structuring group work in a way to generate ideas at will (individually), then collectively evaluating and associating ideas, and finally mapping the collective outcome, makes it straightforward for collaborators to tape into less accessible ideas. Our results showed that this process structuring yielded higher group productivity without taxing collaborators emotionally or cognitively.

We recommend that designers place careful consideration of the contextual, social, perceptual, and cognitive processes' interference in the design and use of collaborative tools. Designing collaborative tools (e.g., brainstorming whiteboards, writing interfaces) that separate and sequence

group work processes in a manner to prevent interferences will reduce the inhibitory effects of the group work and positively stimulate collaborators.

7.3.3 Promote process structuring scaffolds that prevent premature socio-cognitive convergences. Group work dynamics can lead members toward premature sociocognitive convergences, consensus, and conformity, resulting in focusing (and fixating) on a narrow set of ideas. Consistent with research into problem-solving and decision-making, our results show that individuals in the structure-free condition anchored their contributions to the group based on information that readily comes to mind, essentially resulting in productivity loss. From one perspective, because of resource rational bias and given the time and difficulty of identifying and processing additional useful information, individuals tend to consider good enough (sub-optimal) productions [8]. From another perspective, research has found that individuals typically underestimate and overestimate how many ideas they will produce before exhausting a problem's solution space, leaving their best ideas undiscovered because of converging too early [50]. Relevant ideas or solutions occur with persistence and deeper exploration. However, deeper exploration might not be readily accessible to collaborators. Interestingly, our study shows that process structuring provides a sharp strategy to support persistence and deeper exploration. Generating more alternatives (e.g., fluency) resulted in a deeper exploration (e.g., originality and flexibility). Individual idea generation positively moderates the divergent thinking of the group, enabling members to take unique perspectives. A lack of divergent thinking might explain why participants in the structure-free condition converged on initial ideas. Individuals tend to generate ideas within conceptual categories until they exhaust accessible ideas. Then, they shift to other conceptual categories if stimulated; otherwise, they anchor prematurely on what is contextually salient.

We recommend that designers provide process structuring scaffolds to support deeper explorations of alternatives and less-accessible ideas in collaborative tools. Tools can guide users to shift their thinking to explore different conceptual categories of a subject [e.g., 86]. Tools can incrementally help users explore alternatives and prevent them from converging too early on good enough (sub-optimal) productions. For example, in the process structuring condition, on average, collaborators generated a larger number of ideas during the first stage (IAG). Then, they dropped a significant number of ideas in the evaluation and association stage. And, they added a few more ideas in the mapping stage. Although collaborators dropped a significant number of ideas when comparing the first stage and third stages of the process, their productivity was still significantly higher than in the structure-free condition. Thus, tools can foster users' persistence to exhaust solution space by alternating different strategies of thinking, e.g., generating ideas, associating ideas, evaluating ideas, and mapping ideas. On the same note, we recommend that designers provide scaffolds that, at the same time, support divergent [71] but also convergent thinking [20] (possibly, according to users' contextual constraints of time and resources).

7.3.4 Promote externalization scaffolds to map out and manage collaborative outcomes. Collaborative work requires complex perceptual and cognitive resources and processes, including attention, memory, and metacognition. Collaborators need to attend and build on each other's ideas. They need to identify and activate potentially helpful information from all available information. And, they need to monitor internal (e.g., thinking, behaviors) and external (e.g., group interaction) processes to self-direct their contributions to the group. Engaging in such complex processes can be overwhelming for individuals during group work because of our perceptual and cognitive limitations. In addition to the sociocognitive biases that group members face (discussed above), we perceive a small visual field from one fixation to another, and we only hold a few items in the working memory [51]. Our findings suggest that the number of ideas generated by the participants in the process structuring condition would have been difficult to process without the support of

shared mapping of group work. The use of a collaborative whiteboard created a shared repository of ideas that individuals can access and manage with relative cognitive ease [78]. However, this was useful to a great extent when individuals already generated various ideas before group work. Individuals in the structure-free condition focused significantly on a narrow set of initial ideas. Although the whiteboard might have supported collaborators by eliminating the need for an internal representation of their ongoing group work, it might also have had an inhibitory effect on individuals' productivity in the structure-free condition. A shared whiteboard made information contextually salient to the group, possibly at two expenses. It might have increased individuals' focus on contextually salient information. Consequently, it might have increased the likelihood of failing in retrieving additional ideas that were not evoked by the context [89]. Our results show a moderating effect of initial ideas that we provided participants for stimulation. Participants in the structure-free condition fixated more significantly on initial ideas than in the process structuring condition. It is traditionally well-known in human-computer interaction research that contextual awareness cues are crucial for collaborative work to stimulate information sharing and coordination. However, the inhibitory effect of such information on group work is not examined extensively.

We recommend that designers provide scaffolds to map out and manage collaborative outcomes. Such scaffolds can direct collaborators' attention to essential information (e.g., create focal points), augment memory (e.g., facilitate cognitive offloading), and organize actions (e.g., support cognitive scaffolding). Further, externalization scaffolds can capture group outcomes and create a visual artifact that supports further information processing and sharing, joint coordination, and negotiation of ideas. We also recommend that designers bear in mind that shared external representations of group work will make information salient to the collaborators, potentially resulting in a fixation on contextually salient ideas.

7.4 Confounding Factors

While it is difficult, and in some cases impossible, to control for all confounding variables, especially in field studies, we were careful in controlling the most critical variables. We were aware that having different activities (tasks) in both conditions (treatment and control) would potentially confound the results. However, having the same activity was not adequate in our settings (in-the-wild) because it can result in confounding results in case participants between conditions shared their productions. Instead, we proceed with a two-fold approach to control for the tasks' differences. First, we designed two identical DESIGN activities, but with two slightly different problem statements. We made sure that both activities have the same scenario and level of difficulty. We changed five generic utterances in the statements (see section 5.4.1). Four initial ideas were common in both subjects and the five remaining ideas were relatively related conceptually. In addition, we designed the post-survey to capture the emotional experience and cognitive load, which did not reveal any significant difference between the participant post-hoc self-report (see results 6.5), suggesting that the activities were at the same level from an instructional perspective. Second, we designed the FEEDBACK activity to gather further empirical data about the effectiveness and generalizability of process structuring. Combining results of DESIGN and FEEDBACK activities suggest that the difference in the results is not due to differences in the tasks but most certainly the treatment (process structuring).

Another potential confounding variable could be that the participants between conditions shared or talked about the content of the activities. This could have happened in sub-study #1 and sub-study #2. We controlled this in two ways. As reported in the procedure (section 5.6), we kept the participants unaware of the conditions of the study — we only disclosed the activity and the set up for each group by the start of the activity. In addition, for both studies, we started with the control group. The participants of the follow-up condition, certainly, were unaware of the treatment. Second, because we used two slightly different problem statements in the DESIGN activity, in our

view, even if the participants shared or talked about the content, this will not have a significant impact on the study, mainly because the activity is generative and intellectual and requires the participants to mentally think in the context of the problem statement. Furthermore, our statistical analysis showed marginal correlation effect sizes of stem words of DESIGN ideas between groups (see results 6.2.1). Similarly, the FEEDBACK sub-study is evaluative in addition to being generative and intellectual and requires the participants to provide feedback on a design solution of their peers within the group of which the subject is different from the other group.

We conducted the FEEDBACK activity four weeks after the DESIGN activity mainly for better integration with the timetable of the course. In addition, we did not vary the tasks within each condition to avoid confounding the results. Comparing eight or seven different tasks (i.e., the number of groups within each condition) empirically would likely involve a mix of confounding variables — it would have been challenging to accurately distill any differences in the results. Another potential confounding factor could be that the participants in the treatment condition showed higher productivity because they were asked to collaborate in three blocks (time segments). The participants in the control condition worked in one block. We think that this is unlikely because both groups were given the same amount of time in the study and participants in the two conditions completed the tasks at about the same time.

7.5 Limitations and Future Work

The present study successfully showed effects and synergies between social, perceptual, and cognitive processes involved in group work productivity. However, one could ask whether productivity has occurred and which factors or stages yielded what effects. Addressing these two questions precisely is not determined from this study because of the lack of control groups. It is possible (most likely) that both groups suffered productivity loss. The current study results showed only a productivity gain of process structuring compared to a structure-free condition. A complete design would consider at least three more control groups, a group of individuals working alone, another of individuals collaborating without a shared whiteboard, and more importantly, a group of individuals collaborating in a sequence of three-time segments to match the three stages of the process structuring condition. Such control groups will provide valuable empirical data to conclude the effect of each aspect of the current study on group work. Future studies can collect participants' interactions with the whiteboards to trace individuals' contributions across the different stages of the process. A main limitation of our work is gender diversity, which is known to have a significant impact on group work [7]. Unfortunately, this was a contextual constrain of our setting —only two women participated in our study. Our findings are, therefore, limited to groups of men. Future studies can complete our results by examining the interplay between gender diversity and process structuring. Our findings focused on group productivity (i.e., performance). Such findings can be useful for future studies on group work strategies. Similarly, our study can inform future research to close the loop on peer feedback and examine its receptivity in group work. In the individual idea generation stage, we asked each participant to generate ideas on a sheet of paper first before typing them on the whiteboard for the subsequent stages. We did so to prevent participants from exploring each other ideas in the first stage. At the time of the study, there was no effective way to hide collaborators' content from one another on a shared Miro board. Participants in the structure-free condition used the shared whiteboard directly; they did not generate ideas on a sheet of paper. Future studies could use a whiteboard with more control parameters to control the used techniques. Will current findings transfer to other design problems, activities, and contextual settings are yet to be examined.

8 CONCLUSION

Collaborating to achieve otherwise unattainable objectives is a unique attribute of human success and intelligence. Thousands of people around the globe are spending their lives in groups collaborating on shared activities, for life and work, and on activities that can hardly be advanced by individuals working alone. Their collaborations and interactions rely on productive idea exchange, which involves complex contextual, social, perceptual, and cognitive processes and interferences. Research into how group work processes interact with one another and what effects on group work productivity are involved is limited in number and consensus.

We built upon previous research and articulated a process to support group work productivity in a comprehensive collaborative design problem-solving: individual idea generation, collaborative idea association and evaluation, and collaborative idea mapping. We conducted a field study with 40 participants ($N = 40$). We examined how processes structuring shaped group work productivity, using two groups and two design-related sub-studies: conception of a design and peer feedback on design solutions. The results showed that process structuring yielded greater productivity in both design (generative and intellectual) and peer feedback (evaluative and goal-directed) sub-studies in terms of quantity and quality of ideas. Our findings indicated that process structuring attenuated inhibitory effects of group work, namely negative priming, fixation on familiar ideas, and social comparison. In sum, our work has shown effects and synergies between social, perceptual, and cognitive processes involved in group work productivity. Careful consideration of processes' interferences in group work can catalyze productivity. In light of our results and previous research, we discussed implications to support productive group work processes in collaborative tools and insights into a pattern of the group folding effect that might provide a conceptual umbrella for process loss in group work. We hope our work provides a new perspective and knowledge platform for future group work research. We hope our research helps spark new ideas to support group work productivity.

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A DESIGN ACTIVITY

The groups, in the condition WITH PROCESS STRUCTURING, received bullet points highlighting why structuring their work in three steps might be necessary. The additionally provided information was:

To optimize teamwork, you have decided to do the work in three steps:

1) First, in individual mode, each team member brainstorms on their own to generate concepts and ideas around the product “Hybrid meeting room.” This first individual work is important because:

- it gives freedom to each team member to explore their ideas around the subject
- it prevents each member from being influenced by the ideas of others
- it pushes each member to contribute/participate in the team’s work
- helps the team explore a variety of ideas from all members

2) Second, in collaborative mode: although the first individual work helps to explore diverse ideas, the individual ideas will be “heterogeneous.” The members must discuss their ideas to develop a coherent solution collectively. This involves team members discussing their ideas to combine, evaluate and refine them:

- it helps members make associations (e.g., connections, links) between their ideas
- helps members to appreciate, analyze, compare, and contrast their ideas
- it helps members negotiate and transform their heterogeneous ideas to converge on a coherent solution
- it helps members to develop their initial ideas, combine similar ideas, reject less promising ideas, and leave only the most interesting ones

3) Finally, in collaborative mode: group work requires creating a representation that effectively communicates the team's outcome. This implies that the team members must work collectively to create a visuospatial representation of their solution. A visuospatial representation is essential because:

- it communicates the result (content, structure, relationships) of a collective work using a visuospatial language
- it creates a coherent and cohesive solution
- it creates a representation that shows both the big picture and the important details of the solution

B SCENARIO FEEDBACK ACTIVITY

Motivation: Feedback is giving information to someone to help them improve some aspects of their life or work. Feedback is beneficial to individuals receiving it and the ones giving it. Feedback helps sharpen our knowledge, outcomes, and inter/intrapersonal (e.g., behaviors, processes). Feedback is a reflective experience: by giving feedback to others, we implicitly reflect on our work.

Peer Feedback is mutual feedback provided by a student or a group of students to improve on aspects of learning.

Your mission: In your last collaborative activity, you worked in teams and created unique representations of a conception of a design.

Today, and in the same teams, your mission consists of providing feedback to the team members to help them improve their design.

You will get a solution's representation of a team. Then, you will collaboratively:

- reflect on and discuss your peer's group-work result, and
- write a feedback report to your peers on:
 - (a) how do you see their work and
 - (b) how they can change their solution to improve it, i.e., make it better, unique, meaningful, creative, etc. The limit is your imagination and the time :)

The feedback report must contain at least 200 words. You can use an online tool to calculate the number of words (e.g., <http://compteur-de-mots.net/>).

You can use the template below to help you structure your feedback reports [see appendix C].

Write concrete and concise ideas in your feedback reports.

C TEMPLATE FEEDBACK ACTIVITY

We provided the template below to the groups in both conditions to help structure their feedback reports.

You can use this template for your feedback reports. The template has three sections: 1) introduction, 2) body, and 3) conclusion, thoughts and perspectives.

(1) Introduction

- What is your overall feeling about the work of your peers?
- How do you see their work?

(2) Body

- Describe concisely your feedback ideas concerning the content (the elements of the solutions), structure (how the elements are organized), and relationships (how the elements are associated with each other).

- How do you think your peers could change their solution to improve it, i.e., make it better, unique, meaningful, creative, organized, complete, etc. The only limit is your imagination :)

(3) Conclusion, reflections, and perspectives This part of the report may include your conclusions or reflections on:

- Collaborative work and peer feedback; namely, you can highlight your thoughts and perspectives on the dynamics of group work from your own experience (e.g., social, emotional, inter/intra-personal aspects).
- Your ideas to improve your own visuospatial representation. When working on the feedback for your peers, you will come across ideas for your own design solution, which is quite normal. Remember that the feedback activity is a reflective experience. Include such ideas for improvement in this part of your report.

D PRE SURVEY

D.1 Visuospatial Literacy

- I'm comfortable with visual tools, such as Powerpoint, Google Slides, Illustrator, Photoshop, etc.
- Usually, I use visual representations, such as visual note-taking, diagramming, etc.
- How do you rate your visual skills in terms of interpreting, understanding, producing, and appreciating the meanings of visual representations?
- I have prior knowledge in modeling; for example, from a previous course, internet, a book, etc.

D.2 Collaboration

- Group work is often productive compared to individual work
- I feel pretty productive when I work in a group
- I feel pretty productive when I work alone
- I find it challenging to share my ideas in groups

D.3 Creativity

- I like to express ideas that others do not think of
- I like to choose my own way to demonstrate my understanding
- I dare to ask questions that may seem off-topic or silly
- I enjoy open-ended tasks; for example, tasks without a strict procedure to follow
- I prefer to discuss ideas rather than facts
- I prefer new ways of approaching a problem rather than accepted ways

D.4 Feedback

- I like to give feedback to others, such as group work members, friends, colleagues, etc.
- I like to receive feedback from others, such as group work members, friends, colleagues, etc.

E POST SURVEY

E.1 Design Activity

- How difficult was this session for you?
- How appealing was this session for you?
- Do you want to have more sessions like this?

E.2 Feedback Activity

- How would you rate the effort you exerted in this session?
- Giving good feedback is important to me
- I would like to see a new design iteration of my colleagues based on my feedback
- This activity helped me get better at giving/writing feedback

F DESIGN SOLUTIONS

Figure 15 and Figure 16 present the design solutions of the groups in both conditions.

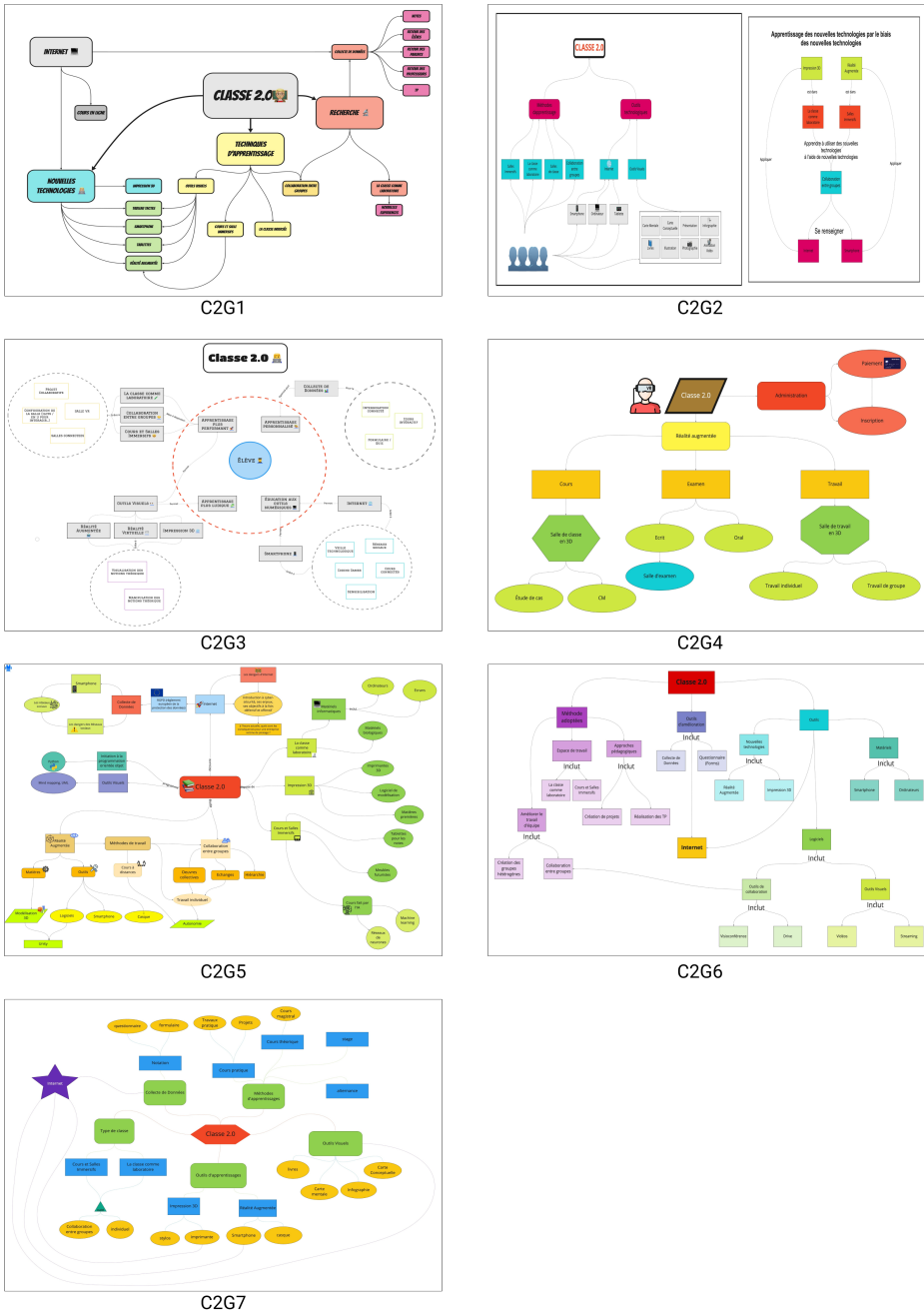


Fig. 15. Design solutions of the groups in the condition WITHOUT PROCESS STRUCTURING

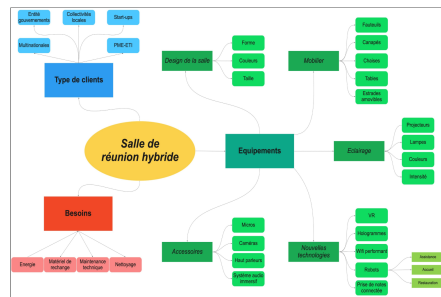
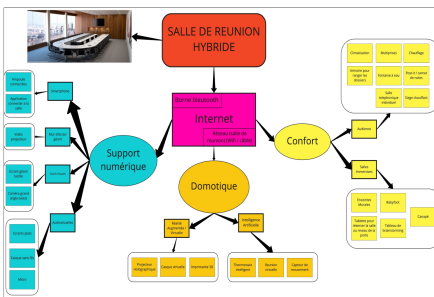
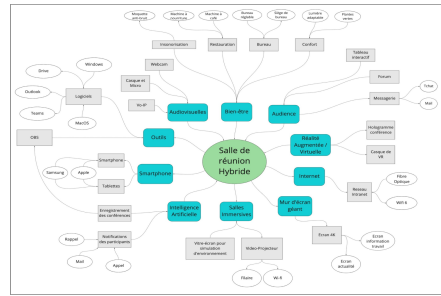
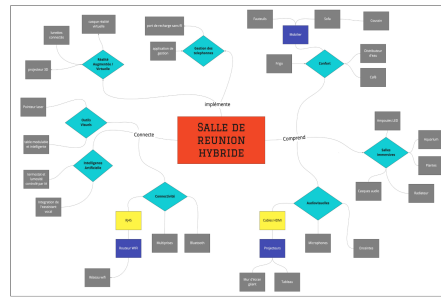
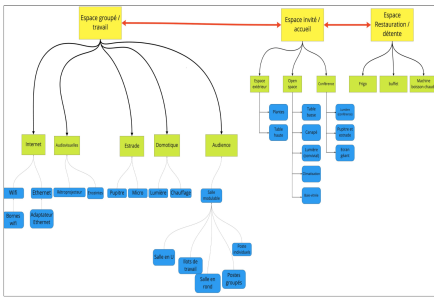
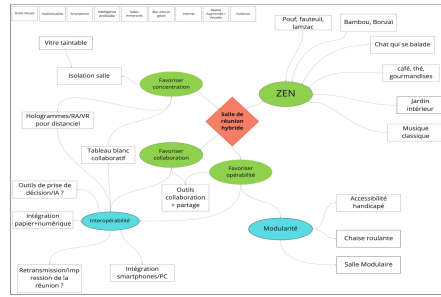
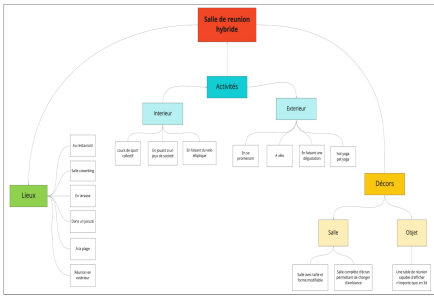


Fig. 16. Design solutions of the groups in the condition WITH PROCESS STRUCTURING