# Creating Shared Mental Models: The Support of Visual Language

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**Abstract.** Cooperative design involves multiple stakeholders that often hold different ideas of the problem, the ways to solve it, and to its solutions (i.e., mental models; MM). These differences can result in miscommunication, misunderstanding, slower decision making processes, and less chance on cooperative decisions. In order to facilitate the creation of a shared mental model (sMM), visual languages (VL) are often used. However, little scientific foundation is behind this choice. To determine whether or not this gut feeling is justified, a research was conducted in which various stakeholders had to cooperatively redesign a process chain, with and without VL. To determine whether or not a sMM was created, scores on agreement in individual MM, communication, and cooperation were analyzed. The results confirmed the assumption that VL can indeed play an important role in the creation of sMM and, hence, can aid the processes of cooperative design and engineering.

**Keywords:** visual language, cooperative visualization, cooperative decision making, shared mental model, multiple users.

## 1 Introduction

When involved in cooperative design, multiple stakeholders might hold different mental models (i.e., ideas and views; MM) of the problem at hand, the ways to solve it, and to its solutions. These different MM might stem from different worldviews, cultures, backgrounds, interests, and paradigms [1]. Initially, these different views are probably part of the reason to bring together these multiple stakeholders. However, different MM might cause problems in communication [2] and cooperation [3] and might result in a disappointing team performance.

Visual language (VL) is thought to support the creation of a (shared) MM. As such, VL can aid problems experienced with cooperative design. This research strives to discover whether or not VL supports the generation of shared MM (sMM) in cooperative design. Because of the complexity of the concepts MM and VL a brief explanation is followed next.

Different definitions of MM are used in different fields of research: e.g., [2,4,5]. From these definitions, we have inferred the following: a MM is the mental representation

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of (some aspects of) the dynamics of the external world, such as problems, tasks, actions, and products. In line with this definition, we define sMM as the overlap in both understanding and consensus of individual MM.

sMM can aid cooperative decision making and cooperative engineering through facilitating cooperation [3], anticipation [5], and prediction [5] of team members' behavior. Moreover, sMM are thought to support decision-making by having a positive effect on team processes and team performance [3]. sMM also affect the speed, flexibility, and implementation of a decision [5]. Last, sMM can support positive affect and trust [5]. Hence, sMM play a crucial role in cooperative design.

Par excellence, cooperative design processes could benefit from the advantages of using sMM. A sMM can be created through either experience [6], communication, or their combination [5]. This research focuses on communication; in particular, visual communication through visual language (VL). VL are said to aid the creation of sMM in cooperative design. However, most of these claims stem from experience and gut feeling of people, instead of scientific research.

VL is thought to support communication steps involved in creating a sMM; among other things, this should involve:

- explaining individual MM in order to establish meaning [2],
- initiating negotiations of meaning [7],
- persuading [8] in order to negotiate, and
- promoting group consensus [8].

In addition, the use of VL provides the following advantages:

- support efficient work and (faster) decision making [8,9],
- help to see the big picture, making things easier to understand [9],
- support collaboration between multiple users with different backgrounds and multiple points of view [10], and
- enable cooperative visualization of problems which is particularly of interest when having various stakeholders communicating.

In different fields of research, different definitions of VL exist, e.g., [11,12]. We use the definition of Robert Horn, who defines VL as tightly integrated communication units that are composed of words, images, and shapes [10]. Examples of VL are icons, resemblances, quantitative charts and graphs, tables, cartoons, diagrams, and blocks of texts [10]. In this research, cooperative visualization is used as VL; e.g., mind mapping on a large screen, visible to all the stakeholders, digital drawings on a large screen, and sharing individually made drawings or diagrams on another large screen, see also Fig. 1.

The claims made concerning VL clearly mark its benefits, in particular when creating a SMM. In line with this, we hypothesize that VL will indeed support the creation of sMM. In the next section (Section 2), we will denote how we operationalized our main research question: Do VL support the creation of a sMM?. Next, the results on the case study are presented (Section 3). We end with the interpretation of the results and conclusions, in Section 4.

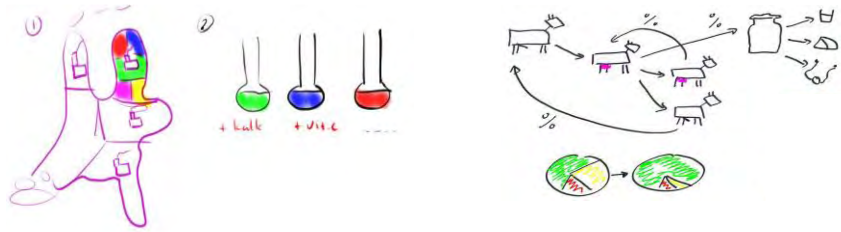

**Fig. 1.** Visualizations made by stakeholders on tablet PCs and, subsequently, shared, using a large screen. A capturer organized discussions, which resulted in mind maps including these visualizations. The left image depicts an idea that involves milk with different qualities (e.g., with extra calcium or vitamin c) produced in different parts of the Netherlands. The right image depicts a breeding program to produce milk that can be used for different dairy products.

## 2 Research

To determine whether or not VL can support the creation of a sMM, case studies were conducted both with and without (i.e., solely words) the use of VL. However, the determination of sMM is difficult since this concept is hard to operationalize. To tackle this problem, the paradigm of triangulation is adopted [13]; i.e., the use of multiple information sources, multiple analyses, or both to assess a concept.

Several ways of measuring sMM have been proposed, among which the amount of agreement among participating stakeholders and the efficiency of the team process in terms of communication and cooperation, e.g., [3]. Consequently, is hypothesized that VL will account for:

H1. More agreement in MM, assessed through questions on:
   a. the content of the task and
   b. expectations based on the MM that can be used to assess a sMM [14];

H2. Better communication through sMM, whose generation is facilitated by VL.

H3. Better cooperation through sMM, whose generation is facilitated by VL.

To assess the three hypotheses, a case study was conducted in which twelve participants were asked to cooperatively redesign the Dutch milk chain; i.e., how the milk gets from cow to consumer. The participants were asked to prepare stakeholders' roles; e.g., the farmer, breeder, and dairy processor. The case comprised a full-day session in a virtual reality (VR) laboratory; see also Fig. 2. This VR laboratory was designed to facilitate cooperative design processes for complex problems.

**Fig. 2.** The virtual reality (VR) laboratory in which the case studies were conducted. The twelve stakeholders were divided over two gaming tables (left and right of the center).

During the full-day session the stakeholders were asked to perform two tasks:

Task 1: Identification of the problem, defining the current milk chain, and thinking of some directions for solutions; see also Fig. 3. This task was executed in the morning.

Task 2: Definition of the future milk chain for one of the chosen solutions, its implications, and the things/changes/actions necessary to realize that future milk chain. This task was executed in the afternoon.

For Task 1, a group of six stakeholders was instructed to use VL; i.e., using/creating drawings, pictures, diagrams mind maps, or any other kind of visualization (i.e., Group B). The other six stakeholders were instructed to use no VL; i.e., only spoken words and typed words (e.g., no visual arrangement was allowed) (i.e., Group A). In the afternoon, the groups changed from VL to no VL or the other way around.

On both tasks, using Likert(-type) scaled questions, the following aspects were determined:

- perceived agreement in content; i.e., what has been discussed during the task,
- perceived agreement in expectations that could be drawn from the content,
- communication, for which a questionnaire was adapted from Eby, Meade, Parisi, and Douthitt [15], and
- cooperation, for which a questionnaire was adapted from Pinto and Pinto [16].

Two moderators and two capturers facilitated the session. Together, they will be denoted as raters. In addition to the stakeholders, the raters were also asked to fill in the questionnaires on communication and cooperation. This provided a set of unbiased scores on the issues communication and cooperation.

We used Mulder's [17] self-scoring method to determine the (perceived) agreement in MM concerning content and expectation. The participants wrote answers on questions on content and expectation. All answers were collected and one randomly selected answer (of one question) was read aloud to the team. All team members indicated, on a Likert-type scale, the extent to which the description read aloud corresponded with their written answer and with their perception of what the answer should be. In this test, the answers of three participants per question, instead of one, were read aloud to judge correspondence.


**Fig. 3.** This cartoon depicts one of the ideas generated in the visual language setting (a spectator of the experiment made this cartoon based upon the brainstorm of the participants). It describes an energy efficient solution in which the cow drives a meat processing machine.

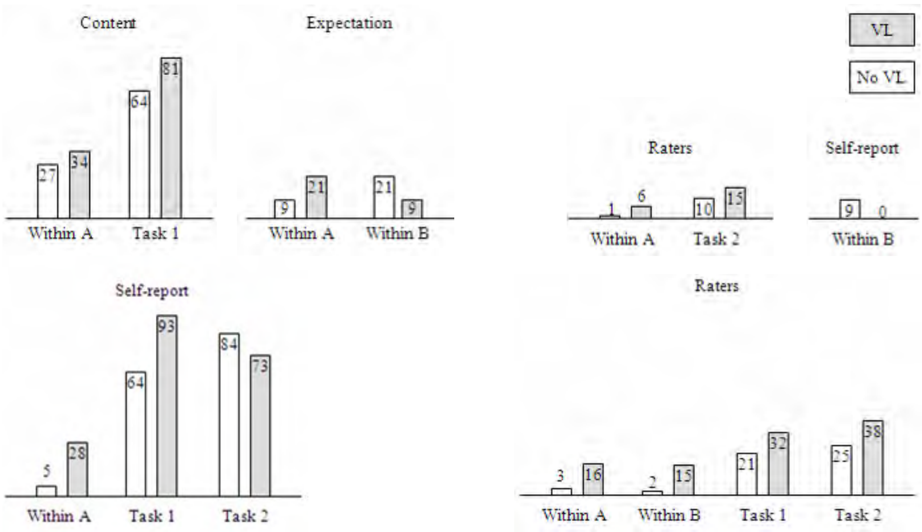


**Fig. 4.** The results on the first hypothesis (more agreement) are the two graphs at the top left: content and expectation. The results on the second hypothesis (communication) are divided in self-report results and rater results, presented at the top right. The results on the third hypothesis (cooperation) are presented at the bottom. Only significant differences are presented.

## 3 Results

The Likert(-type) scale answers were analyzed both between groups (Mann-Whitney tests) and within groups; i.e., between both tasks (Wilcoxon Signed Ranks tests). First, the results on agreement on content and expectation will be described. Second, the results of team processes (i.e., communication and cooperation) will be presented. With these analyses, T- indicates the amount of negative scores of Task 2 compared to Task 1, T+ indicates the amount of positive scores of Task 2 compared to Task 1. N stands for the total amount of comparisons (between scores of Task 1 and 2) and the tie-scores between the two tasks (not reported here) are n minus T- minus T+. The reported means are the means of the scores ranked from low to high (mean ranks).

H1. A significant difference in favor of VL was found in the results on the content of the sMM within Group A (T- = 27, T+ = 34, n = 72, p = .041), while no difference was found within Group B (p = .288); see also Fig. 4. A significant difference in favor of the VL setting was found between the groups for Task 1 (Mean A = 63.88, Mean B = 81.13, n = 144, p = .006). For Task 2, no difference was found between the groups (p = .429). For agreement in expectation, a significant difference was found within Group A in favor of VL (T- = 9, T+ = 21, n = 36, p = .011). Within Group B, the no VL setting scored better (T- = 9, T+ = 21, n = 36, p = .010). Between the groups no difference was found (Task 1: p = .146; Task 2: p = .436).

**Table 1.** An overview of the results per hypothesis with 95% reliability (α = .05). The results on both agreement and cooperation support the added value of visual language (VL), whereas the results on communication are ambiguous. Note: Hx denotes hypothesis x.

| | agreement in mental models (MM) (H1) | | communication (H2) | | cooperation (H3) | |
|---|---|---|---|---|---|---|
| | content | expectation | self-reports | raters | self-reports | raters |
| Task 1 | VL | | | | VL | VL |
| Task 2 | | | | VL | No VL | VL |
| Within Group A | VL | VL | | VL | VL | VL |
| Within Group B | | No VL | No VL | | | VL |

H2. From the self-reports within Group B, a significant difference in favor of the no VL setting was found on communication (T- = 0, T+ = 9, n = 30, p = .003), see also Fig. 4. However, the raters (see Section 2) judged in favor of the VL setting within Group A (T- = 1, T+ = 6, n = 10, p = .062) and between the groups for Task 2 (Mean A = 15.13, Mean B = 9.80, n = 25, p = .034). In addition, no difference was found from the self-report results within Group A (p = .143) and between the groups for the two tasks (p = .292 and p = .306) and from the raters results within Group B (p = .190) and between the groups for Task 1 (p = .439).

H3. A significant higher score on cooperation was found in the VL setting from the self-report results within Group A (T- = 5, T+ = 28, n = 78, p < .001) and between the groups for Task 1 (Mean A = 63.62, Mean B = 93.38, n = 156, p < .001); see also Fig. 4. A significant difference between the groups was found, from the self-report results, in favor of the no VL setting for Task 2 (Mean A = 72.83, Mean B = 84.17, n = 156, p = .030). The results of the raters showed a significant higher score in the VL setting: within both Group A (T- = 3, T+ = 16, n = 26, p = .003) and Group B (T- = 15, T+ = 2, n = 26, p = .001) and between the groups for both Task 1 (Mean A = 20.81, Mean B = 32.19, n = 52, p = .003) and Task 2 (Mean A = 38.45, Mean B = 24.83, n = 65, p = .001). In addition, the self-report results showed no difference within Group B (p = .426).

The hypothesis that VL will account for more agreement in MM is partly supported by the results. The results on the content support the hypothesis while the results on expectation are less supportive. The results on communication do not support the hypothesis that VL supports the creation of a sMM. The results on cooperation, however, do support this hypothesis. For an overview of these results, see Table 1.

## 4 Discussion and Conclusion

This research presents a scientific foundation for the idea that VL supports creating a sMM. Various stakeholders participated in a full-day session in which they executed a task with and without VL. The results on agreement of individual MM indicate that VL supports creating a sMM (H1). A time or task effect might have occurred in the results on agreement in expectation because the scores were higher in the afternoon (in both settings). Although little is known about the effect of time on sMM [18], it is noted that common experience or team familiarity can lead to more common and/or compatible MM over time [19]. This might explain the higher scores in the afternoon. The higher scores on expectation might also be explained by group difference. Personal preference can be involved here [20]. We have tried to minimize the effects of group differences by asking the participants to fill in questionnaires on personality, communication competence, skills/experience, and team characteristics. No significant differences were found between the groups on these items. The participants were not used to work with each other and had different backgrounds. They were asked to prepare their roles by reading and searching for information. In normal decision-making settings the stakeholders often have different backgrounds and knowledge. Still, it might have been possible that group effects occurred.

The results of the team processes are denoted as issues on both communication and cooperation. The results of communication were ambiguous and did not show a more efficient team process because of VL (H2). The results on cooperation of both the self-reports and the raters strongly support the idea of a more efficient team process because of VL, which indicates a sMM at work (H3). It appeared that Group B outperformed Group A on both tasks (ergo, both settings). In addition, no significant difference was found within Group B. This can be due to the fact that Group B was cooperating well from the start and could not improve much more.

Some remarks can be made on the case used. First, measuring a sMM is difficult because it is mental. In addition, the questions asked on content and expectation were not validated. Triangulation to measure a sMM has already been applied but could be extended further; e.g., using physiological measurements, inter-subject correlation, and by participants indicating after each utterance, whether or not, they understood it.

Taken the results all together, sMM are shown to be beneficial in supporting cooperation [3], prediction [5], and positive affect towards the team [5]. sMM also account for speed, flexibility, and implementation of a decision [5] and for team performance. In addition, the stakeholders preferred VL over no VL. This all emphasizes that VL can indeed be a valuable tool for cooperative (re)design. Even its most simple implementations (i.e., pencil and paper) or tablet pc's can aid the process of cooperative design and engineering.

Visualization to support cooperative design and decision-making processes is already widely used. However, so far, the underlying assumption did have little or no scientific ground. It explained the benefits of VL through the concept of sMM. Although many issues remain a topic of investigation, this research can be considered as a first step toward a scientific foundation for the use of VL for cooperative design and decision-making.

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