Sunnen, P.; Arend, B.; Heuser, S.; Afkari, H.; Maquil, V. (2019): Designing Collaborative Scenarios on Tangible Tabletop Interfaces – Insights from the Implementation of Paper Prototypes in the Context of a Multidisciplinary Design Workshop. In: Proceedings of the 17th European Conference on Computer-Supported Cooperative Work: The International Venue on Practice-centred Computing and the Design of Cooperation Technologies - Exploratory Papers, Reports of the European Society for Socially Embedded Technologies (ISSN 2510-2591), DOI: 10.18420/ecscw2019_ep13

Designing collaborative scenarios on tangible tabletop interfaces - insights from the implementation of paper prototypes in the context of a multidisciplinary design workshop

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Abstract. Within the context of the research project ORBIT (Overcoming Breakdowns in Teams with Interactive Tabletops), we design and study a joint problem-solving activity at an interactive tabletop, that gives participants the opportunity to develop their collaboration methods. To gain design insights for the development of a scenario soliciting participants to collaborate, we set up a multidisciplinary design workshop. During the latter, we explored and discussed three different collaborative scenarios, implemented as paper prototypes. In this paper, we report on first results gained from an exploratory analysis of the video data that was recorded in the context of this workshop.

Introduction

Shared interfaces such as multi-touch tables and tangible tabletop interfaces were repeatedly found to mediate and support collaboration. Ioannou and Antoniou (2016) summarize that tabletops enhance the sense of teamwork, sollicit interaction and willingness to participate in group tasks, increase equity in physical interaction and facilitate joint attention on the task. These benefits are largely due to the big shared screen and the possibility for direct and simultaneous interaction by multiple users (Mercier and Higgins, 2014). When participants' attention is drawn to the tabletop, they can see each other's actions as well as the system's feedback, potentially changing the nature of the collaboration (Price, 2013). So, explicit awareness of other's (hand) actions can facilitate explorative conduct and increase collaborative forms of construction and interpretation (ibid.).

While multi-touch tabletop interfaces are operated using finger touches, tangible tabletop interfaces (TTI) additionally make use of physical objects that can be placed, moved or rotated in order to interact with the system. Due to their physical nature, a TTI can be conveniently embedded in a real physical space and situated in a social setting (Fernaeus et al., 2008). In particular, the physical objects support participants in partitioning and coordinating their activities (Scott and Carpendale, 2004), and facilitate individual ownership and announcement of tool use as support for group awareness (Speelpenning et al., 2011).

A vast body of research has already identified how the design of TTI enables multiple users to jointly work on a shared task or enhances group work (Fleck et al., 2009; Yuill et al., 2012; Stanton et al. 2001; Woodward et al., 2018). Our work contributes to and attempts to extend these previous works in two aspects. First, we focus on a specific understanding of collaborative conduct. Second, we seek to create and identify design aspects which go beyond 'just' enabling participants to collaborate, but furthermore elicit them to collaborate.

In everyday life and in some literature, the term 'collaboration' is often used very broadly to describe two or more persons working together on the same task. However, in our work, we go beyond this general understanding of collaboration and to do so, we mainly rely on Roschelle and Teasley (1995). They define collaboration as a coordinated, synchronous activity where mutually engaged participants rely on a mediational framework to construct and maintain a negotiated and *shared emerging conceptual space* to jointly solve a problem (according to a shared understanding of the latter). The above-mentioned conceptual space is referred to by the same authors as "Joint Problem Space (JPS)" to grasp how collaborative activity gets organized in participants' interactions. JPS incorporates participants' orientation to (shared) goals, their descriptions of the current problem state, their awareness of available problem-solving actions, and associations interrelating the previous aspects. So, the JPS is considered here as an interactional achievement rather than as a convergence of individuals' mental representations (Sarmiento-Klapper, 2009).

Within the context of the ORBIT-project (Sunnen et al., 2018), we design and study a joint problem-solving activity at an interactive tabletop, that gives participants the opportunity to develop their collaboration methods. To develop design implications for that matter, more precisely, for the development of a scenario soliciting participants to collaborate, we set up a multidisciplinary design workshop. During the latter, we explored and discussed three different collaborative scenarios, implemented as paper prototypes. In this paper, we report on first results gained mainly from an exploratory analysis of the video data that was recorded in the context of this multidisciplinary design workshop.

Designing collaborative scenarios

So, the very first design question that arises from the above described perspective on collaboration is the following: How can we design a TTI-mediated joint problem-solving activity that elicits collaborative conduct among the participants, or in other words, the construction and maintenance of a JPS? More specifically, we focus here on the design of the TTI, which is meant to be a fundamental component of the mediational framework through which participants establish and maintain a joint problem space.

Thus, in the course of developing the design, we retained the following 'preconditions of collaboration': the TTI is supposed to afford the co-construction of a shared semiotic space as well as to solicit and sustain the participants interactions as mutually organized. In line with these prerequisites, three intertwined TTI aspects can be varied in order to explore their consequences on the collaborative conduct of the participants: the difficulty of the task, the complementary distribution of participants' competencies[1] and the organization of the physical semiotic space of the TTI.

A group-worthy *task* should be challenging and equally addressing all the participants, and invite them to work together interdependently and reciprocally to reach a common goal. This can be achieved if the task aims at creating a situation in which participants' exchange of ideas and information, and their joint construction of understanding are vital to success (Mercer, 1995; Vass and Littleton, 2010; Cohen and Lotan, 2014). Within each of our scenarios, we rendered the sub-tasks more and more challenging by adding further constraints at each level.

Closely related to the task are the competencies that are assigned to and realized by the participants. In order to have the possibility to participate in the accomplishment of the task in a mutually engaged way, participants need to be provided with complementary abilities so that they have to rely on multiple resources that cannot be mobilized by one person alone. The complementarity of the competencies was implemented here as a mobilization of tangibles in time, either simultaneously or sequentially ordered. Note, that even though the TTI-activity pre-determines what can be done and what cannot not be done, meeting the

[1] By 'competency' we mean here the potential abilities and roles 'provided by' or 'built into' the TTI-mediated joint activity. Whether and how these competencies are actually embraced and enacted by the participants is, of course, a different story and constitutes a primary concern of our analytical work.

task-challenge via competencies ‘is not given’ but has to be, explored, negotiated and (or at least) coordinated by the participants.

We already mentioned that the large shared screen of a TTI is of paramount importance when it comes to supporting the construction of a joint focus among the participants. So, we decided to explore the physical semiotic space of the interface with regard to directionality and visible access, and in terms of the organization of the space (parcels, fields, connected space).

Thus, the following, more specific intertwined design questions emerged for us:

1) How can we organize the physical space of the TTI to solicit the construction of a joint conceptual space?
2) How can we design TTI-instantiated complementary competencies so that they elicit participants' mutual engagement with one another to construct and maintain a negotiated and shared emerging conceptual space?
3) How can we design a challenging task that solicits participants mutual engagement in a joint problem-solving activity?

We then tailored these three aspects to our context, goal and target audiences and the outcome turned out as three scenarios (see table 1), which we tested as paper prototypes during our multidisciplinary design workshop. In the following, we shall give more information on the design workshop, the three scenarios and how we evaluated the latter.

Multidisciplinary Design Workshop

A central element in all of the scenarios was a shared central space, where all the participants have equal access to the current state of the game. All three versions were designed to be 'played' by three adult participants with no required training or specific skills. After defining the details of each scenario such as the main goal, tasks, roles, levels and challenges, we made a paper prototype of each game to test them in the design workshop. The scenarios were developed by a team of two computer scientists. The latter also participated as moderators in the workshop, and a team of three social scientists[2] participated as users (without being aware of the exact game mechanics). The social scientists, furthermore, provided a feedback from the perspective of researchers investigating collaborative conduct. The aim was to evaluate the aspects of collaboration in each scenario and decide about the features to consider for further development. The session lasted in total four hours and was audio and video recorded. The participants played each scenario on average for 30 minutes and there was on average 40 minutes of discussion after each test session.

[2] The involved computer and social scientists are also the authors of this paper.

Table I. Overview of the designed and evaluated collaborative scenarios

	Task	Complementary competencies	Organization of space
Scenario 1: Damaged spaceship (Figure 1)	Retrieving various specified parts (appearing randomly in the different parcels) with the fitting tools	Retrieval and carrying means are distributed among the three participants: • every participant can carry 2-3 parts, • every participant can use his/her two exchangeable tools to retrieve a part placed in one of the three terrains, • later, an extra tool is needed to get the parts (two participants must simultaneously mobilize tools).	Three enclosed, rectangular parcels representing different terrains (desert, ocean, forest).
Scenario 2: Growing crops (Figure 2)	Cultivating various types of crops on the fields by applying different farming resources in a specific sequence	Farming resources and seeds are distributed among participants: • participant has tractor and wheat seeds, • participant has water and bean seeds • participant has fertilizer and orange seeds Sequence: tractor, seed, water, fertilizer	Eight closed areas with different shapes and sizes (from 1 to 6 units) representing fields to be cultivated.
Scenario 3: Collecting garbage in the see (Figure 3)	Steering a ship to specific positions in the open sea to collect items (garbage and later fuel) and to return ship to harbor	Movement options distributed among the three participants: • participant in the North (N) can move southward (S) and southeast (SE) • participant in the Est (E) can move westward (W) and northwest (NW) • participant in the South (S) can move northern (N) and northeast (NE) Movement to E is only possible through an alternation of NE and SE. Movement to SW is only possible through an alternation of W and S Movement to SW is only possible through an alternation of W and S.	One connected space representing the sea with several islands and a harbor.

Each test session started with the explanation of the 'game' by the computer scientists (as moderators), followed by the pilot level to let the participant familiarize themselves with the features of each scenario. Then, the participants played different levels of each scenario with one of the computer scientists acting the reactions of the computer, moving and placing the objects of the paper prototype. During each test session and discussion, all the members (testers and moderators) were taking notes of the remarks and the raised ideas. At the end of each session, the participants discussed the experience, focusing on the potential of the scenario to trigger collaborative conduct as well as the suitability of the scenario to be instantiated in various contexts. After the workshop, we went through the recorded materials to further investigate the scenarios from the perspective of collaborative conduct. The latter is what we report on in this paper.

Description of the three scenarios

Scenario 1: Damaged spaceship

Figure 1. Picture of the damaged spaceship scenario.

For the first scenario (Figure 1), we subdivided the central space of the tabletop into three parcels representing different terrains: ocean, forest and desert. Participants were told that they were astronauts and had to repair their spaceship.

To achieve this goal, they had to collect different parts (provided as picture cards on the tabletop), which were scattered over the three different terrains. To collect the parts, specific tools (provided as picture cards[3]) were needed and each terrain required participants to use two different tools (for example, a hammer and a torch) for pick-up. After being informed about the required number and type of the different parts (visualized through a list), they needed to have the right tools to retrieve the required parts, which appeared randomly in the different terrains. Every participant had a personal area with two slots, where the previously collected tools could be placed. To use the latter, participants had to touch the part with their avatar (an astronaut). The part was then moved to the designated place disposing of 2 or 3 slots (according to the level) in the personal area of the collecting participant.

These constraints were here our way of implementing complementary competencies among the participants. Everyone could only store two respectively three parts and dispose of two tools. So, the main collaborative task in this scenario was therefore distributing the tools among them to collect the parts. We expected the participants to discuss their strategies and to coordinate their actions with regard to picking up the right part at the right time. In the last level, to emphasize the coordination challenge of the task, three tools were needed to fetch a part[4]. To do so two of the participants had to simultaneously touch the part with their avatars.

Scenario 2: Growing crops

The second scenario was set in a farming context (Figure 2). The shared space was divided into eight areas of different shapes and sizes designated as fields. Every participant received a tangible representing a bag of seeds (wheat, bean, orange) and a tangible providing him/her with the control over a farming resource (tractor, water, fertilizer). The set goal of this scenario was to grow certain amounts of the available crops in different fields.

To reach this goal the participants had first to discover and then apply the procedure to cultivate a field. As soon as a tangible is placed on the shared space, participants receive a feedback (green check or red cross) from the TTI whether the tangible was applied at the right moment in the sequence (which is: tractor, seed, water and then fertilizer). Therefore, they had to try out and explore together different combinations of using their competencies to make the products grow. To keep the task challenging and to further solicit discussions and coordination efforts among the participants, a number of constraints were introduced along the levels (adjacent fields cannot contain the same product, amounts to grow are given, time constraint).

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[3] In the TTI implementation the parts would be provided as digital objects and the tools as tangibles.

[4] Two tools related to the terrain and one extra tool related to the part.

Participants' main collaborative task was here to coordinate their actions to apply their complementary competencies in the right sequence to cultivate a field successfully. Furthermore, they had to discuss and agree on cultivating strategies (where to plant, what to plant and how much). The task was considered as accomplished when participants had harvested the asked amount and so the overall success was the result of the joint performance of all participants.

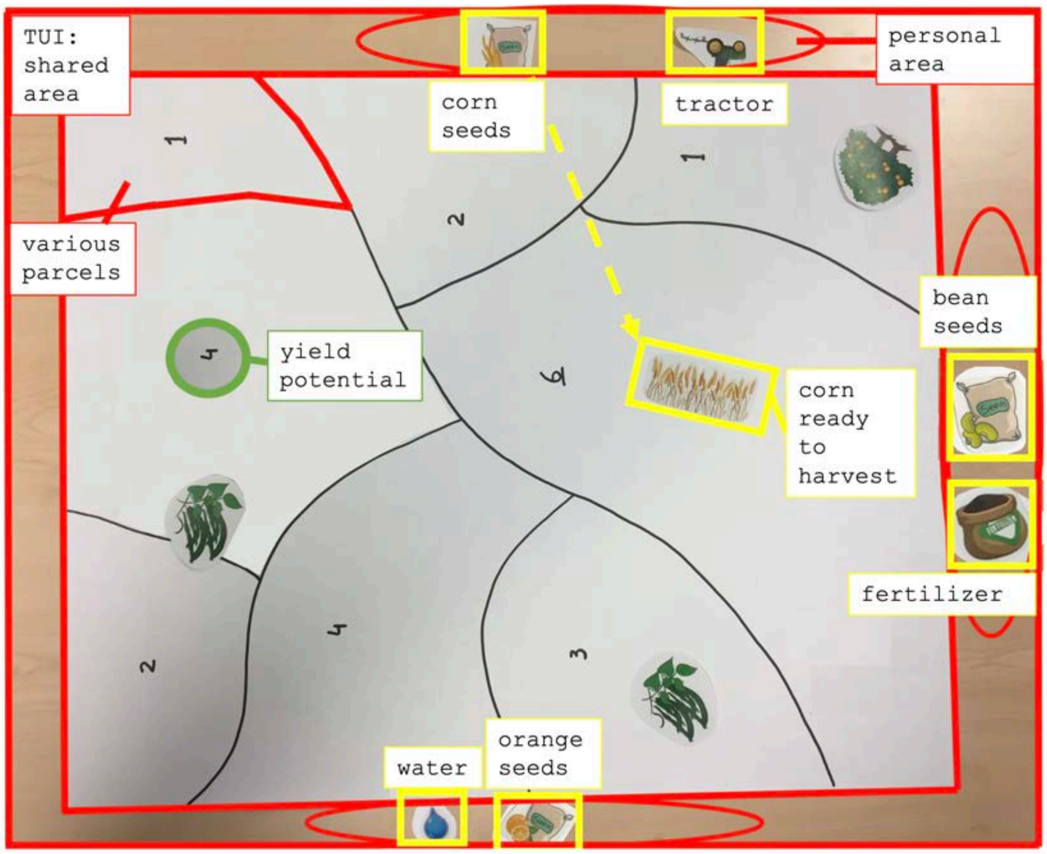

Figure 2. Picture of the growing crops scenario.

Scenario 3: collecting garbage in the sea

The third scenario was inspired by Piper et al. (2006) and the central space consisted of an 8*8 grid representing an ocean with some islands and a harbor (Figure 3). As common goal participants were asked to collect with their ship a certain amount of randomly distributed garbage items, while avoiding crashing into an island. At the end of each level they had to return their ship to the harbor. Reaching this goal became more challenging in later levels, since we introduced fuel usage (1 unit per movement, restorable through refills) and time constraints (limited availability of garbage items, overall time limit).

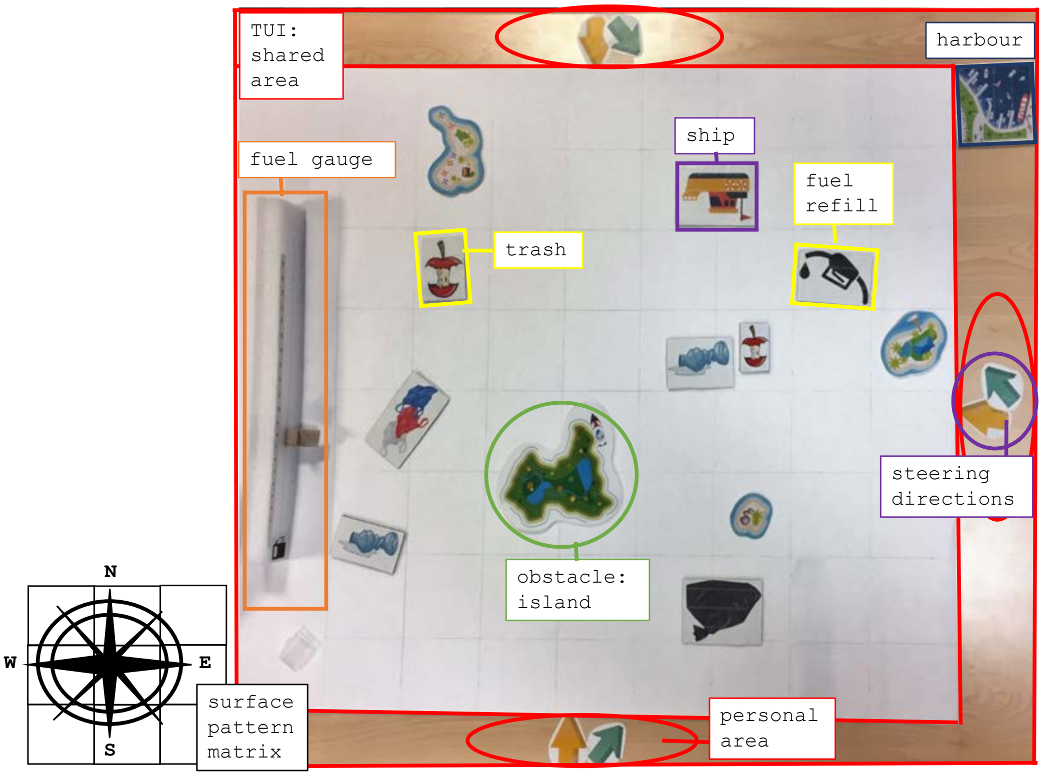

Figure 3. Picture of collecting garbage scenario[5].

The collaborative challenge of the task was that participants had to steer the ship together to reach a targeted location since the movement options (their competencies) were distributed among them in a complementary way. Indeed, each person was given the ability to steer the ship in just two different directions by taping on one of the two arrows situated in his/her personal area. The ship would then move by one cell per tap in the required direction.

The resulting consequences of these movement options (see Table 1) were the following: First, only six directions were immediately available; second, two directions could only be taken via the composition of two other directions (allocated to two different persons); and, third, the chosen route could only be taken by sequentially operating the different - distributed - steering widgets. Consequently, in order to successfully accomplish the task[6], participants had to agree (ideally after a mutually engaging discussion) on the items to target as well as on the route to take, and they had to coordinate their steering actions.

[5] The wind rose and the surface matrix (on the left side of the picture) are depicted here for the convenience of the reader and were not part of the design.

[6] Collecting the required amount of garbage items and returning to the harbor (levels 1-4), without running out of fuel (levels 2-4) or time (levels 3-4) and without crashing into an island.

Exploratory analysis of the three scenarios

Scenario 1: Damaged spaceship

The batch of three parcels constituted the central space of the TTI and all the participants had visual access to the three regions. Perhaps unsurprisingly, this parceled organization of a large part of the tabletop space did not elicit the construction of a joint focus in the same way all along. After discussing the task of the respective level, participants organized the allocation of the tools (competencies) in such a way, that they had at their disposal the requested pair of tools providing them with the ability to collect the parts located in the terrain closest to them. The terrains being exchanged (by the moderator) after each completed level, this interactional work was achieved several times. To get this distribution done (see transcript of extract 1 as an exemplary instance), they were mutually engaged (all three participants participated equally in the exchange), oriented to a shared goal (solving the task efficiently by allocating the terrains to participants), described the current problem state (e.g., lines 6 and 8) and were aware of problem-solving actions (e.g., lines 1, 10 and 12). So, they constructed a shared understanding of the problem and established a joint conceptual space (JPS).

Transcript of extract 1 (17:16-17:53)

01 P^1 we could negotiate and say ((...)) ah Patrick (.)you could focus on (.) that ((pointing at list of collectable parts))

02 P^2 we have to be careful

03 P^1 and you ((pointing at P3)) can focus on that ((pointing at list of collectable parts)) and I could

04 P^3 maybe we should focus on the (.) the worlds ((tapping at each parcel))

05 P^1 or on the worlds (.) yes

06 P^2 because the problem if you focus on this ((pointing at list of collectable parts))

07 P^1 yea (.) yea

08 P^2 you will not have the right tools

09 P^1 yea

10 P^3 or you need to say oh ((pointing at P^1)) please pick it up now ((pointing at ocean parcel))

11 P^1 Yes

12 P^2 What we could do (.) we could exchange the tools and everybody is closer to his territory because now my territory is there ((pointing at desert parcel))

However, once this allocation negotiations were concluded, the shared focus became less discernible as a visual instantiation. Overall, participants tended to focus more on their terrain, and waited for the requested parts to appear and retrieved them (Figure 4). After the completion of level 1, one participant made this explicitly accountable by saying to the moderator "I was focused on that (pointing to forest parcel) because I had these (pointing to her tools) (...) so that was mine (laughing)" (Figure 5). Notice that during the activity the participants categorized one another with labels such as "forest lady" or "desert space man" thus emphasizing the previously established connection between a participant and his/her terrain. They, however, continued to monitor each other's inventories of collected items and each other's retrieving attempts to guide their collecting actions. This mutual monitoring enabled them to describe the current problem state, for example, by calling out "no more screw (.) I have a screw" as a reaction to another's attempt at picking up one too many parts of this kind (which would have resulted in failing the level). In this way, they also continued displaying their orientation to the shared goal of accomplishing the task together.

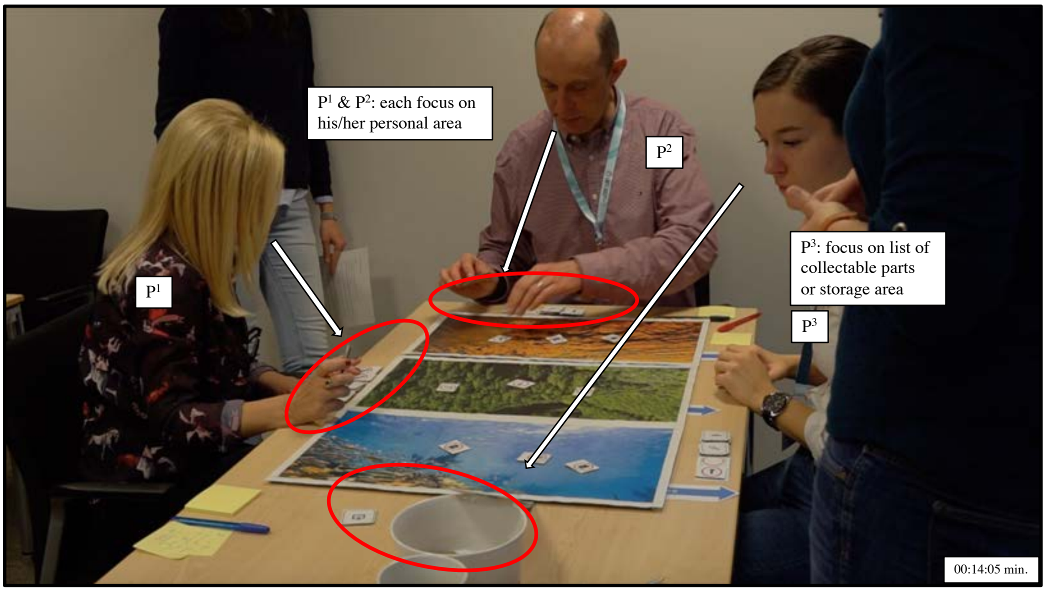

Figure 4. Divided visual focus of the participants

001 P1	because for the moment I was focused on THAT	
002 P1	because I said okay I have THESE (.) TOOLs	
003 P1	so I can pick up THESE things because (.) yea (.) so that's MINE	

Figure 5. Making terrain-specific adherence accountable

Level 3 introduced the rule that an extra tool was needed to retrieve a part. Thus, most of the times, the competencies of two participants were needed to retrieve the requested parts. In response to this new constraint, participants coordinated among themselves to mobilize the appropriate tools (see figure 6). P1, with the assistance of P2, retrieves the information about the supplementary tool which is needed to collect a part from her terrain (lines 1-3), P2 announces that he disposes of it (line 5) and the two participants jointly retrieve the part via a simultaneous mobilization of their respective avatars (lines 6-9).

001	P1	what what what (.) I need my glasses	*((P1 pulling part-card close to her face to decipher))*
002		what's that	*((P1 showing part to P2))*
003	P2	showel(.) showel	
		((P2 reading out word on part-card, joint group focus on part))	
004	P1	okay (.) okay I have one	*((all checking personal tools in front if them))*
005	P2	I can give you a showel	
006	P1	so I (.) can (.) take	
		((P1 & P2 reaching @relevant part with both avatars, joint group focus on part and collection activity))	
007	P2	okay	
008	P1	I have one (.) I can take	
009	P2	okay	*((P1 & P2 retraction from collection move))*

Figure 6. Simultaneous conduct of simultaneous retrieving action

Throughout this level until the end, participants remain mutually engaged to successfully complete the level and so display their goal orientation; call out what tool or part is needed and advise caution, thus, pointing to the problem state; and show that they are aware of how to solve the ongoing problems, for example, by announcing that they dispose of the needed tool or by suggesting to take other tools from the storage area.

Scenario 2: Growing crops

After a trial and error phase (in level 0) participants figure out together the appropriate order in which the farming resources have to be used to grow the crops successfully (tractor, seeds, water, fertilizer). The discovered procedure, which requires the sequential mobilization of the distributed competencies, becomes then available and recognized as a shared routinized problem-solving action to accomplish the tasks in all the levels. Overall participants establish a joint focus oriented at the field where the procedure is being applied, so that they can coordinate their actions to place the right farming resources in the right spot at the right time (see figure 7). At the end of the last level the procedure is further rationalized in the sense that a participant no longer waits until a field is finished but immediately moves on to the next one to apply his farming resource.

Figure 7. Joint focus

A perhaps more elaborate moment of JPS construction occurs, when the participants are challenged by new task constraints in level 1 (neighbor fields may not contain the same crop) and in level 2 (given amounts of different crops have to be harvested). On suggestion of one of the participants the seed bags are used during both levels as a planning aid to visualize distribution possibilities without actually initiating the procedure (figure 8). In this way potential solutions were shared, discussed, agreed upon and then implemented.

Figure 8. Mobilizing tangibles for visualization and planning purposes

So, again we could witness how mutually engaged participants displayed their shared commitment to accomplish the tasks, their collective awareness of the challenges of the tasks and of how to tackle them. As in the previous scenario the central space is fragmented, but there is no personalized appropriation of the fields by the participants. Probably, this is not solicited because the individual competencies are not tied to the fields.

Scenario 3: Collecting garbage in the sea

During level 0 a situation occurred demonstrating that designers have to give special consideration to the allocation and organization of participants' competencies. As outlined above, the operation of the steering directions was distributed in a complementary way, meaning that the participants had to coordinate among themselves to sequentially operate their respective directions to reach the previously negotiated destination. Due to the location of the harbor in the Southwest (levels 0 and 1), where the ship departed, and the location of most of the garbage items in the East, P^1 and P^3 controlled all the required movements to reach the related locations (figure 9). This combination of circumstances solicitated a close mutual engagement among P^1 and P^3 to select a destination and to collectively steer for it, but it also solicited a disengagement on the part of P^3, who made this explicitly accountable (figure 10).

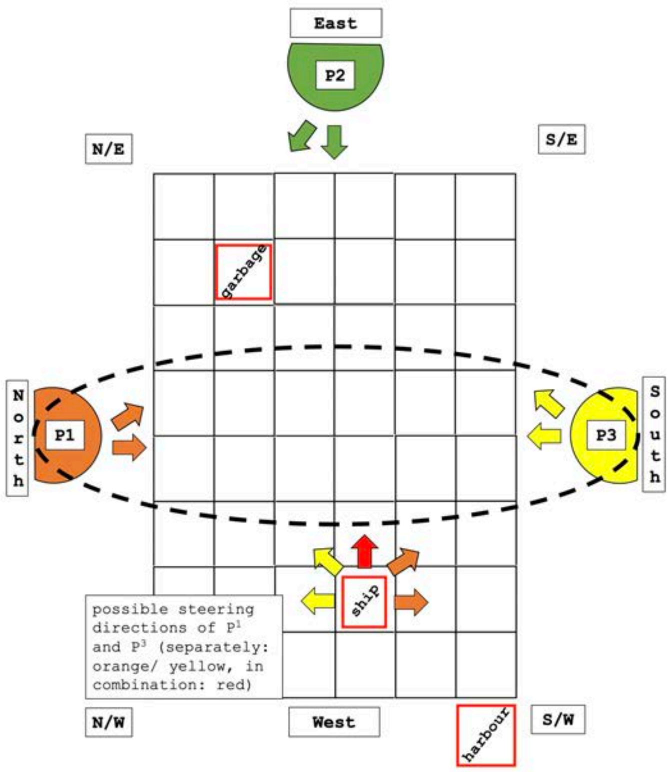

Figure 9. Distribution of steering directions leading to a temporary exclusion of P^3

Figure 10. Displaying being excluded

As long as there were no restrictions placed on the length of the route via fuel consumption (level 1 and 2), participants rather quickly agreed on the destination to target and moved the ship accordingly. During the steering they monitored one another's actions and sometimes prompted the participant, whose turn it was. During a spontaneous exchange between two levels, participants pointed out that they were instructing one another to do the requested steering, a conduct that was made possible through the general visual access to everyone's competency. This observation led to the concern that - at least in theory - one person alone could plan the trajectories and, all along, instruct the others accordingly. It is very unlikely that this organization of conduct would contribute to the establishment of a joint problem space.

Level 2 introduced a new rule (which was maintained for level 3), namely that every movement (in any direction) consumed 1 unit of fuel. 20 units were available in the ship's fuel tank (visualized through a gauge) and collectable refills (5 units) were located in the ocean. In response to these new constraints and in order to accomplish the task (shared goal), the participants mutually engaged in long planning and discussion phases where they considered various possible routes, carefully weighted them, and agreed upon a trajectory. Finally, they carried out the latter, while monitoring one another. During these phases, participants described the problem state, for example, by highlighting the current fuel limitations and the steering restrictions for the route under scrutiny (figure 11), and they displayed their awareness of the available problem-solving actions, for example, by pointing to an interesting target area containing a high concentration of collectable garbage and being in proximity of a fuel refill (figure 12); or by counting and verbalizing the steps to test a potential itinerary.

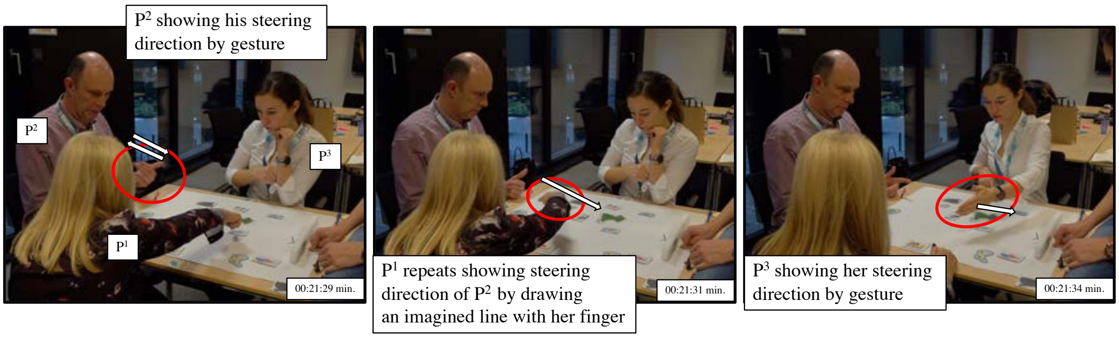

Figure 11. Problem-oriented sharing of individual steering options

Figure 12. Highlighting an appropriate destination

After completing level 2, the participants displayed in an off-scenario discussion, that they were aware of these extensive and demanding planning phases. Indeed, contrary to the previous scenario, where the seed bags were spontaneously used as an organizing tool with regard to the crop-to-field allocation, the collecting garbage scenario did not provide an artefact that could be used to mediate/facilitate the decision-making process with regard to the best route to take.

Conclusion

The implementation and evaluation of paper prototypes in the context of a multidisciplinary design workshop was the first design step of an iterative research process, that aims at developing and investigating a TTI-mediated joint problem-solving activity (Sunnen et al., 2018). Although a paper prototyping cannot fully simulate a computer interface, with regard to crucial features such as the provision of instant feedback and multitouch manipulations[7], the results we gained from our investigations will provide valuable insights to inform the choice of a scenario and the design of the upcoming digital prototypes.

Through our exploratory analysis we could show that collaborative conduct was elicited by all three scenarios. We could further highlight that the design of the task, the physical organization of the tabletop space and the distribution of complementary competencies have to be considered as intertwined design aspects, that are highly consequential on participants' collaborative conduct in TTI-mediated joint activities. Through the introduction of supplementary constraints, the tasks in the different scenarios became more challenging with regard to coordination and planning. With regard to the latter, it can be said that the requirements increased substantially from the first to the third scenario and solicited an appropriate and engaging joint response from the participants. In the first scenario ('damaged spaceship'), the additional constraint was implemented through a modification of the user competencies which rendered the participants' retrieving actions interdependent and synchronous. As we could observe, this entailed mutual monitoring and engagement. The second and the third scenario ('growing crops' and 'collecting garbage in the sea') required a sequential mobilization of the competencies, and solicitated coordination efforts and the establishment of a joint focus. The third scenario further teaches us that the complementary competencies have to be carefully thought through to elicit mutual engagement among all the participants in a balanced way. The organization of the tabletop space was particularly 'intriguing' in the first scenario, where the central space was threefold. This spatial arrangement, being bound to the competencies, did not facilitate the construction of a joint visual focus but did not impede the construction of a shared problem space either. The joint visual focus was restored when participants' competencies became interdependent.

A major design challenge is to expand the role of the TTI in the mediational framework of the joint problem space to bring forward the added value of the TTI. By that we mean that the TTI should become a powerful resource to be embedded in and interweaved with participants' joint meaning making processes. This aspect became most noticeable during the extended and demanding phases of the last scenario. Indeed, the tabletop did not provide the participants with facilitating means to keep and display uttered potential solution-oriented steps (for example, a hypothetical trajectory). Such a feature would make those contributions available for re-integration and transformation in the joint problem-space, thus, supporting a crossed backward-forward oriented joint decision-making process regarding the actions to take to achieve the shared goal.

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[7] Participants sometimes made this jokingly accountable by saying "the computer is slow" or "it's a single processing computer".

Acknowledgments

We thank the Luxembourg National Research Fund (FNR) for funding this research under the CORE scheme.

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