Developing competencies for collaborative work settings in a virtual simulation laboratory

Training approach and performance measurement

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1. Introduction and problem definition

The transformation of the working environment towards industry 4.0 is accompanied by an increase of automation and flexibilization of work processes, leading to a merge of manufacturing and knowledge work (Spath et al. 2013). Furthermore, new digital data driven process technologies are incorporated into work settings, resulting in an increase of overall work complexity (Bauernhansl 2017). Employees are confronted with new task profiles with respect to process regulation and market development. Work becomes more interconnected while process controlling, organizing and planning aspects come into focus (Hirsch-Kreinsen 2017). These changes are affecting the shop floor as well as the management level, leading to the reorganisation of work for all business entities (Wilkens/Hermann 2016). In order to meet these new challenges, it is necessary for employees to develop critical competencies for Industry 4.0 (Teichmann et al. 2020).

These critical competencies for coping with Industry 4.0 work environments have already been specified and empirically investigated in several studies in terms of coping with complexity, multiple role development, collaboration and continuous reflection-on-action within (remote) work settings (Petzold/Bullinger-Hoffman 2017; Wilkens et al. 2017; Voigt et al. 2015; Spath et al. 2013), process oriented thinking and remodelling the use and management of knowledge (Gronau 2020) as well as digital competencies (Süße et al. 2018).

With respect to competence development, various training approaches related to these competencies have been developed such as learning factories, business simulations and serious games (for an overview see Sudhoff et al. 2020; Teichmann et al. 2020; Wilkens et al. 2020; Nyhuis et al. 2019; Reuter et al. 2017; Meier et al. 2015; Voigt et al. 2015). These approaches address different operational levels in terms of process knowledge or business skills. Besides creating appropriate settings, it is important that these training activities are accompanied by suitable performance measurements to ensure a purposeful development of competencies. The issue of performance measurement can more likely be integrated in production-related competence development. Transferring this to appropriate training

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settings referring to new business environments in collaborative ecosystems is a challenging task, as outputs are not always clearly delineated and performance cannot easily be related to specific action and becomes visible on the overall system level.

The present article addresses this challenge by summarizing current research results regarding competencies, deemed important for industry 4.0 and related training approaches. Subsequently we introduce a critical evaluation and reflection of a digital simulation laboratory and an accompanying performance measurement for collaborative work settings in industry 4.0. The aim is to find a suitable design for evaluating training scenarios with an emphasis on work demands in collaborative ecosystems.

2. State of the art: Which competencies matter in Industry 4.0 work settings and how to train them

To gain a better understanding of co-existing approaches regarding competency conceptualizations and training methods in the context of industry 4.0, it is first of all necessary to develop a deeper understanding of different work settings within industry 4.0 and its employee demands. The shift towards Industry 4.0 does not only affect existing manufacturing processes and methods, but also leads to the evolvement of dynamic digital ecosystems (Hirsch-Kreinsen et al. 2019). Based upon this argument of digitization and accompanying servitization, there are two dimensions describing the transition journey towards industry 4.0, the back-end and the front-end digitalization (Coreynen et al. 2017). Back-end digitalization describes the manufacturer's production operations with the goal of optimizing processes through automation and digital integration. Front-end digitalization describes the interaction with customers, driven by the manufacturer’s aspiration and need to provide customer-centric solutions in order to gain competitive advantages (Coreynen et al. 2017).

Across all perspectives, competence can first be defined as the capacity of social actors to develop problem-solving skills in situations that can be characterised by both, their complexity as well as a certain degree of uncertainty. These are based on self-organised actions which ultimately brings innovation forward (Wilkens et al. 2015). Competencies, unlike qualifications, thereby become visible in the form of performance through and within related actions. Based upon the systematization of work perspectives according to Coreynen et al. (2017), the assessment of which competencies are particularly important in industry 4.0 work settings and also the accompanying training approaches can be differentiated regarding their addressed context. Table 1 gives a brief overview of existing competency conceptualizations and corresponding learning approaches and the respective work context

	Wilkens et al. (2017)	Gronau et al. (2017a; 2017b)	Prinz et al. (2016) based upon Dombrowski et al. (2014)
Generic competencies	Coping with complexity Self-reflection Combination Collaboration	Process Competence Organization Competence Interaction Competence	Technical and methodological Competence Social Competence Personal-Competence
Specified for Industry 4.0	Multiple role concept Coping with complexity Reflexive team-based learning	Organizing machines, work pieces and information Process knowledge Flexible Cooperation and Collaboration	Problem solving and supervision Widely spread expertise Judgement Interdisciplinary Personal responsibility Holistic thinking Ability of communication Adaptability
Addressed context	Collaborative team settings in digital ecosystems	Industrial flow processes in the context of the industrial internet of things	Real world manufacturing and production processes
Related training approach	IPSS Business Simulation	IoT-Laboratory	LPS Learning Factory

Table 1: Overview of existing competence conceptualizations and accompanying training approaches

The comparison of the selected concepts underlines that the different approaches rather complement than contradict each other. The training approaches address different work settings either more front-end or more back-end related. Bringing them together would lead to a comprehensive approach.

It is apparent that concepts focusing on the back-end are primarily centred on aspects of process and organisational competence, since these are mainly focused on production processes. Competency development for back-end processes usually takes place in learning factories, e.g. in the IoT-Laboratory and LPS (Gronau et al. 2017a; 2017b; Prinz et al. 2016). Recent studies show that in Germany alone, there are currently 30 learning factories that focus on competence transfer in the back-end by addressing challenges such as the improvement of production processes, digitization, product management and automation of processes, to name only a few (Sudhoff et al. 2020). Learning factories allow participants to directly act on applications to test work processes and thereby support competence development through observations, reflections but also generalizations (Tisch et al. 2013; Tisch/Metternich 2017). Based upon the presented competence perceptions (Table 1), different learning objectives can be derived, for example becoming comfortable in the use of new methods and technologies in production and adapting to new application contexts (Prinz et al., 2016). These learning objectives create a base for further applications in terms of competency development.

When considering concepts that focus on the front-end, a shift occurs with regard to the consideration of important competencies. Regarding front-end work settings, employees have to be able to work within heterogeneous teams and combine different knowledge sets in order to create customer-centred problem solutions, which is why the set of competencies deemed most important is leaning towards team interaction abilities (Mänz et al. 2013; Wilkens et al. 2017). Regarding the identified competency facets by Wilkens et al. (2017) a business simulation was introduced for a specific PSS working environment, mainly focussing on elements such as cooperation and team work within a digital learning environment (Voigt et al. 2015; Cibat et al. 2017). Similar to the back-end approaches, the simulation is characterised by the depiction of concrete work processes. Comparing to existing back-end competency development approaches it thus becomes apparent, that the landscape of existing training methods concerning the front-end is rather small.

When it comes to performance measurement the back-end approaches are more advanced in providing a measurement approach which is directly integrated in the training scenario with respect to time, resource saving or quality management. These can be monitored using indicators such as process cycle times or general output measurements, e. g. process improvements, fulfilment of customer requirements or other key performance indicators (Prinz et al. 2016). Concerning the presented front-end training approach, the performance measurement occurs through the recording and evaluation of participants' actions (Süße et al. 2017). The measurement of performance within front-end settings cannot directly be linked to key figures as it is possible in the back-end training approaches, since it only becomes visible within the entire socio-technical system. Thus, making specific measurements more difficult.

In the following, a digital simulation laboratory and accompanying performance measurement approach, addressing the front-end perspective of industry 4.0 is presented. The aim of this simulation laboratory is to train interdisciplinary teams in coping with the demands of front-end working contexts and simultaneously identify performance indicators for this work environments.

3. Introduction of a simulation laboratory for collaborative work settings

The digital simulation laboratory "Collaboration Space" was established in a public-private partnership between the Ruhr-University Bochum and the local start-up Think Square. It was first put into operation in September 2020 as part of an interdisciplinary seminar. The scenarios within the laboratory are aligned to an escape game approach. The overall setting represents the work context of Industry 4.0 in a gamified way, including corresponding challenges as for instance the processing and systematic usage of large quantities of information and the achievement of solutions only with the help of joint collaborative (digital) work. According to the systematization introduced in chapter 2, the simulation laboratory therefore represents a competence development approach that addresses the front-end perspective of industry 4.0.

There are several target groups invited to the laboratory training, participants of graduate seminars as well as people from professional environments in post-graduate trainings. Since its first introduction, the simulation lab has been integrated into a wide variety of seminar settings, each with the aim of confronting interdisciplinary student teams with challenges of digital collaboration in the context of Industry 4.0 on an abstract level. So far, the simulation lab has primarily been tested with heterogeneous student groups consisting of, among others, majors in master degrees of economics, chemistry, biochemistry, business psychology and educational science as well as part-time students.

The different scenarios are embedded in an online game interface. The teams are provided with a protected environment in which they can test out different actions, without having to be concerned about consequences of wrong decisions, although these consequences are experienced in an abstract manner. In teams of three to six members, the participants assume the role of an interdisciplinary team of laboratory technicians and managers who have been commissioned with the overall goal to develop a water disinfectant. Followed by a hacker attack, the team must get access to critical data and formulas for the imminent market launch of the product. To fulfil this task, the teams work through three simulation scenarios (see illustration 1), which are based on the competence facets according to Wilkens et al. (2017).

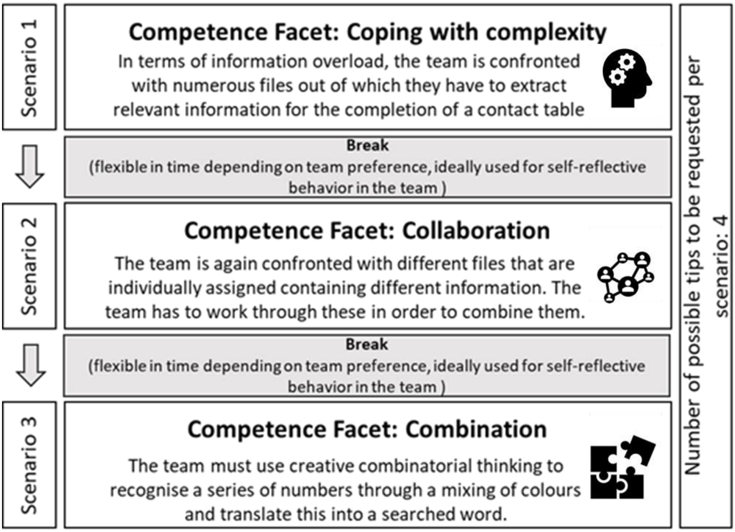

Illustration 1: Scenarios of the simulation laboratory "Collaboration Space"

The learning levels build on each other to create an overall game flow setting. Each of these scenarios place a particular competence facet in the centre of interest. One scenario is addressing the competency facet of coping with complexity, followed by one scenario each focusing on collaboration and combination skills. The competence facet of self-reflection is not assigned an explicit sub-scenario, but the teams are free to reflect on the group's performance in the short breaks between the individual scenarios. This allows the groups to reflect on action routines and adjust them if necessary. The run through the simulation happens within the game flow and does not require any interaction with the game master during the whole gameplay. Once the solution for the simulation sequence has been entered by all participants, the next scenario opens up.

The simulation laboratory is accompanied by a measurement approach specifically adapted to the scenarios. The measurement approach builds on research findings from the fields of game-based learning (Pan, Lo & Neustaedter, 2017) and competence measurement methods (Wilkens et al., 2017). In addition, formative factors as well as moderators and performance outputs are measured (see Figure 2).

The formative factors are based on the individual competencies of the team members, which are collected via self-assessment questionnaires prior to the beginning of the simulation. The survey is based on the competency facets of complexity management, collaboration, creative problem solving and self-reflection according to Wilkens et al. (2017), which were also decisive for the scenario design and thus run congruently with the game scenarios. The existing set of variables is supplemented by the competence in activity and action factor according to Heyse & Erpenbeck (2009). The individual competence self-assessment is based on a total of 30 items, which have to be rated on a 5-point Likert scale.

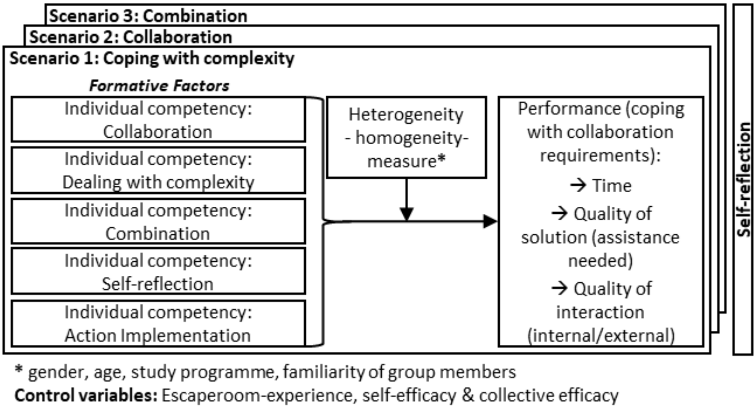

Illustration 2: Design of analysis

In addition to the above-mentioned competence facets, moderator variables were gathered to obtain information about the heterogeneity or homogeneity within the groups. In addition to data with regard to age, gender and study programme composition of the team, it is also ascertained whether the group members are familiar with each other and have already worked together. As control variables, the collective and individual efficacy expectations according to Schwarzer & Jerusalem (1999) as well as previous escape room experiences of the team members are surveyed.

The measurement of performance, which can essentially be summarised as dealing with the hurdles of (digital) collaboration in the working environment of Industry 4.0, is conducted using three different output factors, described in the following.

1. *Time*

   The time that the teams need per scenario is measured to provide information about the partial performance, as well as the overall performance. The time limit per scenario is 25 minutes for a performance that would be considered as optimum.

2. *Quality*

   For each scenario, the teams can request a total of four hints. These hints are predefined and standardised to ensure comparability between the teams. If the teams were able to solve the riddles without any support in terms of requested hints, the performance is categorized as optimum. The quality of the achieved solution decreases gradually with the number of used/requested hints.

3. *Team atmosphere (sustainability of team setting)*

   The third performance measure is the perceived team atmosphere (also called sustainability of team setting), which is assessed post-simulation, using self-assessment surveys completed by each team member as well as an external observation survey completed by the game master. The surveys are based on the items of mutual support and general communication according to Lechler (2001) as well as supplementary variables on goal-oriented communication. A high score is assumed to indicate that team members will collaborate with each other also in the future.

While the team atmosphere refers to the entire game, the output factors of time and quality in form of requested tips allow deeper insights into the sequential performance of the team.

The present evaluation is based on a sample size of 19 groups which participated in both the simulation and the surveys as part of different seminar contexts. This means that the presented evaluation is a work in progress and has to rely on a more qualitative comparison between high, medium and low performing groups. For the distinction of these groups we primarily referred to the time needed by the teams to complete the simulation. Given that the optimum time per simulation sequence is set to be 25 minutes, the high performer category includes every group that was able to complete the simulation within a total of 75 minutes. The category of medium performers includes all groups that took 76 up to 105 minutes and the low performer category includes all groups that took more than 106 minutes. For each group, the individual competency assessment results were aggregated into a competency index, likewise to the sustainability assessment results, the moderators and the control variables.

4. Preliminary Findings

The preliminary results, presented in table 2, show that out of the 19 groups, nine groups fall into the high performer category, while six groups can be categorized as medium performers and four as low performers, regarding their average time needed to complete the simulation.

	High Performer	Medium Performer	Low Performer
Team specifics			
Teams	9	6	4
Average Team Size	4,3	4,5	5
Performance Measurement (mean)			
Time	01:06:04	01:30:04	01:51:11
Quality (hints requested)	0,1111	0,3333	2
Sustainability Self	4,6119	4,0688	4,1678
Sustainability Ext.	4,3024	4,1944	3,8055
Competencies (mean & distribution)			
Overall Competence	3,7134	3,4286	3,6872
Distribution	0,355025	0,46326	0,2959
Cooperation	4,07977	3,77881	4,14444
Distribution	0,44441	0,66580	0,44166
Coping w. Comp.	3,0667	2,9167	3,1700
Distribution	0,55693	0,32552	0,36288
Reflection	3,5795	3,4769	3,6500
Distribution	0,50009	0,59887	0,57993
Action Implement.	3,9230	3,4872	3,6917
Distribution	0,45055	0,79850	0,51943
Creative Probl. Sol.	3,9179	3,5111	3,7800
Distribution	0,57256	0,70456	0,44438
Moderator variables			
Age range	19-49	20-31	22-34
Gender distribution	38,5% male	37% male	15% male
	61,5% female	63% female	85% female
Study programme	64,1% business rel.	66,7% business rel.	35% business rel.
	12,8% part-time	7% part-time	50% part-time
	23,1% other	25,8% other	15% other
Familiarity of team members	59% knew all	33,3% knew all	25% knew all
	15,4% knew some	25,9% knew some	55% knew some
	25,6% knew none	40,7% knew none	20% knew none
Relationship between team members	23,1% friendship	3,7% friendship	15% friendship
	53,8% collegial	40,7% collegial	50% collegial
	12,8% cursory	22,2% cursory	25% cursory
	23,1% n.a.	33,3% n.a.	10% n.a.
Experience in working together with the team members	15,4% yes	7,4% yes	20% yes
	41% no	63% no	40% no
	43,6% partially	29,6% partially	40% partially
Control variables (mean)			
Self-Efficacy	3,6267	3,2482	3,5327
Collective Efficacy	4,1949	3,9037	4,04
Escape Game Exp.	2,72	1,1	0,8

Table 2: Preliminary results

With respect to the performance quality in terms of requested hints in the overall simulation it is noticeable, that the number of hints required increases with a descending performance regarding the time. This effect can probably be attributed to the duration of the simulation, as the frustration level increases with the duration of the simulation. In terms of the team interaction index, which is based on the mean of the team survey results as well as the external observations, the high performers have the highest self-assessment at 4,6119 in comparison to the medium and low performer, scoring at 4,0688 and 4,1678. These results indicate a high level of cohesion within the high performer category. This tendency is also reflected in the results of the external observation.

Considering the overall competence assessment there are only minor differences between the three groups. Even though the high performer accumulated the highest score at 3,7134 it becomes apparent, that the medium and low performer considered themselves only slightly weaker, low performer considering themselves at 3,6872 even higher than medium performer with 3,4286. Similar tendencies can be observed in the analysis of the individual facet values. The low performer consistently considered themselves higher than the medium performer and regarding the facets of cooperation, coping with complexity as well as self-reflection even higher compared to the high performer. This indicates that their individual competency assessment may either be distorted or that the individual competencies may not have a predicting effect on team performance. Only the facets of action implementation and creative problem solving could have an impact on the simulation outcome, as the high performer considered themselves as the strongest regarding these facets scoring at 3,9230 and 3,9179. At the present state of observation, these results lead to the assumption that individual competencies are not necessarily the only predictors of performance. Thus, resulting in the question if there are certain characteristics of team teams themselves that influence a team's performance.

Considering the assumed moderators, it can be noted that the age range within the medium and low performer group is quite similar, showing a range of eleven and twelve years, leading to more homogeneous structures. Within the high performer group, the age range spreads to thirty years, which constitutes a considerably higher age heterogeneity.

In terms of gender diversity, it becomes apparent that the low performer are quite homogeneous with 85% female participants and 15% male participants. This could be an indicator for the lower performance, since the medium and high performer teams tend to be more heterogeneous when it comes to gender diversity, both being close to a 60/40 distribution. In terms of the study programme diversity, all teams show a certain level of heterogeneity, with the high and medium performer including higher rates of business-related students (64,1% and 66,7%) and the low performer including a higher rate of part-time students (50%).

Regarding the member familiarity it is noticeable that the high performer were most familiar with each other. Here, 59% of the participants stated that they knew all their team members. The familiarity level of the medium performer lies at 33,3% and of the low performer at 25%. In comparison, the familiarity of the high performer is noticeably higher. This tendency also applies to the moderator variable of the relationship between the team members. Here, 23,1% of the high performer considered their team members as friends whereas only 3,7% of the medium and 15% of the low performer could say the same about the relationship to their team members.

As far as self-efficacy is concerned it shows that even though the high performer rated themselves highest, the deviation from the low performer is rather small (0,0997). Regarding the collective efficacy, the high performers rate themselves considerably higher at 4,1949 than the medium (3,9037) and low performer (4,04), which could also be a consequence of the higher familiarity level within the high performer group.

At the current point of observation, it has to be noted that there is a possible distortion, namely the prior existing escape game experience of the teams. The data indicates, that with growing escape game experience the teams performed better. This could be attributed to the teams being more familiar with the way of thinking and logic necessary to solve escape games, which is usually rather similar. Therefore, it cannot be ruled out that the prior escape game experience has an impact on the team performance at the current state of the simulation. In a more optimistic way of data interpretation one can conclude that prior experiences with a challenging work setting impacts performance in a positive manner. This would be an argument for training on the (demanding) job.

In summary it shows, that at the current point of evaluation no clear tendencies regarding performance influencing competency facets on the individual level can be drawn. However, it will be interesting to further monitor whether the two competence facets action implementation and creative problem solving remain consistently higher when it comes to high team performance. It should be noted, that the positive influence of these facets may also be due to the simulation design, since these cognitive aspects are more relevant in order to be able to solve escape games in general. However, the analysis of the current set of observations indicates that team characteristics themselves in terms of familiarity of team members, heterogeneity regarding the age range as well as gender composition seem to have a positive impact on the performance of teams. Thus, team staffing seems to be more important than individual competence profiles.

The high performer showed a high level of heterogeneity within their group while simultaneously reaching the highest degree of cohesion, both regarding the team interaction quality and the familiarity level of the team members. These parameters appear to have a substantial influence on the team member's abilities to work effective within their team. Ultimately, these team characteristics could be the reason that teams that assessed themselves weaker regarding individual competencies nevertheless performed better than teams with a higher individual competence assessment, since they felt more secure within the group and thus resulting in a higher level of trust.

These tendencies are in line with the findings of Wilkens et al. (2017) stating that within front-end settings oriented towards collaborative work, the team level has a high impact on the actual performance. It is evident, that work within the collaborative ecosystem relies on heterogeneous work groups that have to be able to exchange and combine different perspectives (Mänz et al. 2013). These results also refer to findings from team research. Here, a higher level of team heterogeneity is positively attributed to team performance regarding complex tasks. Also, it is stated that higher levels of team diversity lead to higher team satisfaction and team outputs (Higgs et al. 2005). In order to benefit from different knowledge and skill sets that come with a high level of heterogeneity, it seems important that the teams furthermore reach a certain degree of cohesion. This result also confirms with findings from Paul et al. (2016) regarding the positive influence of cohesion on team performance of virtual teams. Contrary to back-end approaches such as learning factories that often focus on individual development goals for employees in manufacturing and production (Abele et al. 2010), for front-end settings there is a need to ensure development methods on the team level. Still, there is a need to transfer these findings into training practices in the context of industry 4.0. In terms of competency development for front-end work settings in the context of industry 4.0.

5. Outlook and conclusion

In recent years, various training scenarios have been examined and developed in the context of competence development for employees with regard to Industry 4.0 work contexts. These have mainly focused on the back-end field, directly addressing specific working processes and related output measurements. Besides back-end working processes, Industry 4.0 also impacts work processes in the front-end, for which comparatively few training approaches are known so far. Based on this, the present article addresses the performance measurement in the front-end on an overall systematic level. For this, a front-end training approach in form of a digital simulation laboratory with an accompanying measurement approach, focusing on the overall performance of teams, has been presented, integrating existing prior considerations from theory and practice.

The preliminary results show that the impact of individual competencies on the team performance was found to be less impactful as variables in terms of heterogeneity and team cohesion. These findings are in line with results derived out of existing team research. Although the present work presents preliminary results that need to be validated in future research, some implications can be drawn for practice for further competence training. For working within collaborative ecosystems, it seems appropriate to ensure a certain level of heterogeneity, especially regarding age and gender composition, while simultaneously promoting cohesion in terms of the relationship between team members resulting in a higher interaction quality as well as overall performance within the team. It seems appropriate to not solely focus on individual competence development, but also on the development of team structures and dynamics, as these ultimately ensure a certain level of performance quality. At this stage, it can therefore be stated that the team level has an effective and maybe even higher impact on performance than individual competencies tend to have.

In terms of limitations it hast to be noted that the current simulation is prone to distortions in form of prior escape game experience of the participants. For future research this should be considered. Also, it could be shown that individual competencies that are more focused towards cognitive skills in terms of combinative capabilities seem to have a positive impact on the team performance. This could be due to the design of the simulation as an escape game since these games are usually based on logical and combinative riddle designs. For future research the simulation setting therefore should be altered regarding the riddle design, for example by focussing more on creative problems that can only be solved in a collaborative manner. By doing so, the participants would not be able to rely on prior experiences in terms of logical and combinative patterns of action, gathered through former escape games.

The data evaluation was rather a first screening and qualitative evaluation. This means that findings have to be further validated in a test design. However, the gathered data and preliminary findings were most helpful to deduce hypothesis for a test design with respect to the influence of team characteristics and individual competencies on group performance.

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