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PRODUCTIVE FAILURE AS A METHOD FOR LEARNING ABOUT EFFECTIVE COLLABORATIVE PROBLEM SOLVING

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Collaborative Problem Solving (CPS) skills are receiving increased attention in the current workforce and in lifelong learning. In learning and labor contexts, successful teamwork is however not always guaranteed, due to several reasons, such as an unequal level of individual participation. Training in CPS for all groups is therefore needed. However, resources for CPS competence development are scarce. As part of our project entitled Supporting Teamwork in Ambient Learning Spaces (STEAMS), we, therefore, designed an interactive professional training on CPS, in which CPS is perceived both as a method and as a goal. In this paper, we outline the design process of our CPS training along with some crucial decisions we needed to make, and we aim to illustrate how implementing productive failure in the learning design can foster adults' CPS-competencies development.

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INTRODUCTION

As a result of the adoption of new technologies (e.g., cloud computing, big data analytics, and encryption and cyber-security) in industry and the automatization of certain jobs (e.g., Arntz et al., 2016), organizations expect that re-structuring their workforce will be necessary for the coming years. As reported by the World Economic Forum (2020), skills such as critical thinking and analysis, problem-solving, and working with people will be rising in prominence towards 2025. Similarly, Neubert et al. (2015) mentioned the rising importance of problem-solving and collaborative skills. Both these skills are brought together in collaborative problem solving (CPS).

In recent years many academics have been researching the conceptualization of CPS, resulting in several frameworks of CPS competencies (e.g., Graesser et al., 2018; OECD, 2017b; Sun et al., 2020). Accordingly, various methods have been designed to assess CPS competencies, mainly in formal education settings (e.g., Hesse et al., 2015; OECD, 2017a). Resources and research on how CPS can be effectively taught or trained are however limited within lifelong learning in general (Fiore et al., 2018; Graesser et al., 2020). This is especially the case in adult education, which is defined by Mizerow as "an organized effort to assist learners who are old enough to be held responsible for their acts to acquire or enhance their understandings, skills, and dispositions" (p. 26). In work contexts, adult education is closely related to—though distinct from—human resource development (HRD; Hatcher & Bowles, 2014). Within our project entitled "Supporting TEamwork in AMbient learning Spaces" (STEAMS, see https://www.imec-int.com/en/research-portfolio/steams) we designed an interactive professional training on CPS grounded in educational theory. In what follows we will elaborate on the STEAMS context in which the training was designed. Second, we will illustrate the design process in more detail by providing some further background, elaborating on the different choices we made through an iterative design process, and showing our end design.

FIGURE 1. Overview of the project partners.

SHAPING THE STEAMS CONTEXT

The current training was designed as part of the STEAMS project, running from October 2020 until October 2022. Central in this project is the idea that the value of CPS competencies is widely recognized, but that in practice teamwork is not always guaranteed to be successful and is different to assess compared to individual learning. This is the case both for students (OECD, 2017a) and employees (Fiore et al., 2018). The general aim of the STEAMS consortium was therefore to investigate how technology can help to teach, support, and assess CPS in educational and professional contexts to deliver a set of metrics, tools, and insights to support the assessment and teaching of teamwork skills in youth education and corporate training.

We did so by creating a prototype of a flexible learning platform to be used in technology-enhanced learning spaces (TELS), along with (a) CPS training for students and (b) CPS training for adults. It is the design of the training for adults that is being discussed in this paper. In a later stage, we also aim to design an interactive dashboard to support teachers and coaches in providing teams with feedback and insights into how they performed within this training, but this design is beyond the scope of this design paper.

Scientifically Situating the Steams Project

The STEAMS project is very much in line with research and educational design in the field of computer-supported collaborative learning (CSCL). This is seen as a branch of the learning sciences "concerned with studying how people can learn together with the help of computers" (Stahl et al., 2006, p. 409). It focuses, among others, on how technology can support classroom orchestration (Dillenbourg & Jermann, 2010), the design and management of multiple classroom activities taking place at different social levels (i.e., individual, team, classroom), and (b) how design choices in classroom orchestration can optimize the orchestration load of trainers. The latter is described in the literature as the effort a trainer needs to make to coordinate the different learning activities and processes (Prieto et al., 2018), which is according to Dillenbourg (2015) a combination of both cognitive load and workload. Many of the insights from this field were used for the design of our training, to optimize the learning experience for participants and coaches.

The Design Team

A multidisciplinary team was involved in the project, with members of both research and industrial partners (see Figure 1). The academic partners are Itec and Augment, both research groups at KU Leuven. The industrial partners include FTRPRF, Hudson Belgium, Averbode Publishers Group (Uitgeverij Averbode), and the Flemish Radio and Television broadcaster (VRT). The main contributors to the current design case are part of Hudson Belgium, Itec, and VRT, which are further introduced hereunder.

- Hudson Belgium is an HR consultancy that provides services covering the entire HR lifecycle. One of its strengths is its Research and Development department which has the capacity to develop tailor-made, innovative, and evidence-based HR tools for private and public organizations across the world. These include psychometric instruments and reward tools. The contributors of Hudson have a strong background in psychometrics, industrial and organizational psychology, talent management, and training and coaching in a professional environment.
- Itec is an interdisciplinary research group at imec and KU Leuven mainly focusing on instructional design and educational effectiveness, more specifically related to the evaluation of digital solutions in the domains of education, training, and health. The researchers of Itec involved in the current design mainly have interests and experience with research focusing on CPS, CSCL, and optimal experience in TELS. More specifically they conduct both design research and experimental research in in-vivo and in-vitro settings.
- VRT, is the Flemish Radio and Television broadcaster with a broad educational role, including developing and participating in projects around topical themes with a societal added value. More specifically, VRT is renowned for the EDUbox (see https://www.vrt.be/nl/edubox/). The contributors of VRT in the current design process mainly have a background in computer sciences, graphical design, and storytelling.

The Design Criteria

The training needed to meet three main criteria that were decided on at the start of the design process.

Enjoyable experience for a specific user group

The first criterion is that the training needed to appeal to a large variety of end users, to have a broad societal value fitting within lifelong learning initiatives for highly educated (European Qualification Framework Level 6) white-collar workers. Lifelong learning should be understood as "all learning activity undertaken throughout life, with the aim of improving knowledge, skills and competences within a personal, civic, social and/or employment-related perspective" (European Commission, 2001, p. 9). A further distinction can be made between formal, non-formal, and informal learning. Different, sometimes contradictory definitions can be found of these types of learning (Colley et al., 2003). We refer to the typology as mentioned by Boeren and Nicaise (2009). According to them, formal learning takes place in a formal context (e.g., schools, universities, and training institutions) and diplomas or certificates are handed out after participation or upon completion. Non-formal learning takes place in similar contexts, but no official diplomas, certificates, or credits are being awarded. Last, informal education takes place spontaneously in everyday life and is mostly unintentional. The training we designed can be categorized as non-formal, as part of adult education in a professional context. Based on the needs analysis conducted among the companies who would follow the training, the "fun factor" was mentioned as an important criterion, next to the learning effect. Additionally, the training had to be suitable for adults with multiple educational and/or professional backgrounds.

Criteria related to time and resources

The second criterion is related to the time investment required from the participants and is partially a consequence of the first criterium. More specifically, since the training is designed for professionals, we decided that it could not last longer than one full working day. Additionally, a shorter, half-day version also needed to be provided, which of course limited us in the design of our training.

The third criterion concerns the available resources for providing training. We decided that it should be manageable for one coach to facilitate the training for several teams at once, with the assistance of one observer. To aid the coach and the observer, enough hardware would be used throughout the training, including participants' individual laptops and mobile devices and a shared monitor per team. Furthermore, we could deploy a digital learning platform designed by our partner FTRPRF and an experience dashboard designed by Augment. Yet, in this design case, we will focus mostly on the development of the CPS curriculum and not on the development of the dashboard since this would lead us too far.

Didactic Principles from the Learning Sciences

In the past decades, significant progress has been made in research on cognitive, metacognitive, and emotional processes in CPS (Kapur, 2016). A great part of this literature was very important for the theoretical basis of our training design, in which we tried to implement multiple principles for teaching and learning. One of the theories within the learning sciences which has been used in our design is the one of "Productive Failure". Another theory that was central to our design and development process is the theory of optimal experience in learning. In what follows we will further elaborate on each of these concepts.

Learning through failure

A specific method that incorporates (collaborative) problem-solving to establish learning is the 'productive failure' method. Designing for productive failure involves two main phases: a generation phase and a consolidation phase (Kapur & Bielaczyc, 2012). Problem-solving (cf. generation phase) is in this method thus used prior to the instruction of the key elements (cf. consolidation phase). Central in the productive failure design is that during the problem-solving phase, learners do not get instructional support or scaffolds. The productive-failure theory is based on earlier research suggesting that in the long term, failure during a learning process can be productive (Schmidt & Bjork, 1992).

The productive failure method is found to have multiple advantages, as shown in an expanding corpus of research (e.g., Schwartz et al., 2011; Sinha & Kapur, 2021). First, it is a great way to activate learners' prior knowledge and form new experiences which can then in turn be reflected upon during a later stage (Kapur, 2016). This is also strongly related to what Jarvis (2010) refers to as experiential learning, which is most effective when the process of learning comes as a response to a problem or a need. Second, it is proven to bring about the earlier mentioned affective benefits such as greater levels of engagement and motivation (Kapur, 2016).

Optimal experience

A central concept in the theory on optimal experience is the concept of 'flow', which is described as "a gratifying state of deep involvement and absorption that individuals report when facing a challenging activity and they perceive adequate abilities to cope with it" (EFRN, 2014, as cited in Peifer et al., 2022, p. 1). Different conceptualizations of flow exist. Recently, however, three core experiences of flow were defined by Peifer and Engeser (2021), including absorption, perceived demand-skill balance, and enjoyment.

To reach a state of flow, it was important for us to activate and challenge our learners during the training. More specifically, we wanted to integrate forms of collaborative learning. Learners are more likely to experience flow when they are activated instead of being passive and when they learn collaboratively instead of individually (Biasutti, 2011; Peterson & Miller, 2004; Shernoff et al., 2003; Walker, 2010). CPS is a specification of collaborative learning requiring a specific task design that we certainly wanted to use. In this case, CPS is thus not only seen as an outcome or goal of learning but also as a teaching method through which these goals can be learned.

In literature, optimal experience is often studied in relation to motivational indicators. These include but are not limited to interest, motivation, and engagement, important aspects for the design of meaningful learning (Renninger & Järvelä, 2022). This is not surprising, since in the early years of the flow concept, Csikszentmihalyi (1975) already referred to it as an experience of "complete involvement of the actor with his activity" (p. 36).

One specific way to foster learners' engagement is by selecting an appealing theme for the training. Remember that our first design criterion entailed that our training needed to appeal to a broad public. Moreover, we wanted to prevent participating teams from relying too heavily on pre-existing knowledge to solve the training tasks and assignments. Our overarching training theme could therefore not be too closely linked with one specific type of industry or field of study, instead, it should be novel to most participants. Therefore, we decided, together with our colleagues specialized in digital storytelling, to build the training tasks around the central theme of space travel.

A second way of engaging the learners is to draw on their experiences and prior knowledge. This aspect is mentioned in the theories of many major teaching and learning scientists (Jarvis, 2010) and is often described as the knowledge integration approach (Linn, 2005). In our training, specific moments were created to discuss prior experiences with CPS which we will refer to later.

(RE)DEFINING CPS

Considering the different givens and constraints of our design task, we decided that it was necessary to look at available literature on CPS to find out how we could teach and evaluate the concept of CPS with our training.

Exploring the Concept of CPS

CPS is considered to be a complex construct (Andrews-Todd & Forsyth, 2020). We therefore first wanted to select a working definition of CPS and a general CPS framework that we could use throughout the design process. Several definitions exist and are being used. One example is the definition by Sun et al. (2020), describing CPS as "the coordinated attempt between two or more people to share their skills and knowledge for the purpose of constructing and maintaining a unified solution to a problem" (p. 2). A second definition is the one of Hesse et al. (2015) who describe CPS as "the joint and shared activity of transforming a current problem state into a desired goal state" (p. 53). A leading resource about CPS is the PISA 2015 CPS framework (OECD, 2017b). CPS is herein defined as one's capacity "to effectively engage in a process whereby two or more agents attempt to solve a problem by sharing the understanding and effort required to come to a solution and pooling their knowledge, skills and efforts to reach that solution" (p. 134). This definition has been and is still being adopted by many researchers in the field (e.g., Fiore et al., 2018; Rosen et al., 2021). We hence selected this working definition to be used in our further work. It is important when talking about CPS to emphasize the difference between collaboration and cooperation. More specifically, CPS is a collaborative process, because partners need to work on a certain task synchronously with interaction and the possibility of negotiation (Dillenbourg, 1999) and because they orchestrate their activities together to complete a task or solve a problem (Hesse et al., 2015). In cooperation, on the other hand, partners divide the work, finish their individual tasks, and assemble their solutions to create a final product (Dillenbourg, 1999).

Along with the PISA definition of CPS, OECD (2017b) also designed a framework for CPS, which can be clearly distinguished from other CPS frameworks such as the one of Hesse et al. (2015). More specifically this framework distinguishes three main sets of CPS competencies (OECD, 2017b):

- Establishing and maintaining shared understanding (i.e., discovering perspectives and abilities of team members, building a shared presentation, and negotiating the meaning of the problem, communicating with team members about the actions to be/being performed, and monitoring and repairing the shared understanding)
- Taking appropriate action to solve the problem (i.e., discovering the type of collaborative interaction to solve the problem, along with goals, identifying and describing tasks to be completed, enacting plans, and monitoring results of actions and evaluating success in solving the problem)
- Establishing and maintaining team organization (i.e., understanding roles to solve problems, describing roles and team organization, following rules of engagement and monitoring, providing feedback, and adapting the team organization and roles).

For an in-detail discussion of each of the sub-skills, we refer the reader to the OECD's (2017b) PISA report.

Making CPS Tangible

The previously mentioned frameworks for CPS were in our opinion not tangible enough for our stakeholders. Therefore, we decided to design an adapted framework for CPS, that could be used within our training. It was important that this framework (a) would be fully adapted to the needs of our stakeholders (e.g., mainly focusing on what is different about working together as compared to working individually) and (b) fully fits within the projects' context, whilst (c) being scientifically grounded.

To get to know the needs of our stakeholders better, an important source of input was Hudson's interviews with a representative selection of nine client organizations, including both public and private organizations, and large as well as smaller organizations. During these interviews, HR managers were asked how their teams were formed, how they communicate and cooperate, how they learn and evaluate themselves, and what changes or evolutions they expect in the future. Two main takeaways could be distinguished.

First, results show that HR managers think that teams need to get to know each other better to be able to collaborate more efficiently. Learning to do so does not seem possible when teams rely merely on guidance and support from the organization. Teams must, in other words, also make their own contribution by learning more about themselves and their specific context to improve their team awareness or team consciousness. This requires a certain maturity and goal orientation whereby teams actively question and evaluate their existence, composition, objectives, and methods. Teams must be able to grow organically and challenge themselves along the way to reach a higher level of maturity.

Second, the input from the organizations brings us to a cliché that is very often referred to: 'communication is key to the proper functioning of a team'. However, transparent and respectful communication is still experienced as a very challenging aspect in many organizations. Teams often lack the trust and informal connectedness to be able to discuss matters openly with one another. Training could certainly be useful in this respect, but repetition and practice will remain necessary.

Next, on a Miro whiteboard, we brainstormed about the ways in which each of the CPS competencies as defined by OECD (2017b) might manifest as concrete, observable behavior during a team task. We did this both for positive and negative types of CPS behavior. In Figure 2 we show how this was specifically done for the competency 'discovering perspectives and abilities of team members.

Subsequently, based on our overview of the different behaviors we wanted to observe, we also thought about how we could trigger each of these behaviors through learning activities. More specifically we searched for task characteristics that would aid in making these behaviors observable and measurable during CPS. For the competency of 'team awareness', for example, we noted that typical behaviors could be triggered through assignments for which certain skills are needed that not every member of the group would possess. This way, we would be able to observe whether teams succeed in identifying and efficiently deploying their members' skills. Another competency is related to 'team flexibility'. For this aspect, we noted that it could be

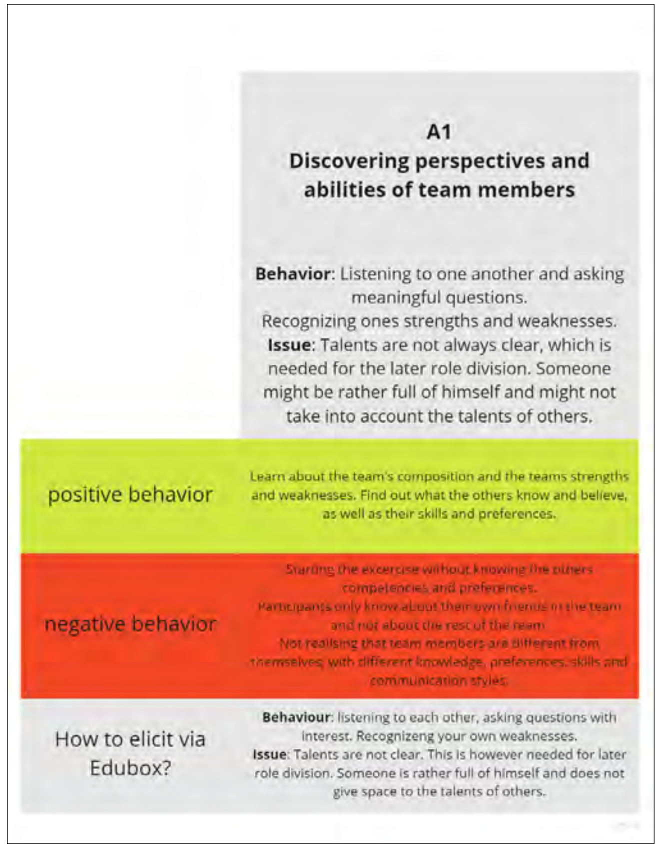

FIGURE 2. An exemplary section of our translation of CPS competencies into specific behavior.

triggered through an activity in which unexpected things would happen that would throw the teams' action plans into disarray. The characteristics we defined here would be of great importance for further design.

DESIGNING THE TRAINING

Developing the Different Parts of the Design

Based on the instructional principles coming from the learning and teaching approaches mentioned earlier (e.g., CSCL, CPS, productive failure), an overall blueprint with different training parts was defined, as shown in Figure 3. The following parts can be distinguished: a general introduction to the training and the space travel theme, a 'selection test' activity based on principles of productive failure, an instruction part with explanations about four CPS 'building blocks', an 'end-game' activity, and a general debriefing part. After defining the overall structure, the individual parts were further developed. Throughout the development of these different parts, we encountered several difficulties. These can be referred to as examples of design failures (see Lachheb, 2020). These design failures will also be discussed more in-depth since they helped us to improve and finetune the development of our final design.

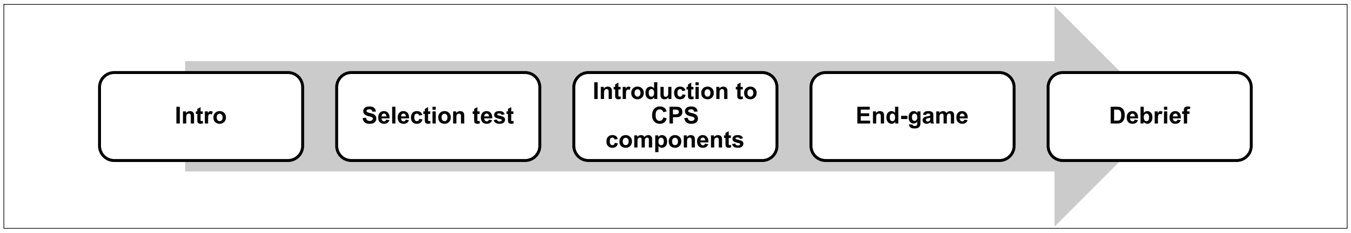

FIGURE 3. Blueprint of the training.

In what follows we will further discuss the development of each of the parts in chronological order of the development process. This means that we started with the development of the instruction part (part three), followed by the development of the other parts. We chose this strategy because the other parts needed to be in line with the content presented in part three.

Part 3: Introduction to CPS Building Blocks

The third part of our training needed to include the instruction of different CPS building blocks and how these can be put into practice on the work floor. These building blocks were selected based on the existing CPS frameworks (e.g., OECD, 2017a, 2017b) and were restructured and renamed according to the needs discussed earlier. More specifically we selected four main CPS building blocks (see Figure 4), which were introduced in the following order:

- **ALIGN**, i.e., exploration and building shared understanding.
- **ACT**, i.e., team planning, coordination, and execution.
- **GROW**, i.e., reflection, debriefing, and team climate.
- **COMMUNICATE**, i.e., efficient and respectful communication styles, which runs across all steps of the process.

Subsequently, we developed various instructional materials for each of the principles, based on what was found in the literature, and on the experiences and knowledge of the different partners involved in the development of this part. The materials used here mostly consist of textual slides, that either must be used at the individual level, the team level, or on the class level together with the support of the trainer.

To make this part more engaging and fun, we also included videos with real-life testimonials or funny television fragments, and do-and-reflect exercises at the team and class level. For example, the trainer asks the teams to reflect on personality differences within their team and on how this affects their team's functioning.

Try-out and feedback

When a first draft version was created, we wanted to get feedback on the design, so the Hudson contributors asked some of their colleagues to form teams and go through one of the building blocks (i.e., align, act, grow, communicate)

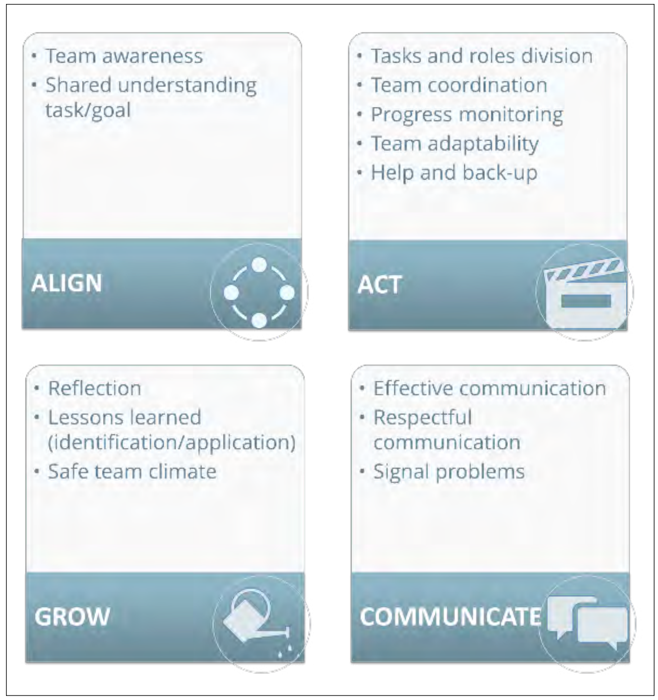

FIGURE 4. Representation of the CPS curriculum principles in our training.

from the perspective of a participant in the training. This helped us establish a realistic timing for each of the blocks. During these tryouts, participants were observed using an observation template. The observant paid attention to any problems or successes encountered; what went well or wrong; and what technical problems eventually occurred. Specific observations listed in the template were, for example:

- Do the participants pay attention?
- Is guidance from the coach needed? At what moment?
- Are the assignments clearly understood?
- How are the group dynamics?
- How does the trainer give guidance?

At the end of each try-out, participants completed a short feedback questionnaire and participated in a group-level discussion where questions were asked such as:

- What do you think of the content?
- What do you think of the timing?
- What tips do you have for the designers of the training?

- Would you like to do this again in the future?
- Would this be appropriate as part of a team building/ workshop?

In general, the feedback received on the first design was already promising. The content was found to be interesting even for people who already had experience with the CPS building blocks. Participants also appreciated the format and the design, "with a good balance between theory and fun". There were, however, also some opportunities for improvement. A participant for example mentioned that sometimes, there was too much text, which was discouraging. Participants also mentioned that they would have liked to see an overview of where they were in the process and how much time they had left to go through a certain part. Additionally, they mentioned that they would have liked to get more concrete feedback on their current team functioning: "I know that within my team, we are all very different, but how should we improve our cooperation and what are our action points?" Based on this feedback we could already make some first modifications.

Designing a shorter version of our introduction to the CPS components

In the next stage, we also designed a shorter half-hour version of this part of the training. This is in line with our second design criterion. In this part, we still want to provide the learners with the key information about the four CPS building blocks, so that they would be able to implement these both during the final 'end-game' activity and in their day-to-day work.

Initially, we chose to provide as much theory on the four building blocks as possible during the shortened part three and to leave out most of the interactive moments that were included in part three of the full-day training. However, our first try-out of this version showed that this was not a good choice, since there was a great lack of attention from the side of the participants. Moreover, participants indicated that "this training was too boring and too much". Towards the end of this part, there was however one interactive moment foreseen, in which participants were asked about their own experiences with a specific feedback technique. This was the moment where we could clearly see participants 'come back to life' and become much more engaged. This finding is in line with research on classroom orchestration, suggesting that a combination of activities on different social levels (i.e., individual, team, class) is beneficial for learning (Olsen et al., 2019, 2021). Consequently, we concluded that the interactive moments were crucial for participants to really learn something. Even if time spent on interactions would come at the cost of the time available for explaining theoretical content, we preferred participants to be more engaged so that they would remember what they learned afterward, as opposed to bombarding them with a lot of content that would not be processed as they would not have a chance to reflect on it and search for ways to apply it in their own context.

Again, the try-out pointed out some issues in the design that we considered for the re-design. More specifically, for this shortened version, we decided to reduce theory and focus mainly on reflection by asking questions about the teams' own experiences with the CPS building blocks (both during the first activity and on the job). This enables active processing of the learning material, through activating prior knowledge and "guiding the activation of new knowledge" (Craig, 2019, p. 262).

Part 1: Introduction

Triggering interest within our learners was one of the main aims of the introduction since interest has the potential to positively influence learning, understanding, engagement, and performance throughout the rest of our training (Renninger & Hidi, 2020). In our introduction, we more specifically tried to grab the participants' full attention and generate excitement about what is to come. To this end, a video was shot and edited in which the training topic (CPS or teamwork in the context of space travel) is introduced by a famous Flemish weathercaster (Frank Deboosere) that all participants know. In the video, the weathercaster states that currently, the world is more than ever before challenged with wicked problems (see Lönngren & van Poeck, 2021; e.g., climate crisis, fake news) that can only be solved by bringing collaboration to the next level, which is what they will have to do in the training. Besides generating interest, this introduction also elicits uncertainty and curiosity among the learners because specific information about what is coming next, and how they must bring this collaboration to the next level is lacking. Feelings of uncertainty are shown to have positive effects on learning (Lamnina & Chase, 2021). This is also in line with the theory of productive failure (Kapur, 2008, 2016), to which we referred earlier.

Additionally, in this part participants also meet their virtual assistant (see Figure 5), who communicates messages from the World Aeronautics and Space Agency (WASA, fictional name), and sometimes pops up on the digital learning platform. At the end of part one, the virtual assistant introduces part two of the training.

The combination of the content in the introduction video and the explanation by the virtual WASA assistant invite the learners to take on an unfamiliar role and to imagine themselves in another world, a context that is (at first sight) unrelated to their daily work environment. Although this might seem more challenging, learners indicated that this fictitious context made them feel safer. They were more inclined to be assertive or experiment with new roles since every team member started with a similarly low level of prior knowledge, which is different compared to normal work settings where some team members may have much more

FIGURE 5. The WASA assistant introducing the next part.

experience than others. In literature, this feeling of safety is seen as one of the prerequisites for experiencing flow on the team level (van den Hout et al., 2018).

Part 2: Selection Test

In the second part of the training, we further implemented the principles of productive failure. As explained, this is a form of intentional failure in learning (Kapur, 2008, 2016). Within our space-travel theme, we designed an activity that requires teams to take a so-called 'selection test for space exploration', during which they need to solve as many problems as possible within 30 minutes. Prior to this exercise, participants did not receive any instructions or guidelines for their collaborative endeavors. In other words, learners do not get insights as to how this CPS process can be done most effectively.

We decided to add gaming elements to this part, to make the activity more fun, and thereby increase the participants' involvement and motivation. Besides giving the game a particular look-and-feel, reminiscent of computer games in the eighties, we also added a summative assessment element to the exercise. Points had to be earned by successfully completing the various 'missions' which were presented in a multiple-choice question format. The more correct answers they could find as a team, the more points they would receive.

Additionally, the selected assignments needed to be complex enough to require collaboration (e.g., by dividing the tasks or by calling upon team members' specific talents at the right times). This type of collaboration in turn also needed to be sufficiently observable, so that participants could reflect upon it in the next parts of our training. To stimulate this, we wanted to create missions that would address a wide range of abilities (e.g., verbal, numerical, logical reasoning, spatial insight, detail orientation, memory, gaming…), which would help in creating an activity that could be fun for most participants.

The design of the mission content very much relied on the experience of the contributors of Hudson, since they offer all kinds of (individual) reasoning ability tests that are developed and validated by the Research & Development department. The missions designed for the 'selection test' activity were thus mainly inspired by their item portfolio. However, due to the specific characteristics of our activity, new types of assignments needed to be created, an example of this is a mission that requires participants to spot the differences between two pictures (see Figure 6), and then pick the correct number of differences out of three options.

Individual and team scoring

To evoke behavior related to the 'alignment' building block (see Part 3 and Figure 4) and in line with the requirement of individual accountability (cf. Johnson & Johnson, 2009), we thought it would be interesting to work with both individual scores and team scores. We expected that by doing so, we could create some tension between a focus on individual outcomes (competitive approach) and a focus on group outcomes (collaborative approach), which would in turn be indicative of team alignment. Within the design, we, therefore, decided that participants should view the mission assignment together on the teams' shared screen, but that they had to answer the multiple-choice questions individually on their personal devices (smartphone or tablet). A mission ended when all four team members submitted their answers. At that moment, both the individual and team scores are shown on the team's shared screen (see Figure 7).

The quicker participants can select the correct answer, the more points they earn. In the visual presentation of the individual points, we decided to use bars, so that it would be easy to see who is ahead or behind and by how much. We expect such a presentation to trigger within-team competitiveness for some individuals. Accordingly, the team score is higher if the team can find many correct answers quickly. However, the teams get penalized if members select different answers, or if there are large speed differences between team members who select the correct answer. So, while some participants' individual scores can be high, the team score will be low if the members do not 'align', i.e., if the ones who find the correct answer do not stimulate the others to

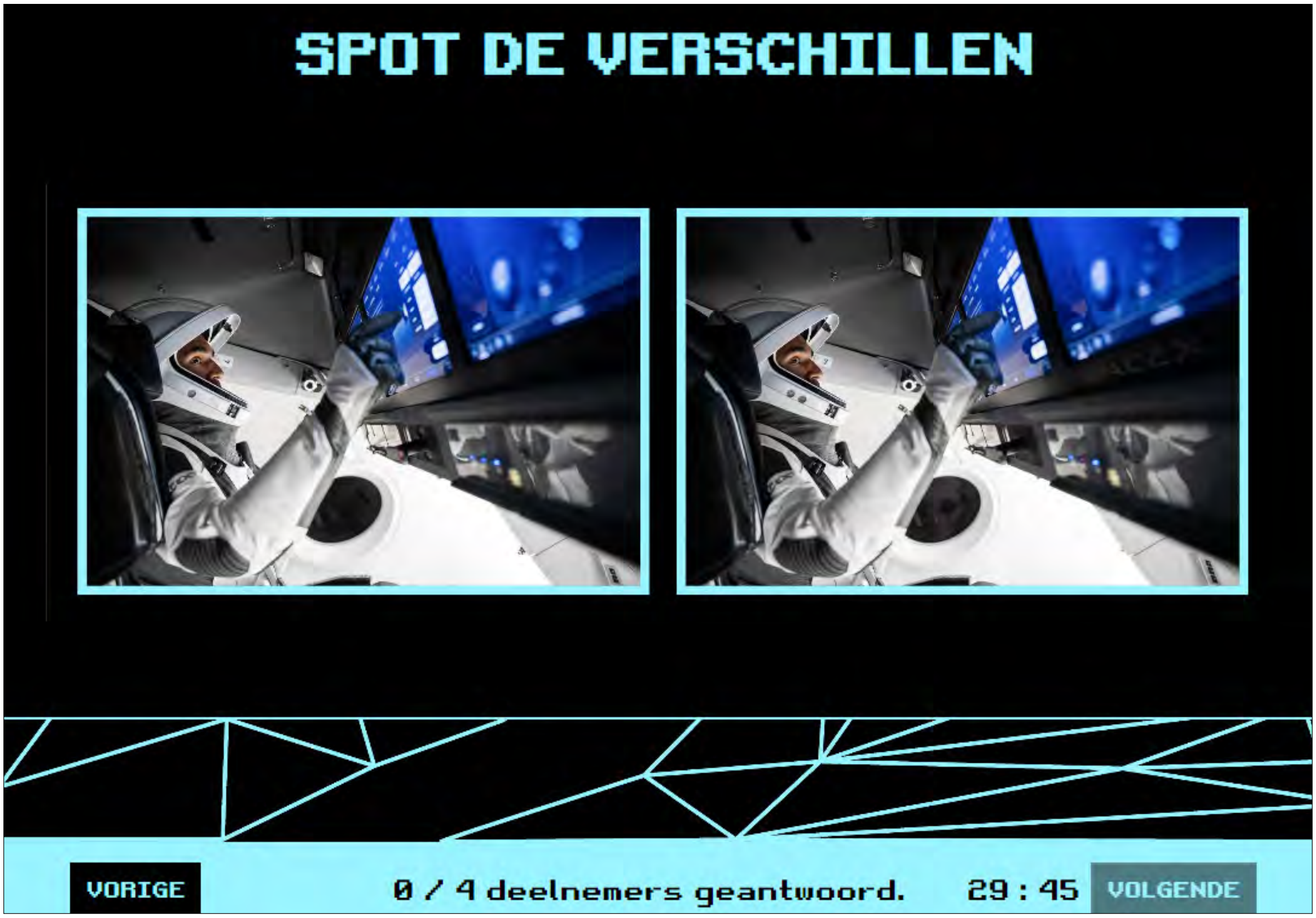

FIGURE 6. Visualization of the WASA selection test mission 'spot the differences' (example of the Dutch version).

choose that answer and wait for them to do so. Teams do not know in advance how the scores are calculated, so they cannot adapt their strategy accordingly.

Tryout and feedback

As with the content designed in part three, we also conducted tryout sessions for the selection test activity in part two. A first try-out was done with close collaborators within the STEAMS project consortium, with the aim of creating a selection of usable missions. Some assignments turned out to be too time-consuming, were not explained clearly enough, or were not suitable for a multiple-choice format. These assignments were either deleted and replaced or adapted if possible. Subsequently, an iterative process of tryouts and adaptations followed, until we were satisfied with the design. As expected, participants reacted in diverse ways to the assignments. In this regard, Figure 8 is a vivid example, showing the variety in participants' facial expressions and body postures while carrying out the selection test activity. More specifically, it depicts frustration, concentration, amazement, and joy.

The feedback we received from participants, both during and after the try-outs, through group discussions and questionnaires, was very diverse. One of the participants, for example, mentioned that this activity "directly makes you feel the group's dynamics". Similarly, another participant mentioned that she liked the way this selection test brought focus within the team. Although many of the participants appreciated the gaming elements and referred to "a good mix of exercises" and "a nice design and great experience", this was not always the case. One participant, for example, mentioned that the way the exercise was conceived, through sequential assignments, made her experience a lot of pressure, which was at certain moments a bit too much. Similarly, for some individuals, the complexity of the assignments led to frustration, "because they could not find the right solution". As designers, this reaction did not surprise us as this result was expected in a productive failure design. More specifically, it was mentioned by some of the teams that there was no time to discuss the individuals' qualities to divide tasks in an optimal way, which they found frustrating, yet this was exactly what our design aimed for. This failure created the learning opportunity to reflect on indicators for qualitative group work in the following instruction phase (see Part 3).

FIGURE 7. Overview of the individual and team scores after participants responded (example of the Dutch version).

FIGURE 8. Visualization of the participants' facial expressions during the selection test assignment.

Part 4: End-Game

The main purpose of the fourth part of our training was to have an activity during which the teams could implement the principles learned in the previous parts. However, we also wanted to give enough liberty to the teams as to how they choose to collaborate. For the trainer, the activity needed to provide an opportunity to observe and assess the learners' CPS competencies on a team level. This also means that the activity needed to be sufficiently long and complex. Again, the expertise of Hudson regarding assessment tools was very important in the development of the end-game. Hudson designs simulation exercises for assessment centers (e.g., case studies, situational judgment tests, role plays, group exercises, analysis, and presentation exercises) on a regular basis. In line with one of their previous exercises in which teams had to make a design for an office building, we wanted to design a similar exercise adapted to the training's general theme (i.e., going into space). This way we came up with the overall goal of designing a space habitat (i.e., the "Invicta" base) on a newly discovered fictional planet (see Figure 9).

FIGURE 9. Introduction of the end-game by the virtual WASA assistant.

The general task design

In our exercise, participating teams need to design a temporary settlement (the Invicta base) on a new planet to conduct research, within a limited amount of time (approximately one hour and a half). To do so, participants have to analyze different sources of information that describe stakeholder needs, available resources, and specific constraints relating to the terrain, the budget, and interdependencies between the needs. When developing this part of the task, we began by noting down general components that would be necessary for a space habitat (e.g., energy supply, food supply, shelter, medical supplies, water, etc.). Starting from these elements, we made a more detailed list of objects, resources, and buildings that we would further need. We made sure to think out various options, with "good" alternatives and some weaker or wrong alternatives, each with a set of pro and con arguments. For example, to have water on the Invicta basis, water pumps, water reservoirs, and a wastewater treatment plant would be needed, and participants have to choose between using water from nearby a river or groundwater. For each of the components, we noted down some characteristics (e.g., why it is important, the surface area needed for it, terrain characteristics to be able to build it on, how much it would cost, etc.). The teams must decide what to purchase (and what not to purchase) with the available budget and how to fit the chosen components on the available surface area.

The amount of information to analyze needed to be large enough, so that (considering the time constraints) it would be impossible for the members within a team to each analyze all the information. A large amount of information would require them to divide tasks from the beginning. This way we could stimulate a perception of positive interdependence among team members, meaning that they have the feeling that "they can reach their goals if and only if the other individuals with whom they are cooperatively linked also reach their goals" (Johnson & Johnson, 2014, p. 1).

The next step was to spread the different pieces of information and pro and con arguments across different documents so that it becomes more of a "puzzle" to solve. These documents include, among others, an official letter from WASA,

Helen Winter

Interview with the Research Coordinator

The main purpose of the mission is research. Therefore, I expect that my input will be the most important for the design of the base.

For the research activities, I need at least the following infrastructure:

- A **lab**, with sufficient storage space and . . .
- For the **research of food crops** we need a piece of agricultural land of 40 square meters on which we will try to grow some basic crops.
- . . .

FIGURE 10. An excerpt of one of the team leader interviews.

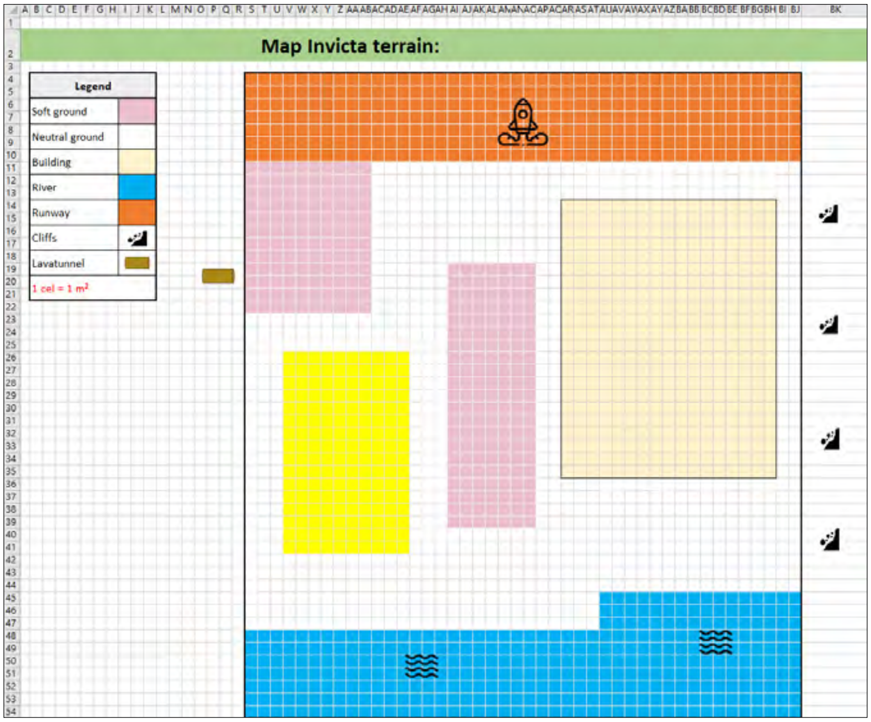

FIGURE 11. Overview of the Invicta base.

interviews with Invicta project coordinators (see Figure 10); a report on new technologies; a map of the terrain they must use to build on (see Figure 11); a price list of all possible items they can buy, and an inventory of materials already on site. In other words, only if team members study all information carefully, and effectively communicate about the information they analyzed, the team could be successful in solving the problem.

Important elements for CPS

Since we wanted to observe several CPS competencies during the task execution (see Figure 4), we implemented multiple specific elements in the task design. The first element is related to the information provided through the interview with Invicta project coordinators. The information provided through these interviews is sometimes conflicting. This could lead to meaningful discussions among team members, which is an important element of good CPS.

Another part of the challenge is that for the design of the Invicta basis, teams need to consider limitations regarding the surface area of the land to build on and available resources (e.g., budget for buying new goods; already available goods; metals...) to build with. In addition, the various goods and components may involve some specific constraints and interdependencies, which means that participants must study all the info carefully to put the puzzle together in the right way.

To challenge and assess the teams' adaptability, we implemented several side tasks, due to which teams cannot always stick to their initial plans. This was done through the virtual WASA assistant (see Figure 12). After 30 minutes of working on the main assignment, for example, the teams receive a message from the WASA assistant that two volunteers who would originally participate in the space mission do not longer wish to take part. The teams' assignment is therefore to draft a creative and attractive advertisement to recruit new volunteers. In another side task, teams are instructed to delegate two of their members for a "digital agility assessment" by WASA. The assessment itself is a small computer game with different levels that is played in pairs. Normally, the agility assessment takes ten minutes. However, if a pair succeeds in reaching the third level faster, they can rejoin their team sooner.

During the end-game, failure is also elicited by not giving all the information at the beginning of the exercise. For example, at the start, teams get too little budget to buy everything they need, which makes their first plans to be doomed to fail. Only after 40 minutes, do teams get some important updates on budgets and recourses. However, at this moment in the exercise, they have already made decisions about many aspects of their Invicta base, which they will need to revisit.

Crucial moments in the design of the end-game

When designing and developing this part of the training, we again encountered some difficulties and challenges. More specifically, it was important to find the right balance between the time constraints and the amount of information and resources provided. This was hard to estimate in advance. Hudson's expertise is mainly related to the assessment of individual performance. In their standard group exercises, every group member gets to read the same information individually after which group members come together to discuss and solve a problem. By contrast, in the current activity, performance is assessed at the group level and teams have to divide the materials themselves among their members. When we first tried out this part with colleagues (see Figure 13), we found that the exercise was too complex. There was too much information and too little time so the teams did not manage to process all information, which subsequently led to a negative feeling, instead of optimal experience (i.e., flow experience).

This observation is in line with research on optimal experience. More specifically, to experience flow, a balance between the difficulty of the challenges to be tackled and the

FIGURE 12. Dutch version of a message by the WASA assistant (virtual moderator) with one of the side tasks.

FIGURE 13. Visualization of the first try-out of the end-game.

FIGURE 14. Visualization of one of the try-outs in a lab-setting.

learner's perceived skill level is important. Adding complexity to the task makes it more challenging, and at the same time causes a lower experienced skill level, which can subsequently lead to worry or anxiety (Nakamura et al., 2019). Therefore, we had to simplify our exercise: some of the information and discussion topics were removed so that the word count decreased by 30 percent; we restructured the remaining information more clearly; we made a new map for the Invicta base that was easier to use; and we provided extra tools that could help them, such as a budget calculation template.

After this phase, we conducted some new tryouts with different teams (See Figure 14). These were satisfying since the trainers who facilitated these tryouts indicated that they could see interesting differences in how teams approached both the main and the side assignments. One team divided the tasks immediately and was quick to tackle the side assignments with lots of enthusiasm. Another team did everything together (hardly dividing any tasks) and chose to first complete the main task and then spend the remaining time (if any) on the side assignments. Participants also indicated that they enjoyed taking part in the end-game, although most of them found it challenging. Especially the different side tasks made it overwhelming at times, according to several participants. For

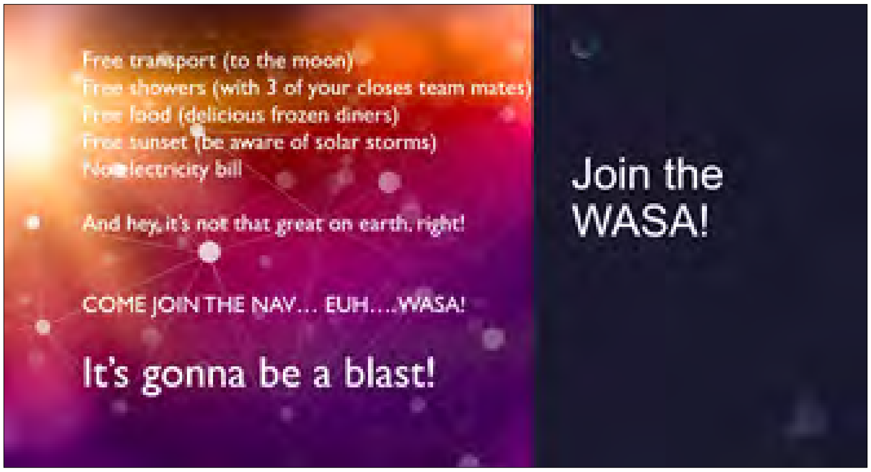

FIGURE 15. Example of the output of the creative assignment.

example, one participant said during one of the group discussions: "it was annoying that these extra assignments kept interrupting our work, but that also happens sometimes in real life". Also, the coaches could observe that some teams were clearly annoyed by the side tasks. One participant, for example, said "shut up WASA" at a particular moment when the WASA assistant popped up. Nevertheless, some participants did enjoy completing the extra assignments and appreciated the fact that these tasks drew on very different skills (e.g., creativity) compared to the main assignment, which was very analytical. One participant liked that they "could really do their thing" with the creative assignment, which was also reflected in the output they produced. An example of this output is provided in Figure 15.

Part 5: Debriefing Activity

The fifth and last part of the training is a debriefing session, in which learners again get to reflect on the process of the last CPS tasks. During a debriefing session, the coach aims to turn participants' experiential knowledge into academic knowledge (Jermann et al., 1999). By means of debriefing activities emergent knowledge is structured by the teacher or learning coach based on previous CPS activities. During the debriefing session, the coach can make use of the experience dashboard, which is without the scope of this design case, but it is important to mention that several parameters are stored during CPS task completion. It was the role of the coach to synthesize the results and link them with the theory on CPS which was presented in the training part.

CONCLUSION

In this design case, we described the development of a training on CPS for adults with a wide range of backgrounds. Central in the design of our training was the implementation of principles of collaborative learning and productive failure for learning. Furthermore, we also tried to promote learners' optimal experience through our design. Throughout the design process, critical events of design failure emerged, which we discussed more in-depth. These events were very important for us to improve our training design and to create optimal educational experiences in the future.

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