

SERIOUS GAMES AS A MEANS FOR SCIENTIFIC KNOWLEDGE TRANSFER - A CASE FROM ENGINEERING MANAGEMENT EDUCATION

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Abstract—Disseminating scientific findings through journal publications is in the very nature of every academic discipline. However, with the emergence of the knowledge society and lifelong learning needs, there is a growing demand for alternative ways to enhance the dissemination of research findings to a broader audience than academics and young students.

In this paper, we first introduce the concept of serious games as a well-acknowledged alternative method to discourse and deliver current engineering or management-related research findings to society. Then, considering the lack of a unified serious game design framework and the gaps in the extant literature, we illustrate our design rationale for the development and evaluation of serious games. The proposed framework contributes the following advancements to the body of extant literature and practices: i) it is strongly centered on a well-known knowledge transfer framework and ii) it is strongly based on a participatory design approach, deliberately involving iterative and frequent testing and fine-tuning sessions, overcoming the inherent limitations of traditional stage-gate or waterfall development models. We conclude by providing some insights gained during the development of the game and the framework as well as by discussing the challenges associated with the design and use of serious games as an alternative genre for disseminating engineering- and management-related research findings.

Managerial Relevance Statement—Business professionals, particularly knowledge workers, are in constant need of educating themselves to stay up to date with the newest findings from science and technology in their field. Because time is becoming a scarce resource, classic knowledge transfer approaches, such as large handbooks or lengthy training sessions, may no longer be suitable. This paper presents serious games as an alternative method that may accelerate learning, increase motivation, and support the development of higher order cognitive thinking skills. More specifically, based on an educational game from the area of engineering management, this article describes a basic pathway for how to create and evaluate this serious game. The findings indicate that the journey through the intervention phases of a serious game is fraught with uncertain and unstructured aspects. Substantial benefits may come from the possibility of replicating the game in different contexts and under different circumstances, providing a flexible tool that is suitable for contemporary education of business professionals.

Index Terms— Serious games, knowledge transfer, management learning.

I. INTRODUCTION

In disseminating and transferring research results into practice, journal publications play a significant role in engineering management. While many researchers argue that peer-reviewed articles in prestigious outlets represent the most valuable form of communicating and transferring research to practice [1], others follow the belief that scientific findings should be much more integrated into professional education, leading to research-based training programs, such as those that are common in clinical psychology [2]. Additionally, they should be much more open and directed to all of society or, at least, to professional non-scientists [3-5], which is particularly evident in the current proliferation of open access publishing or content delivery in the so-called “blogosphere” [6]. However, despite the efforts of making research more accessible and more comprehensible, the interaction between scientists and society (or “practice”) still relies mainly on one-sided written communication.

With the emergence of the knowledge society, many professions, such as software engineers, health workers, or business managers, have an inherent need for lifelong, culturally adapted professional learning [7]. Furthermore, the Accreditation Board for Engineering and Technology also makes demands on the recognition of and the ability to engage in lifelong learning an expected student outcome of engineering baccalaureate and masters level programs [8]. Given this background, we challenge the notion that scientific knowledge transfer should be in written form and directed to peers only and discuss possible alternatives to enhance the dissemination of research findings to a broader audience than academics and young students.

To this end, we first present serious games as a well-acknowledged alternative approach through which researchers may effectively interact with professionals and convey research findings and ideas into practice. Then, we focus on the serious games development process, illustrating a new design framework that is built upon the seminal knowledge transfer

framework [9] and adapted for our purposes, as depicted in Figure 1. This framework represents the main original contribution of this paper: connecting a design research approach with a knowledge transfer framework to inform the development efforts towards effective serious games.

To support our work, first, we provide a review of the extant literature on serious games and potential learning outcomes and benefits associated with using such games. Second, we present detailed information about a serious game that we developed as part of our dissemination strategy along with the design of distinct algorithms for a decision support system (DSS) in the area of supply chain management (SCM) [reference blinded for review].

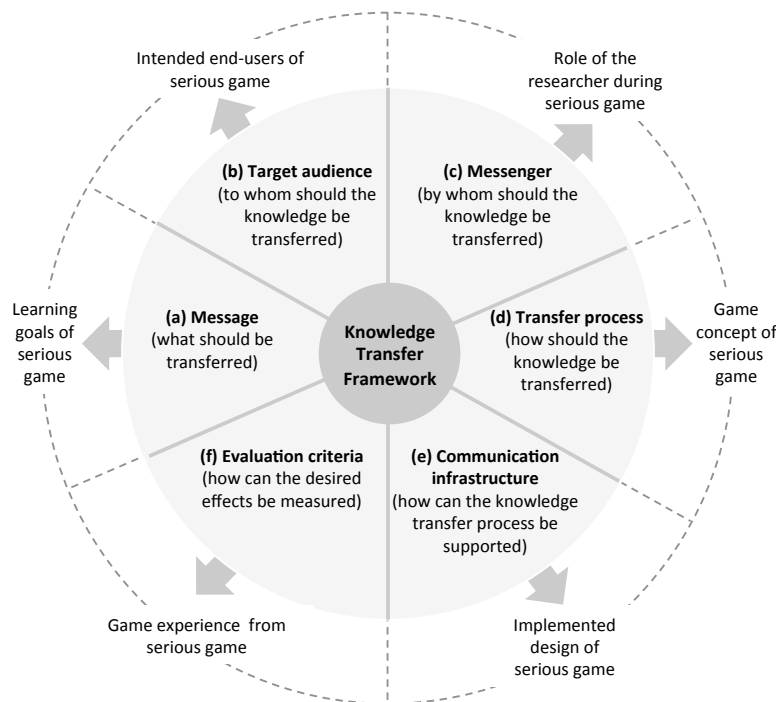


FIGURE 1. THE REFERENCE KNOWLEDGE TRANSFER FRAMEWORK, BASED ON [9]

In this process, we do not focus on the technical aspects of the developed game but rather on the development process of the game. Using the action design research approach, we illustrate how the game was conceived and designed, as well as what impact it had on the learning experience of business professionals. From a pragmatic standpoint, this paper

presents a first rationale for designing and evaluating serious games as part of research projects with strong focus on practical problem solving and knowledge transfer. From a theoretical standpoint, we discuss the challenges associated with the design and use of serious games in practice.

II. SERIOUS GAMES: AN OVERVIEW

Playing games is an activity connatural to human growth and development processes. It is the first form of learning we usually experience in our childhood, as we are born with an innate attitude and urge to learn through experimenting actions and evaluating their consequences.

As the types of games we play change through time, there is consensus in the fact that we can still learn concepts, skills, and knowledge by playing games throughout our entire life [10]. Therefore, there is growing interest in the possibility of using games to communicate the results of research actions, providing the content for training at very different levels, from scholars to professionals. For our purpose, the term “training” holds a very wide meaning: it refers to the acquisition of knowledge, skills, and competencies (i.e., the message in the knowledge transfer framework [9]) as a result of a communication process (not exclusively verbal) between a source (i.e., the messenger, which is the subject providing the contents) and one or more recipients (i.e., the target audience, the people who learn, or learners) through one or more channels (i.e., the knowledge transfer process and the supporting communication infrastructure). In the specific case discussed here, the source is represented by the researchers providing the results of a research action or project, for example, while the recipients are business professionals, and the channel is a properly designed serious game with a strong link to the knowledge transfer process. In this respect, for our purpose, a game is meant to be an environment specifically designed for players to temporarily live in, make decisions, define strategies, and acquire experiences (in general, but not exclusively, in terms

of victory or defeat) interactively through play.

These experiences may become part of the player's background and knowledge; consequently, a serious game should not be considered just as an activity engaged in for the sole purpose of diversion or amusement. In particular, serious games are games specifically designed with an educational aim, a training purpose, and/or a behavior change incentive [11, 12].

A. Seriousness of games: What makes them serious?

The serious games concept has a long history in different fields [13]. Normally, people do not associate games with anything serious because the common association is, indeed, with entertainment. Games are usually perceived to have a prevalent hedonic component (we play games because we have fun and pleasure in doing this), while the word “serious” suggests the exact opposite. We can state that the “serious” component of a serious game is related to the purpose of the game, i.e., why it was created and for what it is used, whereas the “game” component is related to the method used to achieve the purpose [11]. In other words, a serious game is a game with a primary purpose other than pure entertainment [14]. In particular, in serious games, the purpose is related to training (in the wide meaning discussed earlier) and learning. It is meant to convey messages for training purposes or to develop certain skills and behaviors that are transferable to the real world. All of these purposes can be accomplished using artificially generated conflicts to raise challenges for the users, according to a deliberate practice principle [15], i.e., “presents performers with tasks that are initially outside their current realm of reliable performance, yet can be mastered with practice, gradually refining performance through repetitions after feedback.” Key requirements of deliberate practice are demanding (but not impossible) tasks, specific goals for improvement, continuous feedback, and opportunities for repetition. Serious games may offer the right environment for fulfilling the indicated requirements. There exist many game

genres, from advergames (used to advertise products, concepts or viewpoint through games) to exergames (games helping people exercise), and many others [16, 17]. Moreover, they can come in very different forms, as they range from pen-and-paper-based games or board games, to more advanced ones based on computer technology (i.e., simulation) and advanced graphic capabilities.

Indeed, using games instead of (or sometimes, more appropriately, in conjunction with) traditional methods has been proven to be more effective when the result to be achieved is not merely notional. The research literature suggests that, even though it currently is not clear which knowledge transfer process should be used in what context, passive processes are less effective than interactive and engaging ones, regardless of the audience [9]. Games can arouse emotions (amusement, happiness, anger, frustration, etc.) that seem to open direct channels to our mind, allowing for a quicker and deeper grasp of the new knowledge, concepts and skills, and a longer retention in our memory [18]. Furthermore, to succeed or proceed in the game, the players typically need to develop a variety of strategies and skills applying the new knowledge acquired in previous game stages [19]; therefore, games are educationally sound as they require the player to learn and recall rules, game mechanics, and processes [17].

B. Learning outcomes and benefits: Why should we play more?

Serious games might provide a useful and attractive method for communicating the results of research. In fact, modern theories in the field of training, learning, and education suggest that learning is most effective when it is active, experiential, situated, problem-based, and provides immediate feedback [20]. Serious games provide a platform for active learning. In this respect, players learn by doing rather than solely listening or reading, benefitting of active discovery and developing new types of comprehension [17]. Furthermore, players usually enjoy playing games, and these positive emotional experiences can intensify the

learning experience.

It is possible to identify distinct learning outcomes [21], such as knowledge acquisition and content understanding, perceptual and cognitive skills (context awareness, memory improvement, problem-solving attitude, etc.), behavior and attitude change (leadership and trustworthiness), physiological outcomes (emotions), and social/soft skills outcomes (team working and communication skills). Clearly, the performance measures for knowledge transfer should be appropriate and carefully tailored to the target audience and to the pursued objective [9].

Another well-known advantage of using serious games is to allow players to experience situations that are impossible in the real world for reasons of safety, cost, time, etc. [22]. Serious games provide a safe, cost-effective tool for training in hazardous circumstances or situations that are time and labor intensive to set up in the real world [17]. In addition, serious games can have positive impacts on the players' development of several different skills because serious games can be associated with experiential learning [14]. Serious games allow for a shift from learning a concept based on read-and-memorize to learning a concept based on the ability to find and use information, at the same time enhancing the engagement of the learners [23].

In summary, it is possible to emphasize three main reasons for the ever-increasing use of serious games in professional education: (a) they use actions rather than explanations and create personal motivation and satisfaction, (b) they accommodate multiple learning styles and abilities, and (c) they foster decision-making and problem-solving activities in a virtual setting [24].

All of these elements demonstrate that the use of serious games can be an effective means for communicating and disseminating research results beyond the academic audience, possibly helping to strengthen the bonds between science and society.

C. Serious game development frameworks: How are serious games currently developed?

A substantial impediment to the diffusion of serious games as a widespread tool for education and training seems to be still represented by the usually large efforts involved in their development process, which has proven to be complex, time consuming and costly [25]. To date, a dedicated, unified framework for educational games seems to be lacking [26]. Indeed, existing approaches and toolkits for developing leisure games cannot simply be transferred to education, due to their different characteristics [27]; furthermore, the use of these existing methodologies and their toolkits might even be detrimental for developing serious games in higher education because they pay only scant attention to education and learning [25].

A reason for this lacking can be attributed to the number of different disciplines usually involved in this endeavor: from the client who specifies his needs and constraints to cognitive specialists, from pedagogical experts to software developers, among others. Practice has shown that it is very difficult to obtain all of these actors to collaborate and communicate in an efficient way [28]. The result is a largely fragmented domain with no unified views on design methodologies and the underlying theories.

Considering existing frameworks for serious game design, diversity and fragmentation are confirmed by the variety of sources where such contributions have been published, spanning simulation, gaming, education, learning and psychology journals, books and conferences. For example, [29] have developed the Mechanics, Dynamics, Aesthetics (MDA)-framework, a formal approach to understanding games, attempting to bridge the gap between game design and development, game criticism, and technical game research. The MDA framework was originally conceived for entertainment video games development; therefore, to overcome its limitation for educational and training use, [30] proposed the Design-Play-Experience (DPE)-framework to address the need for digital game design approaches for learning purposes.

According to the DPE, in the game design process, three components are primarily involved: the development of the game by the designer (Design), the playing of the game by the player (Play), and the experience the player derives from playing the game (Experience). The DPE framework inherently reflects the iterative process of game design [31], including designing, prototyping, testing (through playing the game), and iterating back to the design based on the experience and feedback.

From a different point of view, [26] the four-dimensional framework (4DF) starts from the primary triad of features concerned with learning and new technology (student/learner, teacher, and tools/resources available) and extends to a fourth dimension encompassing representational issues. Although the 4DF is mainly for evaluating games, it may also provide support in the design phase; to this end, [26] went deep into the learner dimension, describing a framework and development process and helping to ensure that a serious game satisfies the needs of the target audience, relying upon close inter-working between the targeted user group and the development team.

Noticing how learning has changed from being able to recall information to being able to find and use information, [23] illustrate an Input-Process-Outcome game model as a key component in the game cycle: an iterative judgment-behavior-feedback loop, engaging the user in repetitive play over time. However, as stated by the authors, the game cycle is a defining characteristic of computer game play where the skills to be transferred are better acquired through repetitions, while it may not be the same for other types of serious games, where the goal is to inform and to create awareness; in these last cases, the game will be played just once by a player, and repetition would not provide major learning benefits.

Following [32], six “I’s” of serious game design can be differentiated: these I’s involve the identity of the player in the game and the world where the player is immersed. Players should interact with each other and face increasing complexity as the game progresses. Feedback and

embedded assessment within the serious game are defined as informed teaching. All of the above elements allow the game to be instructional.

The P-III framework [33] offers a method characterized by four pillars: 1) player-centered design, 2) iterative process, 3) multidisciplinary teamwork, and 4) seamless integration of play and learning. This framework offers an iterative and incremental approach to game design and development. The process evolves over three main phases (Concept Design, Game Design and Game Development) that interact with each other. However, no validation or effectiveness proofs are provided, besides mentioning three empirical cases that, according to the authors, demonstrate the necessity of P-III's four pillars.

Finally, the EMERGO methodology [25], based on the well-known phasing approach for instructional materials called ADDIE (Analysis, Design, Development, Implementation, and Evaluation) has been developed to guide the development of scenario-based serious games. The authors stated that the EMERGO methodology prevents overspending and minimizes risks for failure through an iterative cycle. However, according to the authors, the EMERGO methodology and toolkit do not guarantee the development of effective, attractive, and efficient learning materials.

In summary, as noticed by [27], extant frameworks usually provide only little design direction, often lack a pedagogical perspective, and fail to suggest how to address game complexity. Designing a game remains a creative process, unique to each situation; as such, there is no such thing as a recipe for design that guarantees success. Approaches to design needs be as open as possible to enable creativity for each particular case [34]. Therefore, informed by these previous works on the matter, in this paper, we propose a different approach to serious game design and development strongly based on the well-known knowledge transfer framework developed in [8]. However, the knowledge transfer framework *per se* does not provide direct guidance about how to develop the game. Thus, we need to

combine it with a design approach, as described in the next section.

III. DEVELOPING A SERIOUS GAME FOR KNOWLEDGE TRANSFER IN ENGINEERING MANAGEMENT

Research on engineering management traditionally has been very open, diverse, and multidisciplinary in nature because a significant part of the incipient scholars emanated from various disciplines, such as engineering, computer science, social science or economics. In this sense, the focus of research is extremely broad: it may range from a critical discourse on the social outcomes of the development, implementation, and use of technology [35] to the systematic creation of knowledge about, and with design to extend the boundaries of human problem solving capabilities [36], or the linking of both the social and design perspective on technology [37]. The core topics of research in engineering management are frequently called “wicked problems”. A wicked problem refers to a unique problem situation generally found in social and organizational environments, which because of the multiple interdependency, incompleteness, and contradictoriness of contextual variables, cannot be formulated in a deterministic manner.

With this in mind, we perceive a serious game as a type of artifact that may support the transfer of complex, yet practical knowledge by creating an active and playful learning environment [38]. In general, the act of designing an artifact is not necessarily dependent on the type of artifact to be designed [39]. Therefore, to develop a serious game that particularly emphasizes knowledge transfer, we adopt the action design research (ADR) approach as a generic design rationale [40]. The term “action design research” was first mentioned by [41] to refer to the combination of action research (AR) and design research (DR). Like DR, ADR is motivated by the urge to design, use, and refine novel and useful artifacts. The term “artifact” is generally used to describe something that is artificial, or constructed by humans (as in our case a serious game), in contrast to something that occurs naturally [42]. To be

considered a science, the creation of artifacts needs to be systematic and produce new generalized knowledge about and with design [36].

We selected a general class of problem that we encountered in previous research aimed at optimizing human-in-the-loop DSS, particularly for SCM-related issues [reference blinded for review]. In the extant literature, collaboration in supply chains has been perceived as key for any organization that strives to achieve a competitive advantage, especially for small or medium sized enterprises (SME) [43]. Such SMEs often need to join their efforts through inter-organizational relationships, constituting non-hierarchical production networks (NHPN) to achieve business goals that might be difficult to accomplish by individual organizations alone [44]. NHPN are a common environment where each involved company faces multiple and dynamic relationships within its network. Unlike more traditional hierarchical networks, which are characterized by the presence of a leader with strong market power that creates lasting relationships with its suppliers (e.g., automotive sector), NHPNs imply a direct peer-to-peer collaboration and trading between the different actors. The advantages of NHPNs are the elimination of the dominance of a single company. However, the complexity of a non-hierarchical network might result in highly volatile, unstable and non-transparent markets, leading to turbulences within the network, and poor performance.

Within the outlined problem domain, delivery reliability in NHPN represents a relevant, yet poorly understood problem in practice, although it is recognized as a pillar of competition for many manufacturing and service firms [45, 46]. With the advent of just-in-time manufacturing and quick response distribution, delivery reliability is currently a critical key component of order fulfillment, as well as a primary concern for many enterprises [47]. Despite the fact that SCM professionals in SMEs have a “gut feeling” about this issue, they are usually not able to identify clearly the origins and the causes of the problems.

A. Adapting ADR for serious games development

A major goal of ADR is to capture the emergent nature of the ensemble artifact and reflect both anticipated and unanticipated designs. Unlike DR, it does not use sequential build-and-evaluate logic [5, 48-50]. Instead, like AR, it puts more emphasis on iterative knowledge creation based on interventions with practice [51, 52]. Therefore, the primary role of the researcher within ADR is to guide the inception design, while the artifact emerges through the interaction between the development and use in context [40]. The overall goal is to link research with practice and thinking with doing [53]. Therefore, a key property of ADR is to generate knowledge through iterative building, intervention, and evaluation (BIE) of artifacts. ADR does not prescribe either the exact manner where BIE should be performed or the number of BIE interventions required. Figure 2 illustrates our adapted ADR intervention schema for developing our serious game, which we called INTIME (as allusion to the importance of delivery reliability for timely order fulfillment). We planned and conducted a total of four interventions during a time period of one year. Throughout the interventions, the ADR team kept a consistent connection with the reference knowledge transfer framework [8] depicted in Figure 1, to ensure the robustness and the effectiveness of the results, as described in more detail in the following sections.

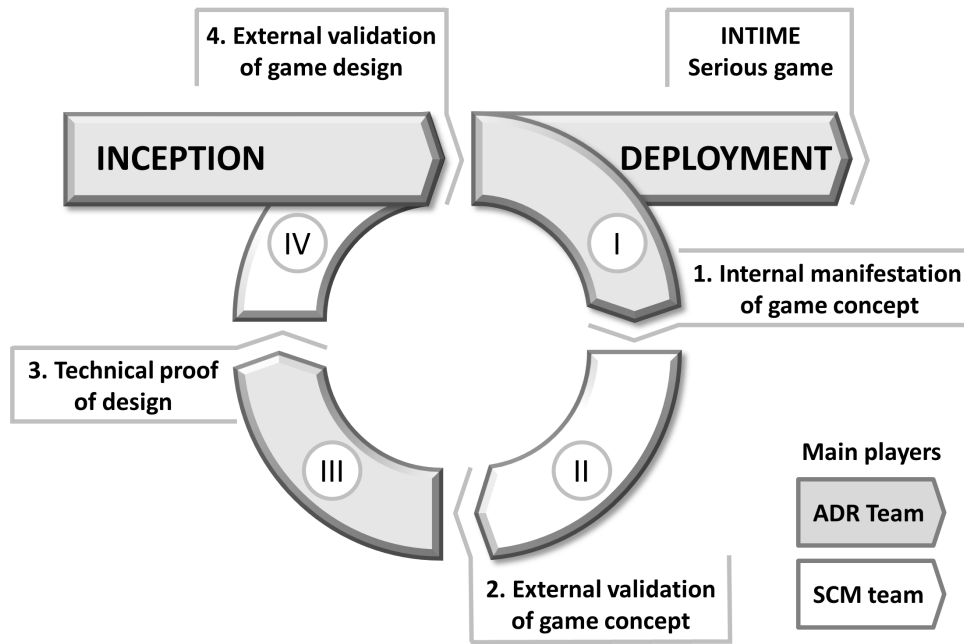


FIGURE 2. ADAPTED ADR INTERVENTION SCHEMA FOR DEVELOPING THE INTIME SERIOUS GAME

Because of the complexity of the selected problem domain and the fact that managing delivery reliability in NHPN cannot be resolved through separate individual actions, BIE was conducted as a team effort using a participatory process to serious game development to collect as many different insights as possible [54]. In our case, the core ADR team consisted of 6 scientists and 4 professionals with interdisciplinary practical and research skills in mechanical engineering, industrial engineering, computer science, and management. To obtain broader and constructive feedback from practice, additional SCM professionals were involved to bring in an outside perspective, as a check and balance to the internal efforts. All study participants were selected based on their high levels of interest and need for SCM-related topics in education, long-lasting experience with order management in NHPN, and commitment to participate in a long-term project. The professionals, who agreed to take part in this project, were assigned randomly to a *design group*, where members had to guide the ADR team in improving and fine-tuning the game concept and implementation of the game (intervention II) and to a *test group*, where members ultimately had to validate the serious

game (intervention IV). Table I provides an overview of all participants involved in this project.

B. Developing a basic understanding of the INTIME serious game (Intervention I)

Because of the diversity of the field, serious games in the area of Engineering Management can be used in various settings and for different purposes, such as part of professional training [55], as facilitators of process improvements and innovation [56], or as boundary objects for internal or external communication and change management [57]. As illustrated in Figure 3, the first intervention was therefore primarily directed to scoping and developing a basic understanding of (a) the message, respectively, the learning goals that the INTIME game should comprise, (b) the characteristics and potential expectations of the target audience, and (c) the role of the artifact as well as the ADR team in conveying this message.

TABLE I. CHARACTERIZATION OF INVOLVED ACTORS

ADR team involved in intervention 1-4

Role	Gender	Background	Experience	Origin	Role
Professional	M	Computer Science	5 years or less	Switzerland	Technical expert
Professional	M	Computer Science	Over 5 years	Switzerland	Technical expert
Professional	F	Mechanical Engineering	Over 5 years	Spain	Domain expert
Professional	M	Mechanical Engineering	Over 5 years	Spain	Domain expert
Researcher	M	Computer Science	Over 5 years	Germany	Developer/observer
Researcher	M	Industrial Engineering	5 years or less	Germany	Developer/observer
Researcher	M	Industrial Engineering	5 years or less	Germany	Developer/observer
Researcher	M	Industrial Management	5 years or less	Germany	Developer/note-taker
Researcher	F	Industrial Management	5 years or less	Italy	Developer/note-taker
Researcher	M	Industrial Management	Over 5 years	Italy	Lead developer/moderator

SCM professionals involved in intervention 2

Role	Gender	Background	Experience	Origin	Group
Professional	F	Mechanical Engineering	Over 5 years	Spain	Design group
Professional	M	Computer Science	5 years or less	Switzerland	Design group
Professional	F	Computer Science	5 years or less	Germany	Design group
Professional	M	Industrial Engineering	Over 5 years	Germany	Design group
Professional	F	Industrial Management	Over 5 years	Spain	Design group
Professional	M	Computer Science	Over 5 years	Switzerland	Design group

SCM professionals involved in intervention 4

Role	Gender	Background	Experience	Origin	Group
Professional	M	Industrial Engineering	Over 5 years	Germany	Test group
Professional	M	Industrial Engineering	Over 5 years	Germany	Test group
Professional	M	Industrial Management	Over 5 years	Italy	Test group
Professional	M	Manufacturing	Over 5 years	Spain	Test group
Professional	F	Manufacturing	Over 5 years	Germany	Test group
Professional	M	Manufacturing	Over 5 years	Italy	Test group
Professional	M	Manufacturing	Over 5 years	Germany	Test group

As discussed earlier, prior research has shown that managing delivery reliability in NHPN requires different strategies, behaviors, and a particular world-view from SCM professionals. Because the problem frequently is not well understood, especially in SMEs, the ADR team was convinced that a serious game that creates awareness of the phenomenon and that provides certain guidance relating to possible coping mechanisms would be valuable initial *learning goals* in the path to generally solve the problem. However, the game was not intended for the use of organizational process improvement or any other purpose beyond familiarizing with the phenomenon.

After having a clear idea about the message and the target audience, further deliberation about the INTIME game was required. In agreement with the procedural rhetoric theory, which follows the assumption that active engagement stimulates learning better than simply informing about a phenomenon [58], along with the learning goals, the ADR team defined additional *game goals* characterized by the intended level of interaction, degree of simplicity, playability (gameplay), and potential enjoyment of the INTIME game.

Distinct creative approaches, such as classic brainstorming, lateral/critical thinking methods or story planning, were used to explore sample outlines for a game concept aligned with the specified learning and game goals [59]. While the ADR team left this step with many ideas, in a subsequent activity, a screening of the most promising thoughts with respect to feasibility, resources available, and alignment to the game goals was needed. However,

without knowing the exact game concept, this step was a challenging task and hardly achievable by pure rational consideration. As a matter of fact, the list of distinct ideas to follow was the result of collaborative group behavior in a first place. An instrument should be implemented to keep track of ideas (e.g., a wiki, mind map), even for the initially discarded ones, which is extraordinarily helpful because game design is similar to other forms of problem-solving and inherently iterative [42].

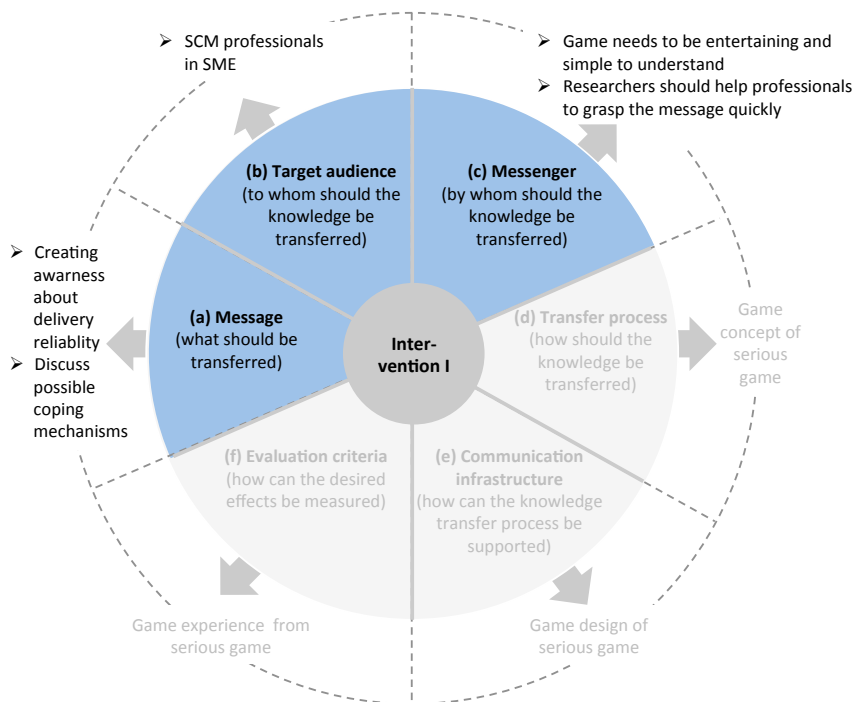


FIGURE 3. ADDRESSED KNOWLEDGE TRANSFER ELEMENTS IN INTERVENTION I

C. Defining and testing the game concept of *INTIME* (Intervention II)

Building upon the results of the previous scoping exercise, a second intervention was started that aimed at further developing, tuning, and testing the initial game concept via the inputs of a broader group of SCM professionals with real-life expertise in NHPN-related issues (see Figure 4). To have a boundary object for the opening of external validation and to keep it simple in the beginning, the ADR team developed a first alpha version of the *INTIME*

game in the form of a paper and pencil board game. An all-day “play event” was organized with the intention to specifically assess (c) the role of researchers in conveying the general message of INTIME (particularly to obtain an outside perspective from practitioners), (d) the comprehensibility and relevance of the specific INTIME game concept, and (e) the ease of use of the board game as the means for knowledge communication. Throughout the all-day event, one researcher was responsible for moderating and guiding the discussions, while the rest of the ADR team was observing and collecting verbal and non-verbal observational field notes during the session.

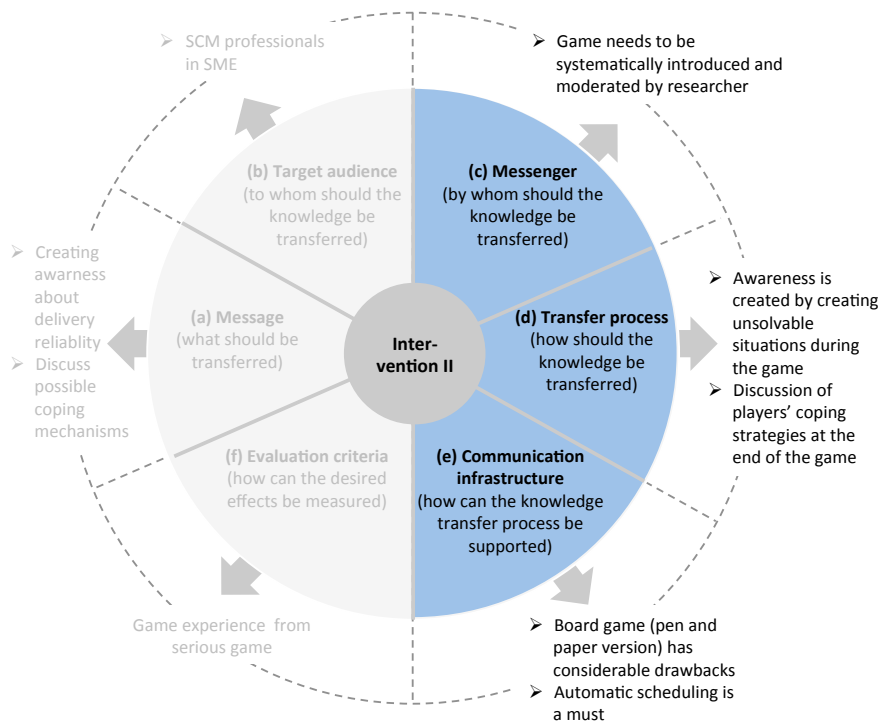


FIGURE 4. ADDRESSED KNOWLEDGE TRANSFER ELEMENTS IN INTERVENTION II

The game session began with a short briefing of the participants of the design group (see Table I) about the initially specified game objectives and rules. After an initial discussion about the general game concept, the professionals were asked to play some warm-up rounds. In the course of the game, the moderator defined ever more challenging conditions, which

deliberately caused unsolvable situations for the playing professionals. The game session ended with an open-ended discussion about the game and learning experience, the general opinion about the INTIME game's realization at that time, and the observations of the non-playing participants.

While the majority of the professionals expressed a positive game experience, they felt that the pregame phase needed to be prepared more systematically because the INTIME game could not be played without additional directives and that the introduction is a cornerstone to introduce the topic quickly. Moreover, the pen and paper version entailed several drawbacks, especially related to the quantitative evaluation of the current performance and the tracking of all of the information within the game, which considerably disturbed the game flow, created insecurity at the players' end, and eventually diverted players' focus away from the learning tasks. All critiques were systematically collected and, together with observational field notes, analyzed for the further development of the INTIME game.

D. Transferring the game concept to a playable prototype (Intervention III)

The third session started with brainstorming several ideas on how to address the raised issues. The ideas were categorized into three groups: concepts for the pregame phase, the play experience or the postgame (debriefing) phase. Together with a more detailed analysis of the professionals' attitudes, knowledge, skills and behavior observed at the all-day event, a lightweight software prototype was created to instantiate the enhanced game concept. Building upon [60], significant emphasis was placed on improving the "flow" of the game because it has been found to be critical for engaging the players via the features made available by the game and keeping their attention focused on learning. Moreover, considerable effort was also placed on improving the introduction and debriefing session because the game is not self-supporting, which has been criticized in the previous validation of the game concept.

Finally, some thoughts were given to the prospective validation of the game design. Considering the defined game objectives, such as providing enjoyment, creating awareness of the problem, and enhancing soft skills, the ADR team was confronted with the major challenge of operationalizing this evaluation. For example, how can “fun” or “enjoyment” be measured objectively? What do we regard as an improvement of soft skills? Again, how do we measure it?

The ADR team decided to focus on evaluating learning outcomes from game experience. As suggested by [61], two approaches for differentiating the assessment or proof of learning exist: the so-called *formative assessment* is a form to evaluate learning outcome during the game with the purpose of developing metacognitive skills, for example, analyzing and evaluating decision-making processes [62]. The ADR team decided to consider these factors by integrating an in-game performance measure related to delivery reliability that is continuously updated as the game progresses through the different stages, consequently to the decisions made by the player. In contrast, *summative assessment* usually occurs before the game is played and/or during debriefing after the game and is essential for grading or similar forms of evaluation. Due to the goal of the INTIME game (i.e., to create awareness) and based on [25], which emphasized the role of debriefing as critical for effective learning with games, the ADR team decided to consider this aspect by extending the debriefing session with voluntary one-on-one interviews, where professionals could express their impression about learning effectiveness more freely. To accomplish this goal, a specific interview protocol problem with open-ended questions was designed (see Appendix). Figure 5 shows the focal points of the third intervention.

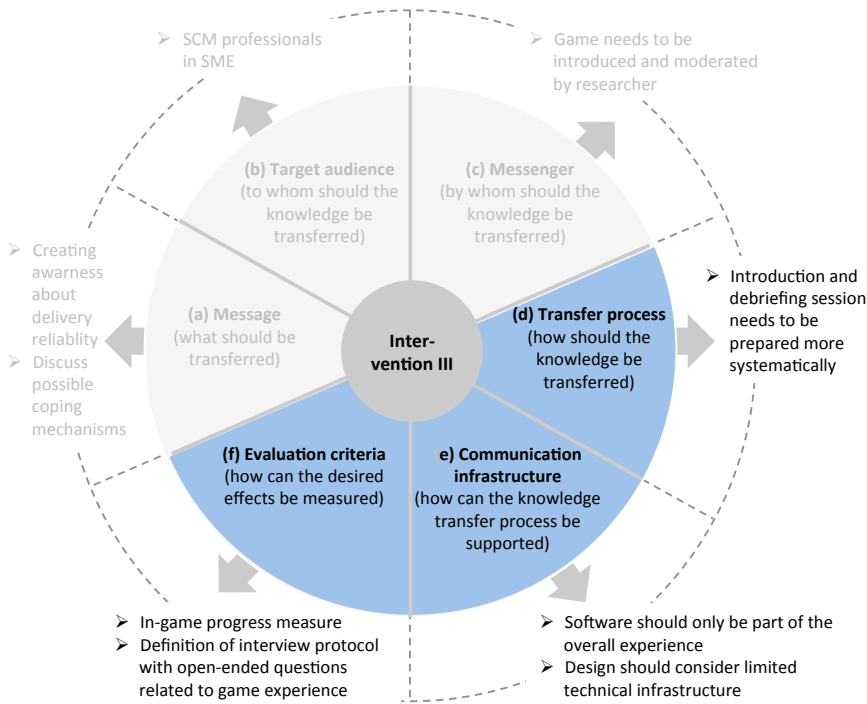


FIGURE 5. ADDRESSED KNOWLEDGE TRANSFER ELEMENTS IN INTERVENTION III

E. Evaluating the overall effectiveness and game experience (Intervention IV)

After having covered the complete knowledge transfer cycle with the first three interventions, the goal of the last intervention was to evaluate the INTIME game from an integral perspective. As opposed to the second intervention, which was used as a forum for fine-tuning and improving the game concept, the fourth intervention was rather focused on assessing the game design's ability to achieve the defined learning goals and the overall game experience.

To obtain unbiased reactions about the quality of the INTIME game, a second all-day event was organized for all professionals, who were initially assigned to the test group.

The game session was organized and performed in the same fashion as the previous one (i.e., Intervention II); however, instead of using the board game, the newly developed electronic version was used together with enhanced briefing and debriefing scripts. In addition, the previously defined summative and formative assessment instruments were used

to collect opinions about the participants' motivation and impressions about their learning experiences with the INTIME game. Particularly, the one-on-one interviews provided positive feedback, as well as some minor suggestions for improving the game flow, all of which were rapidly addressed using the ADR team right after the session. Further retrospective consultations with the same professionals suggested that the INTIME game achieved the goal of creating awareness about the delivery reliability phenomenon in NHPN *de facto*. Thus, no further BIE cycles were needed.

IV. REFLECTIONS

Due to the inherent characteristics of a serious game, combining amusing and educational aspects, the journey through its development phases is usually fraught with uncertain and unstructured aspects, requiring in-process adjustments of the planned trajectory. During this journey, we gained some insights about the game design process, as well as some reflections and implications about the use of serious games that, when combined, led us to the definition of the proposed framework. We purposely avoided the discussion of technical details of the implementation because, for our purpose, there is more value in discussing the lesson learned rather than in the illustration of the technicalities.

Considering the extant literature on serious game development frameworks, we are positive in affirming that our proposed framework benefits from two original aspects: i) in contrast to many other game design frameworks, our proposal is strongly centered on a well-known knowledge transfer framework, allowing us to identify and leverage the major elements that characterize learning activities and ii) the framework is strongly based on participatory design activities through the ADR approach, aiming to continuously include the experiences, ideas, and expectations of professionals during the development of the serious game. In our opinion, the participatory nature of the process is pivotal in achieving the intended goals because “ambassadors” of the targeted audience are involved in the design process because the

beginning. A further benefit of the proposed approach is the possibility to overcome the traditional stage-gate or waterfall development models, deliberately involving iterative and frequent testing and fine-tuning of the serious game.

As previously noted, designing a game is a creative process that is unique to each situation; thus, the design approach needs to be as open as possible to enable creativity for each particular case. This open-creativity combination may generate an issue in defining when the design process has come to an end. Openness implies the possibility of iteratively adding new elements into the game, while creativity is inherently unlimited. In this respect, one relevant insight is about the level of detail that should be included in the game. Indeed, the game should be able to both allow the players to easily understand the rules and the dynamics and favor its development. At the same time, the game must not be trivial or not representative at all of reality. The right balance may be tricky to find because the overall quality of a game is not proportionally connected with the level of detail. To illustrate our point, we refer to the uncanny valley hypothesis. This hypothesis was first introduced by [63] to describe a problem emerged developing human-like robots. In his studies, [63] noted that as the likeness between the robot (aesthetics, expressivity, movements, voice and speech) and a human being was increasing, human observers had a growing acceptance until a certain level where people started to feel a sense of discomfort and repulsion towards the robot. In case of a perfect replica though, the acceptance and the sense of familiarity was very high again. Starting from these observations, Mori developed the uncanny valley hypothesis, referring to the region of negative emotional response in a graph representing the likeness to humans and the level of familiarity and acceptance [63]. This hypothesis applies not only to robots but also to any type of representation of human beings (i.e., 3D graphics).

In our case, the design of a hypothetic perfectly detailed game (i.e., an almost perfect replica of reality) would represent an excellent environment for game-based learning but

presumably at excessive costs in terms of time and resources required. In contrast, opting for a synthetic and essential representation of the system, almost metaphoric, would improve the perceived game quality in terms of its simplicity and immediateness and reduce development costs. At some point in between, the level of detail would be perceived as a negative element, almost distracting players from the real purpose of the game. In fact, as the original uncanny valley hypothesis explains, at a certain level of detail, people feel comfortable and look for similarities between the game and the reality. Beyond this critical point, whose position is clearly not possible to define analytically, people feel less comfortable, and start emphasizing differences between the game and the reality, losing the focus on the learning tasks (see Figure 6).

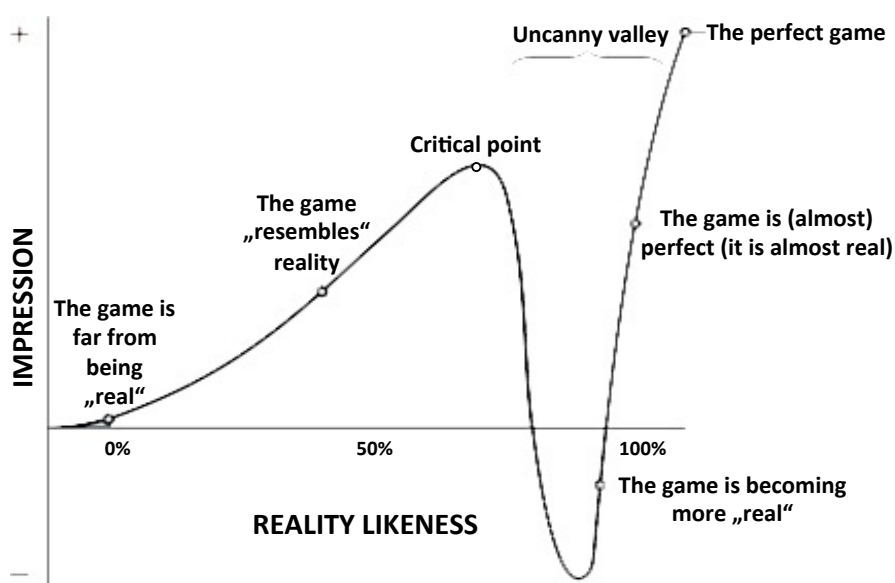


FIGURE 6. THE UNCANNY VALLEY OF SERIOUS GAMES

To avoid this situation, we purposely involved professionals during game development and exploited their feedback to identify when the game is “good enough”; interview sentences, such as *“the game works, but it would be better if...”* were carefully scrutinized using the ADR team, especially at the end of the fourth intervention, to define whether the game was

ready for deployment or another iteration was needed. It is important not to lose the focus on the learning goal of the game just because potential players (i.e., involved professionals) ask for more game features. Indeed, it is important to underline that the level of detail is not necessarily in direct correlation with the effectiveness of the knowledge transfer process; in other words, it has not been proven that a higher the level of detail results in a better game. There may be very simple, or even simplistic, games that are very effective at conveying their message, such as, for example, the classical *beer game* for teaching the basics of the bullwhip effect in supply chain management [64]. Vice versa, an excessively rich game may distract the players from the learning goal, ending up with a set of people just playing for the sake of playing. Thus, the uncanny valley hypothesis can be referred to when explaining the acceptance or rejection of a game as a representative tool in the context under analysis, whereas it does not necessarily help in explaining the outcomes of the underlying learning process.

Because the development of a game may end up being a long and time-consuming process, from the game-developer standpoint, it is also important to assess the benefit/cost ratio. In this respect, substantial benefits may come from the possibility of replicating the game in different contexts and under different circumstances, providing a flexible tool suitable for different learners (i.e., students or practitioners), even with different starting knowledge, thus leveling the potential skills gap. Moreover, the same game can be used for training (i.e., to convey content to be learnt by the learners), testing (i.e., to assess the abilities and competences acquired by the learner through the game, or even through traditional teaching sessions), and communication purposes (i.e., to create awareness in the audience about a specific topic or issue).

Finally, the role of technology in serious gaming cannot go unnoticed. Some serious game typologies heavily depend upon the available technologies to a large extent, and the evolution

of such technologies has fundamentally changed and evolved the way we play today. Therefore, the same game concept can be implemented in diverse ways at different times (or with different resources involvement), opening the possibilities for multiple games addressing the same situation. In this respect, our game evolved through different stages, from a pen and paper board game to an electronic version to improve the flow of the game and to remove the burden of some non-instructional tasks from players, such as the quantitative evaluation of the performance and the tracking of the information. It is important to underline that the technology can support the implementation of the game design and can open up new ways to achieve the learning goal; however, it must be acknowledged that even the best technology available cannot surrogate a bad game design.

V. CONCLUSIONS

In this paper, we present a novel approach for designing serious games with a particular focus on knowledge transfer. In doing so, exploring the potential of serious gaming is a challenging task. It is difficult to devise a unified, standard process for serious game conception and development because, in the majority of the cases, serious games cannot be viewed separately from the context and the purposes for which they are conceived.

Although we believe it is almost impossible to put an end to the quest for an effective serious game design framework (remember, game design is mainly a creative process), we are positive about the effectiveness of our approach in designing a game for disseminating and transferring research results to practice, due to the strong connection with a knowledge transfer framework.

A question that may arise is under what circumstances a game is a better form of science communication than traditional, written form. Although the answer to this question may go beyond the theme of this paper, a proper approach would most likely require devising and conducting experiments with control groups undergoing traditional forms of learning, and

testing groups undergoing the game-based training session, aiming to understand under which circumstances does one group significantly outperform the other. Accordingly, future work should be directed toward exploring learning outcomes resulting from different training approaches.

Even without these experiments, we can infer from both the extant literature and the experience gained from this project that one of the most notable strengths of serious games relies in engaging learners, making them an essential component of the learning and communication process. Although many studies deliberate about the relationship between students' engagement and learning, little evidence exists about the role and behavior of researchers during the game experience. In our case, a moderated briefing and debriefing session considerably impacts learners' motivation and engagement levels. Therefore, we believe that future research should also provide insights into how to setup an effective learning environment with serious games as well as how to effectively prepare and moderate pre- and postgame sessions.

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