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Towards a Comprehensive Methodology for the Research and Evaluation of Serious Games

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Abstract

The author presents the methodological backgrounds and underlying research design of an on-going scientific research project concerned with the scientific evaluation of serious games and/or computer-based simulation-games (SG) for advanced learning. The main questions of this research project are: 1. what are the requirements and design principles for a comprehensive social-scientific methodology for the evaluation of SG? 2. To what extend does SG contribute to advanced learning? 3. What factors contribute to, or determine this learning? 4. To what extend and under what conditions can SG-based learning be transferred to the real world (RW)? Between 2004 and 2012, several hundreds of SG-sessions in the Netherlands with twelve different SG were evaluated systematically, uniformly and quantitatively to give a data-set of 2100 respondents in higher education and in work-organizations. The author presents the research model, the quasi-experimental design and evaluation instruments. This focus in this article is on methodology and data-set to establish a proper foundation for forthcoming publications on empirical results.

Keywords: evaluation; game-based learning; serious gaming; simulation-gaming;

1. Introduction

With the growing attention for digital game-based learning and serious gaming, there is a growing need to know to the effects of what we are doing and promoting. This requires proper methods, tools and principles that the fragmented Game-Based Learning (GBL) and Serious Game (SG) community agrees upon, can validate and apply – in other words, a step towards a 'science of game-based learning' [1]. Considerable efforts are now made, and resources are spent on, the research and evaluation of GBL and SG [2]. As a result, the number and quality of evaluations of GBL and SG is increasing (see for a discussion below) but there are still considerable weaknesses, to mention but a few:

- Lack of comprehensive, multi-purpose frameworks for comparative, longitudinal evaluation [3–5].
- Few theories to formulate and test hypothesis [6], [7]
- Few operationalized models to examine 'causal' relations (e.g. in structural equations models) [8–10]

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- Few validated questionnaires, construct, scales – from other fields, like psychology - or newly constructed for serious gaming and GBL [11–13].
- Lack of proper research designs – other than Randomized Controlled Trials that can be used in a dynamic, professional learning context [14–19].
- Absence of generic tools for unobtrusive ('stealth') data-gathering and assessment in and around SGs [20–22].

In short, there is a promising increase in publications, methods, tools and findings, but an overarching methodology for SG research is lacking. Aligning a fragmented serious gaming community to not only evaluate and research gaming for learning, but to do so in a comparative, systematic fashion using procedures, frameworks and methods that can be validated, checked and reproduced is still a big step to take.

This is the wider context of a SG research project (2004-2012) on the evaluation of SGs for advanced learning: i.e., the challenge to gather data about quality, application and outcomes of a broad range of SG on different topics and with different objectives, used in different institutional contexts, at different moments in time, under uncontrolled conditions. It is valuable to find the effects of playing games with students in a lab - but it is essential to know the effects of GBL in uncontrolled circumstances and for objectives that truly matter for real-life performance (i.e., emergency management, leadership) as the latter is usually the case in professional learning and training. A social-scientific discipline of SG research would include a critical and reflective discourse on:

- Frames and discourses: the multiple, often conflicting ways in which we perceive and discuss SG and GBL [23–25].
- Methodology: the rationale and principles on which SG and GBL research is founded [26].
- Research designs and data gathering: what works, why and when? [27], [28]
- Validated research instruments and tools: questionnaires, surveys, logging and tracking instruments, including their validation, for SG and GBL [11–13], [29], [30].
- A dynamic body of knowledge identifying state of the art and knowledge gaps [31–33].
- Professional ethics of the SG-designer, the SG-advocate, the SG-seller, the SG-interventionist, etc. [34], [35].

This is highly needed because of:

- Accountability: 'users' – clients, players, learners – are becoming more exposed and familiar with SG. They have a right to know what they are actually buying, using or playing, for what reason and what the effects or consequences of the application of SG and gamification are. We project that users will also become more demanding, critical and skeptic.
- Responsibility: The opposite of accountability. A discipline that advocates the use of serious games and gamification to repair a broken reality [36] esp. when vulnerable groups in society are involved – e.g., kids, patients, immigrants - has a high responsibility to critically reflect on the short and longer term value and structural consequences of the gamification tools they are developing, promoting and using.

2. Research objective

The aim of our project is to develop a generic evaluation methodology for serious gaming – i.e. consisting of a framework, conceptual models, research design(s), evaluation constructs and scales, and data gathering techniques. The ambition is to cope with the dilemma between 1) 'generality' and 'standardization' necessary

for comparative, theory-based research; 2) 'specificity' and 'flexibility' necessary for evaluation of singular cases. The main questions of the research project are:

1. What are the requirements and design principles for a comprehensive methodology for SG evaluation?
2. To what extend does SG contribute to learning in a real-world context?
3. What factors contribute to or determine this learning?
4. To what extend and under what conditions can serious game-based learning be transferred to the real world (RW)?

Between 2004 and 2010, several hundreds of SG-sessions in the Netherlands with 12 different SGs were evaluated as systematically, uniformly and quantitatively (and qualitative) as possible, by Technical University Delft (TU-Delft) in cooperation with different partners. The present and still expanding data set contains data from 2164 respondents (students and professionals, male-female, aged between 17 and 75) and 800 original variables on things like player background, session, learning and-or policy context, game quality, player experiences and immediate game results and effects. These data were gathered before, during and after the serious game-sessions, in a quasi-experimental fashion.

1. Marine Spatial Planning game (MSP Challenge 2011, TU-Delft, 2011): a computer-supported, multi-player, policy game revolving around eco-system-based, integrated Marine Spatial Planning (MSP) for international professionals working in the field (Mayer et al., 2012).
2. SimPort Maasvlakte 2 [38]: a computer-supported, multi-player, strategic planning game for higher education and advanced professional learning that revolves around the development of the Second Maasvlakte area, in the Port of Rotterdam, the Netherlands [39].
3. Ventum Online [40]: a computer-supported, multi-player management game for engineering students and professional project managers that revolves around the development of an offshore wind farm.
4. Construct.it (TU Delft 2009): a computer-supported, multi-player planning game for students in higher education revolving around the urban reconstruction of a port area in a real Dutch sea town.
5. Climate Game [41]: a 3D-computer-supported, multi-player, strategic planning game for students in higher education and professional policy makers about integrated water management in relation to urban planning, climate change etc.
6. SprintCity [42]: a computer supported, multi-player policy game about Transit-Oriented Development around rail-way stations for professionals working in the field.
7. Cyberdam [43]: an online, game-based virtual learning environment (VLE) in which teachers can make their online role playing games in higher education. Cyberdam is a platform in which 17 different games in 12 institutions have been developed and tested.
8. Servant leadership game (in Dutch: Veerkracht; TU Delft, 2012): a computer tablet-based, role-playing game about leadership in a changing organization for professionals in a public, infrastructure management organization.
9. SharkWorld [44]: a single-player, multi-media, digital game for lower and higher vocational education on project management.
10. Slogan [45]: a non-digital management game for higher education and professional training.
11. TeamUp (TU Delft, 2010): a 3D-digital, multi-player game on team communication and leadership.
12. SimVenture [46]: a single-player, computer-based game on business entrepreneurship.

3. Comparative and longitudinal research

In theory, comparative, longitudinal research of GBL has a great many advantages: the opportunity to vary possibly context or intermediating variables – such as, the number or intrinsic motivation of students [47], modes of dissemination, the quality or experience of the game-facilitators, the institutional facilities – the quality of the classroom or computer infrastructure, etc.

In practice, comparative, longitudinal research of GBL is a great challenge. It requires a high level of discipline and synchronization among the stakeholders, the use of a common evaluation framework that is both standardized and robust enough to compare, but also flexible enough to allow adjustments to local conditions, institutions, course, topics, games and times. It also requires efficient game-based evaluation tools and techniques to gather rich data on a wide spectrum of variables. And while doing the research, the games, the questions, the methods and tools evolve. We discuss the design of the methodology in the following steps: Framing; Foundations and requirements; Conceptual framework; Quasi-experimental research design; Contextualization; Research questions and hypothesis; Operationalization; Data reduction and analysis.

4. Framing

Words can have different meanings; depending on disciplinary backgrounds, interests etc. Sub-communities are easily confused or in disagreement on notions like ‘learning’, ‘serious games’, ‘effectiveness’, ‘evaluation’ and ‘research’. A better way than ‘defining’ is ‘framing’ - a non-exclusive way of contextualizing the meaning of complicated notions [24], [25], [48]. Different frames can partially be true at the same time; they can compete or complement each other. Frames play an important role in a discourse on, for instance, ‘effectiveness’ of games for learning and SGs. Incommensurable frames can lead to new, synthesized frames. We give a few frames for the use of ‘game’ in a context of research:

- Research theory: Game theory as in economics, political science, etc. [49], [50]
- Research concept: organization, management, decision-making as a strategic or political game [51], [52]
- Research object: Studying game cultures, game economics, game politics etc. [53–55].
- Design artifact: Game as socio-technical design, as an artifact etc. [17], [56], [57].
- Research method: Game as a research method comparable to simulation or experiment [58], [59].
- Intervention method: Game as therapy, educational, learning, change or decision support method [60], [61] .
- Data-gathering method: Game as an environment for observation, group interview, data-modeling [62–64].
- Foundations and requirements

5. Literature overview

A great many PhD theses and related academic papers on the effects of one or a few game-based learning and/or serious gaming experiments have now been published [4], [9], [14], [17], [39], [65–70]. Several review articles on game-based learning have been published, in the last years with increasing frequency [15], [71–87]. Few publications however provide high-quality, evaluation frameworks on ‘what’ and ‘how’ to measure in a comparative fashion, taking into account the real-life and dynamic setting of the project [88]. A recent overview of eleven evaluation frameworks –incomplete and somewhat biased– has been published by Hainey et al., [8], [10]. Among them is the four dimensional evaluation framework proposed by (De Freitas et al., 2010). Not included in Hainey’s overview for instance is the potential of using Technology Acceptance Models [90] (TAM) for SG adoption. More importantly, Kriz and Hense’s framework for theory-based evaluation is ignored [39], [91], [92]. And there are even fewer publications that present evaluation frameworks of game-

based learning in higher education, let alone professional, in-company training or group and organizational learning.

5.1. Limitations of existing frameworks

Most models and frameworks are high level models. They specify a limited number of generic 'concepts' that can / should be taken into consideration when evaluating SG, but they give:

- Few indications how to use the models, for what purpose, with what scope and under what conditions.
- Few procedures how to validate the conceptual research / evaluation model.
- Few research hypothesis and research designs.
- Few definitions, relations and interrelations between the concepts in the model.
- Few operationalization and validation of constructs.

Furthermore in the application of the models we see:

- A dominance of single case studies, one game, one context of application.
- Lacking information on the questionnaires used.
- A focus on GBL of children in formal education; little attention to advanced-professional learning, outside education;
- A focus on learning of individuals in formal training or educational context; little attention to learning of teams, groups, organizations, networks or systems in policy or organizational context;

5.2. Requirements

An important question therefore is what the requirements are for a good evaluation framework for serious game (evaluation) research. Ideally, a generic evaluation framework (and corresponding procedures) for GBL and SG research has the following characteristics:

- Broad in scope: taking into account the broad range of educational contexts, games, learning objectives and topics.
- Comparative: able to use certain data from different games for comparison.
- Standardized: to use pre/quasi-experimental research designs, materials and procedures should be standardized.
- Specific; measuring data precisely by pinpointing variables.
- Flexible; as game play cannot be always predicted, data gathering should be flexible for measurement, however still standardized, specific, etc.
- Triangulated; using a mixed method approach with qualitative and quantitative data.
- Multi-leveled; individual, game, team, organization, system level.
- Validated; validated research methods, e.g. research method and game design.
- Expandable; possibility of measures on new variables.
- Unobtrusive: using gaming for systematic and extensive data gathering. (Research, comparative or theory based evaluation etc.) needs to be unobtrusive.
- Fast and non-time consuming: using real world cases for data gathering implies that tools and methods need to be fast and non-time consuming a in RW project.
- Multi-purposed: persuading stakeholders to do data gathering beyond the obvious and minimal.

In practice, no such framework exists and trade-offs are needed. A GBL/SG evaluation needs to be broad in scope, but light in operation; it needs to address both formative and summative purposes of evaluation [93],

address evaluation interests of designers, players, financers and other stakeholders. At the other side of the spectrum, data need to render itself for more in-depth analysis, to understand what happens and why.

6. Conceptual framework

6.1. Elements

A generic model for the social scientific research, evaluation and assessment of SG in a real world context should provide:

- A flexible and general applicable research model from which we can derive
- A set of research questions and hypotheses
- A research design for applying the model
- A suite of research tools and instruments
- Some guidelines, practices, rules for applying, falsifying, validating and improving the above.
- Empirical testing of the robustness of the model
- Comparative, theory-based evaluation

Before the learning effectiveness and contributing factors can be established, an evaluation framework is required that allows:

- The operationalization of independent , dependent and mediating/context variables, like 'engagement' (i.c., independent), 'learning effectiveness' (i.c., dependent) and age (mediating) / psychological safety (context).
- A systematic, unobtrusive process of data-gathering and analysis.
- The formulation of research questions and hypotheses based on a conceptual research model.

Core to the model is a deconstruction of the game-based learning into:

- The pre-game condition: the subject's attitudes, knowledge, skills, behavior, relevant to GBL and SG and / or the case at hand before playing game. In the 12 cases we have measured a variety of items and constructs, e.g. attitudes towards GBL to organizational commitment. (see 3.1-3.4 in fig. 1)
- The quality of the game-based learning intervention: Subdivided in quality of: a. the game design itself; b. the game play; c. the interaction with the facilitator/teacher; and d. the interaction with the digital game-environment. (see 4.1-4.2 in fig. 1)
- The post-game-condition: the subject's attitudes, knowledge, .skills, behavior, relevant to the game-based learning, etc. (see 5.1-5.4 in fig. 1)
- Background variables referring to the person, student / professional as a participant:
- Socio-demographic variables, like age, sex and nationality, etc. (see 1.1 in fig. 1).
- Professional and student characteristics: position, work experience, level of education, etc. (see 2.1 in fig. 1)
- Mediating variables
- Individual as a participant: e.g. personality characteristics (Big 5, Hexaco) (see 1.2 in fig. 1).
- Individual as a learner: learning styles, etc. (see 1.3, fig. 1).
- Individual as a gamer: e.g. game-skill, game experiences, game attitudes, game-play style, etc. (see 1.4 in fig. 1).
- Professional / student as a serious gamer, e.g., previous SG experiences in a professional context (see 2.4 in fig. 1).
- Professional / student as a participant: e.g. intrinsic / extrinsic motivation [94].

- Context variables: organizational, institutional climate in which the GBL - SG takes place, e.g. commitment to the organization, identification with leader or organization, psychological safety (see 6.1 in fig. 1).
- First order learning: direct influence of playing the game on the individual, small group attitudes, knowledge, skills or behavior (see 7. In fig. 1).
- Second order learning: (in) direct, short-long term influence of the game in the large (incl. design process, sessions, discussions, publications, etc.) on the group, network, organizational, system level (see 8 in fig. 1).

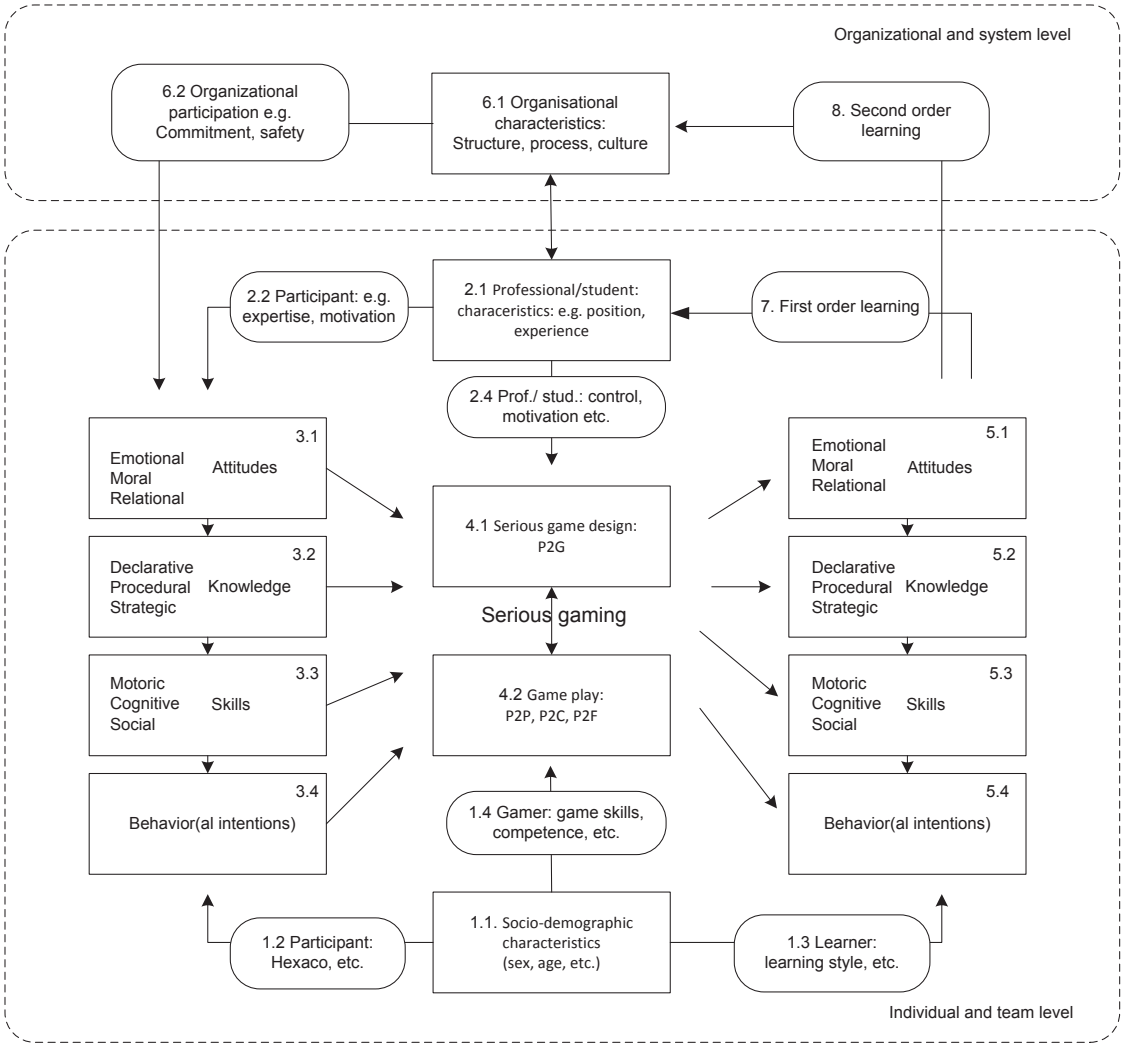

Figure 1. Conceptual research model

7. Quasi-experimental research design

Now the model can be translated to a quasi-experimental design (QED): from the simple 'post-test only', to a 'pre-test/post-test' design, a 'randomized (R)', 'control group (C)', 'repeated measurement' design [95–97]. Fig. 2 shows the translation of the conceptual model to QED (R, C not included)]

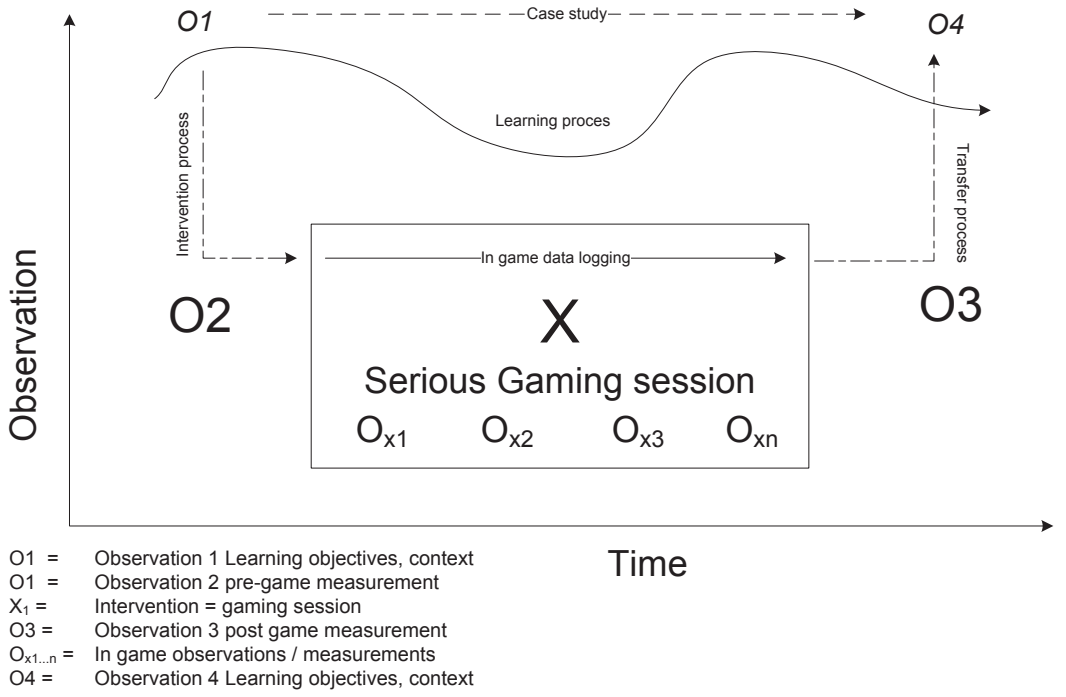

Figure 2. Quasi Experimental Design

8. Contextualization

8.1. Data-gathering

One of the special features of SG for advanced learning is that they provide excellent environments for mixed method data-gathering, or triangulation: from crowd sourcing, to panel discussions, surveys and (video) observations.

For the games, evaluation data were gathered through mixed methods, mostly combining pre and post-game surveys among the players, life or video observations, transcripts of after action reviews and game-results. In a few cases, methods were applied more rigorous with in-game knowledge tests or network and communication analysis from video observations.

9. Defining questions and hypotheses

What type of research questions and hypotheses can guide GBL and SG research? We give the following classification:

- Design-oriented SG research (artifact): 'making it (better)'. The validation of specific and generic game-based artifacts and events. The development and validation of design theories, methods & tools.
- Intervention-oriented SG research (learning, change, policy making, management): 'making it work'. The learning effectiveness/impact of game-based interventions. The transfer of game-based interventions to the RW.
- Domain-oriented SG research (health care, military, energy, etc.): 'making it matter'. The effectiveness of the use of SG to understand the complexity, dynamics in specific domains?
- Disciplinary SG-research (methodology, ethics, explanatory and interpretative theories): 'making it understandable'. The sociological, economic, political, cultural, etc. frames on SG. Theory construction on GBL and SG. Methodology: design and validation of research methods, tools. Reflection and ethics.

Depending on the case at hand, a pre-, in- and post-game instrument for measuring or observing relevant variables can be defined or constructed. There is a great variety of games, players and learning contexts, and trade-offs need to be made between time, resources and evaluation focus (see above).

First order effects can be established as changes between pre- and post-game measurements, with or without control group. In few situations self-constructed items or constructs for measuring attitude, knowledge, skills and behaviors can first be 'tested' or 'validated'. In due course, the number and quality of constructs for SG will increase. Psychometrics from behavioral sciences like psychology, management etc. is still unexplored SG research territory. In few situations measurements of change and learning can be done in the form of objective tests. Self-reporting or self-assessment of change and learning is common, often necessary and sufficient. Yet, even when based upon self-reporting, high quality questionnaires with items, constructs and scales, for comparative and longitudinal measurements, are not commonly available.

10. Operationalization

Operationalization of the generic conceptual model (fig. 1) in the context of a dynamic, multi-stakeholder project can be a real challenge. First of all, most of the educational/client organizations have their evaluation procedures and preferences; sometimes a set of course evaluation questions is mandatory.

(Paying) clients are not always inclined to evaluate beyond their own immediate needs, e.g. did we get what we expected and were promised? In many cases, we need to convince stakeholders that for the purpose of advancing serious gaming, a thorough evaluation should be done. We need to emphasize and keep up privacy, safety and non-obtrusiveness. Another handicap is that the client usually expects case-specific evaluation questions. Ad-hoc and case specific evaluation questions stand in the way of comparative, longitudinal research. Through the years we found flexible ways of working, trying to validate and re-use as much as possible the items, constructs and scales.

We now have a set of validated and re-usable questions for the following constructs and items:

Pre-game

- Socio-demographics: e.g. sex, age, nationality, culture etc. [69], [79], [98–105]
- Previous experiences / skills: with computers, with games, with virtual learning environments, etc. [5], [98], [106]
- Attitudes: e.g. change, conflicts, intrinsic and extrinsic motivation, learning styles, etc. [107–113]
- Skills: e.g. personal competence (with games, with learning, with professional skills, etc.) [105], [114–119]
- Behaviors (behavioral intentions):
- Group, team, organizational characteristics: team/group conflict, psychological safety, psychological collectivism, team and organizational commitment, etc. [120–124]

In-game

- Game performance: e.g. based upon in-game scores like time, avoidable mistakes, etc. [125–129]
- Game play: effort; dominance, influence, power etc.
- Game experience: flow, immersion, presence, etc. [130–132]

Post-game

- Game experience: e.g. engagement, fun while playing the game [13], [80], [133], [134]
- Player satisfaction with: 1. the game (e.g., clarity, relevance); 2 the game digital environment (e.g., attractiveness, ease of use); 3. interaction with other students (e.g., student's efforts, motivation, role identification); 4. the facilitator (e.g., supportive, student's identification with facilitator) [135–137]
- First order learning (short term, individual, participants). player learning satisfaction, self-reported, self-perceived learning, e.g., broad range of items [138–140]. Measured changes in knowledge, attitudes, skills, behaviors (behavioral intentions).
- Second order learning (mid, long term, collective, participants and non-participants). Self-reported, case-based, reconstructive: e.g. asking clients, participants etc. how the GBL results have been implemented. Measured changes in team, group, and organizational characteristics: e.g. safety, commitment, performance, performance.

11. Data-reduction and analysis

A final and important concern is data reduction and analysis. Over the years, we have varied and changed items, questions and constructs. Data reductions through factor analysis and reliability analysis of scales increasingly allow us to select the influential and distinguishing items and construct scales. One of the scales for instance we frequently used has been labeled 'Game design quality'. It consists of 10 items that together give three scales to measure the player's satisfaction with the design of the game. The end goal of comparative research is to test the efficacy of GBL and SG through Structural Equation Models (SEM).

12. Conclusions

We formulated the requirements and a conceptual research model that can be translated into quasi-experimental research designs and operationalized into an evaluation model for specific cases and contexts of GBL. We demonstrated the principles and workings of the model on the basis of a comparative case of twelve SGs. We are aware of at least one weakness in our approach: the authors had multiple roles and potential interests as designers, users, teachers, facilitators, entrepreneurs etc. in all games. We have done our best over the years to separate these roles as much as possible and to approach evaluation as systematic as conditions allowed. We see the three ways forward:

1. Comparative analysis of the data in order to find the influential factors on the efficacy of GBL and SG.
2. Improvement of constructs and scales for GBL and SG.
3. Use of a digital tool for QED research of SG and GBL, that allows immediate coupling of a variety of pre-, in –game and post-game data.

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