

2D-ME: A conceptual framework for explaining self-first and self-third person views of prototyping dynamics in serious games design

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Abstract

Background: Design dynamics that evolve during a designer's prototyping process encapsulate important insights about the way the designer is using his/her knowledge, creativity and reflective thinking. Nevertheless, the capturing of such dynamics is not always an easy task, as they are built through alternations between the self-first and self-third person views.

Objective: This study aimed at introducing a conceptual framework, namely 2D-ME, to provide an explainable domain that could express the dynamics across the design timeline during a prototyping process of serious games.

Methods: Within the 2D-ME, the Technological-Pedagogical-Content Knowledge (TPACK), its adaption to the serious games (TPACK-G) and the Activity Theory (AT) frameworks are combined to produce dynamic constructs that incorporate self-first, self-third person, extension of the TPACK-G to GTPACK, rules, division of labor, and object. The dynamic interplay between such constructs is used as an adaptation engine within an optimization prototype process, so each sequential version of the latter could converge to the designer's initial idea of the serious game. Moreover, higher-order thinking is scaffolded with the internal Activity Interview Questionnaire (iAIQ) proposed here.

Results: An experimental case study of the application of the 2D-ME conceptual framework in the design of a light reflection game is showcased, revealing all designer's dynamics, both from internal (via a diary) and external (via the prototype version) views. The results of this case study exemplify the convergence of the prototyping process to an optimized output, by minimizing the mean square error (MSE) between the conceptual (initial, updated) idea of the prototype, following explainable and tangible constructs withing the 2D-ME framework.

Conclusions: The generic structure of the proposed 2D-ME framework allows its transferability to various levels of expertise in serious games mastering, used both for designer's process exploration and training of the novice ones.

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Original Manuscript

Original Paper

2D-ME: A conceptual framework for explaining self-first and self-third person views of prototyping dynamics in serious games design

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Results: An experimental case study of the application of the 2D-ME conceptual framework in the design of a light reflection game was showcased, revealing all designer's dynamics, both from internal (via a diary) and

external (via the prototype version) views. The results of this case study exemplified the convergence of the prototyping process to an optimized output, by minimizing the mean square error (MSE) between the conceptual (initial, updated) idea of the prototype, following explainable and tangible constructs withing the 2D-ME framework.

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KEYWORDS

2D-ME conceptual framework; Technological-Pedagogical-Content Knowledge (TPACK); Activity Theory (AT); self-first/self-third person Games TPACK (GTPACK); internal Activity Interview Script (iAIS); serious games prototyping

Introduction

Background

Serious games are games that focus on learning while entertaining. As their design entails elements from both the game and learning design, it is a process of a rather complicated thread of decisions. Conceptualizations of this process contribute to serious game design modeling frameworks [1]. Towards the serious game designing, the work of [2] proposed the Mechanics, Dynamics and Aesthetics (MDA) framework. In particular, their work is fundamental in the area and realizes three distinct components that can be viewed from the user's and the designer's perspective. The Mechanics describe specific options of actions that the user can perform while interacting with a game and they can be described through verbs (e.g., move). On the other hand, the Dynamics refer to the combined player options towards a system of interactions at a higher level than the mechanics i.e., they can be considered the system-behavior of a game. Yet, the Mechanics, being more specifically defined at a lower level of abstraction, are more reliable than the Dynamics. Finally, direct and indirect interactions of the player with the game result to the Aesthetics that refer to the emotional responses of the player (e.g., fun), as they are provoked by the combination of the game Mechanics and Dynamics, the latter bridging the Mechanics with the Aesthetics. Thus, a flow is realized during the game design, i.e., initial selection of Mechanics, then Dynamics and finally Aesthetics. Although the work of [2] was criticized as situational [3], it can serve as a direct framework to outline the serious game design. A detailed list of core mechanics was proposed by [4] and a list of comprehensive Dynamics by [5].

Research work in the area of serious game designing resulted in further frameworks that followed the work of [4]. Moreover, [6] provide a systematic literature review regarding the methodologies, frameworks, and models applied to game designs in the period 2008-2016 resulting in 11 approaches, whereas [7] provide a state of the art of six models in the area. However, the LM-GM Framework [8] worth mentioning, as it was based on the idea that learning occurs while interacting with the game i.e., learning Mechanics can be mapped to the game Dynamics and relevant thinking skills according to Bloom's taxonomy. Thus, the learning objectives are diffused in the serious game design [9] to entail the game's educational character. Following this approach, [5] proposed the Game Design Matrix (GDM) structure, which reorients the building block of MDA framework [2] by first selecting the Dynamics, according to the expected level of mastery in the Bloom's taxonomy, so as the emphasis is initially given to the learning objectives that drive the learning outcome of the serious game. The design procedure, however, is an iterative process and [2] underline the importance of iterative analyses and refinement of the game design results. In a more detailed approach [7], following the MDA framework, consider the game design as iterative cycles of design, test, evaluation, and redesign and stress the idea that the iterations would eliminate the risk failure while designing a serious game. In particular, they focus on the prototyping iterations and consider them as series of small steps towards the enhancement of the quality of the game outcome. Following this path, [10] consider prototyping an important part of the game design. Prototyping may take place by various means e.g., by pencil and paper, computer and other artifacts in many disciplines e.g., engineering, in order to

break out a complex problem to sub-problems and work on these separately. A game however is rule based; thus, it is sensitive to changes and/or prediction of possible impacts due to rule changes. Under this perspective, prototyping may resolve unpredictability issues in game design [11]. Moreover, considering games as pieces of art as compared to average software [12], their designing is even unpredictable as the design space may be dynamically evolve through new ideas and creativity.

The aforementioned approaches provide frameworks of designing and establish steps of the enactment of design ideas. However, they do not refer to the knowledge that is needed for the materialization of the game design. Towards this direction, the frameworks described below have been considered.

Design frameworks and serious games

The TPACK framework

The Technological-Pedagogical-Content Knowledge (TPACK) was proposed as a framework to account for the knowledge needed by the teachers in order to use Information and Communications Technology (ICT) in their classrooms [13-15]. In particular, this framework extended the notion of [16] concerning the Pedagogical Content Knowledge (PCK), by foreseeing the inclusion of knowledge related to Technology. Figure 1(a) depicts the TPACK framework and manifests the interplay between forms of knowledge (Content knowledge (CK), Pedagogical Knowledge (PK), Technological Knowledge (TK), Pedagogical Content Knowledge (PCK), Technological Pedagogical Knowledge (TPK) and Technological Content Knowledge (TCK)). More specifically, CK refers to the knowledge of the content of the lesson, e.g., the concept/s that is/are to be taught, PK to the pedagogical considerations as to how to teach the content, TK to the knowledge about the technological affordances and their use, the TCK and TPK to the way the technology could support and materialize the delivery of C and P, and finally PCK the pedagogical way that the content could be delivered to the learners. The contextualized synthesis of all these forms of knowledge constitutes the core TPACK framework. TPACK is usually presented as three overlapping equal circles denoting three forms of knowledge (CK, PK, TK) and their overlaps (TCK, TPK, PCK, TPACK), all included in a circle that denotes the knowledge that is needed towards the integration of technology in a relevant sociocultural context. The TPACK has been widely used as a framework to reflect ICT integration in the classroom even under education emergency conditions [17].

The TPACK-G framework

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theoretical reference framework of necessary knowledge for the technology integration in different contexts, e.g., [18] proposed TPACK as an aid to the teacher, when selecting a game, in order to realize its constraints and affordances for technology, pedagogy, and content. However, [19] commented on TPACK for its abstract reference to general technology that could be used in the classroom i.e., it lacks of specificity that might contribute to further specification of knowledge that is needed. Towards this direction, in the specific case of computer game integration in the classroom, [20] proposed the TPACK-G (Figure 1(b)) to reflect the knowledge that the teachers need in this case. In particular, they define GK as the knowledge about the general usage of computer games, GPK as the pedagogy related to the way a game is used in the classroom and CPCK the “knowledge of using games to implement teaching methods for any targeted content” (p.464). Based on prior work on the developmental pathway of TK, TPK, to TPACK, they proposed the GPCK as a pyramid, where GK constitutes the basis, followed by the GPK and finally at the top the GPCK. Upon this modelling, they claim that for the development of specific GPCK, the GK and GPK are prerequisites, so lack of the foundation knowledge of how to play a game, i.e., familiarity with gaming environment (GK), leads to lack of GPK and therefor GPCK. Structural relationships were also detected between the TPACK-G attitudes towards games and actual teaching usage [21].

Both the TPACK and TPACK-G frameworks are proposed, through a “stationary-like” approach, whereas a more dynamic one might reveal the evolution of type/es of knowledge over time, while an activity takes place, e.g., during the iterative approach towards the designer’s activities while designing a serious game. The Activity Theory (AT) framework may provide a lens towards this direction, as explored next.

The Activity Theory (AT) framework

The AT has its roots in the 1920s and provides a conceptual framework according to which, the human activity connects the individual world of the subject with the social one (Figure 2). Upon

its initial formulation [22,23], the AT framework focused on the activities of the subject, e.g., human being. In order for the subject to meet his/her needs s/he carries out activities by interacting with objects in the world by means of tools that mediate the interaction. Thus, the subject is involved in an activity motivated by an expected outcome (the “why” of the activity), pursues goals that direct the activity (the “what” of the activity) and performs operations (the “how” of the activity) [24]. However, the connection between subjects and activities is bidirectional as they mutually determine one another. Basic principles of AT evolve through the work of [22,23], namely [25]: a) object-orientedness, which states that objects differentiate the activities which are directed to them upon motivation towards a need, b) hierarchical structure of activity, that is a hierarchical system that shows the dynamic relationship among three levels of human activity. From a top-down perspective of the activity, at the top, the activity driven by the motive is considered. The activity however in a lower level is performed through conscious actions that are directed to goals (possibly decomposed to sub-goals) that are to be undertaken in order to fulfill the object. At an even lower-level, actions are performed through unconscious operations that are oriented to conditions under which the goal is to be reached, c) tool mediation, towards a purposeful activity, d) development, as a context to analyze the activity, e.g., from research perspective, this leads to the analysis of the dynamics of the object transformations over time and e) internalization externalization.

Synergies of AT in serious games prototyping

the self is

In the work of [29], the AT framework was used for serious games' analysis and design. In particular, they proposed the Activity Theory-based Model of Serious Games (ATMSG) conceptual model, which contributes to the realization of the components of a game and their roles and to the recognition of the educational objectives. In addition, they foresee three activities, the gaming, the learning and the instructional activity and their tensions in order to describe the contexts where the game is used. Moreover, for each activity they propose elements taxonomized in actions, tools and goals per activity, upon which a game may be analyzed/designed. Yet, the ATMSG model is restricted only at interactions between the triad, subject, object and tools. The works of [7] and [26] use the AT approach to propose analyses of the prototyping procedure during the design of a serious game. In particular, [7] focus on the iterative character of the serious game design and present an early-stage methodology and a prototype for learning a case-concept. Moreover, [26] also focus on the game prototypes and among other, on the role of the prototype to the internalization and externalization of the designer's ideas. The combination of the AT with the TPACK framework, namely TPACKtivity, has been proposed by [30] as a lens to follow preservice teachers' TPACK development through their activities, i.e., realizing its dynamic character across the time.

Contradictions, social and relational self-views within AT

The traditional logic considers contradictions in a system as problems; dialectical logic, however, considers that learning and development are driven by them. Hence, within the AT framework (Figure 2), analysis of the trajectory of the object across time can contribute to the realization of the evolution of its current existence and the expected contradictions that may drive its further development [25]. Thus, a deep assumption is that the activity develops across the time mainly through contradictions that arise, i.e., upon resolving one contradiction another may arise. Continuous approach of the activity provides continuity in viewing the driving forces (triggers and resolutions of contradictions) that steer this activity further. Focusing on the subject of the activity system, initial ideas about the dichotomy of the context-free information processing of human functioning as opposed to society were further elaborated, extending the subject approach in the AT. In this direction, [31] proposed a framework to combine the social and relational view of the self. In their approach, the subjectivity that is developed outside and in the activity system of reference, may result from the role according to the social position of the human being, i.e., serious game designer, which along with social interactions and collective practices co-evolve. On the other hand,

considered as an active agentive role that s/he does not only acquire historical cultural norms and experiencers, but develops them further through change and novelty. In this sense, the ever-expanding social practices entail human subjectivity and both, social and relational, views of the self-coexist among planes of the activity through the internalization and externalization processes.

The aforementioned design frameworks either present the design of a serious game through the lens of the AT or the combination of TPACK with the AT. However, they hardly focus on the subject of the activity, i.e., the designer, and when they do so, a macro-level is adopted, referring mostly to the procedures per se, e.g., connection of the subject's internal plane with the world's plane.

Study Aims

Here we introduce the 2D-ME, an innovative conceptual framework that adopts a micro-level approach towards the serious game designer's inner world while s/he is prototyping. In particular, we dynamically follow the designer's 1st and the 3rd person views (2D-ME) during the prototyping activity under the lens of the AT and an extended version of TPACK in the game design area, namely GTPACK. Under this aim, the following research questions were investigated:

1. Is 2D-ME a useful framework for describing the prototyping dynamics during the design of a serious game?
2. How the internal (1st person) and external (3rd person) views facilitate the optimization of the prototyping output during a serious game design?

Although we refer to the serious game designer, the 2D-ME could easily be transferred to the case of serious game developer (sometimes these two roles are undertaken by the same person). Moreover, as it offers new insights in the internal processes during prototyping, the 2D-ME could also be used as a research framework for analyzing the research aspects of dynamics during creative prototyping.

In spite of the conceptual character of proposed 2D-ME framework, its practical implementation can easily be realized via a series of steps:

1. Conceptualization of the initial idea-target of the serious game.
2. Identification of the AT constructs.
3. Activation of a metacognitive process (e.g., reporting in a diary via a self-interview script), which could facilitate the interplay between the roles of first- and third-person view during the

prototyping.

4. Enabling and capturing of the dynamics between the AT constructs.
5. Adaptation of the AT dynamics towards the convergence of prototype successive versions to the initial idea-target of the serious game.

$S(i)$, motivated towards the materialization and optimization of the object $O(t)$, that is, the game prototype $P(n, k)$, $n=1, 2, \dots, N; k=1, 2, \dots, M$, at specific time instances k , uses his/her current $GTPACK(i)$ to produce each prototype version ($P(:, 1), P(:, 2), \dots, P(:, k)$ towards $P(:, M)$), which is the final version of the outcome of the activity system. It should be noted that the n

Methods

The proposed 2D-ME conceptual framework

Main constructs and dynamics

Serious Stemming from the design frameworks presented so far, the proposed 2D-ME conceptual framework is described in this section. Figure 3, depicts the main constructs of the 2D-ME framework. As it is apparent from the comparison between the shapes of Figure 2 (AT) and Figure 3 (2D-ME), a connection of the 2D-ME with the TPACK, TPACK-G and AT is noticeable. This is materialized by the inclusion within the 2D-ME of: (a) the concept of triangles and interactions as in AT, and (b) the combination of TPACK with the TPACK-G as a new entity in the AT triangle, namely GTPACK. However, all constructs of AT (Figure 2) are replaced with new ones (Figure 3), as follows:

- Instruments/Mediating artefacts $\rightarrow$ $GTPACK(t); t=1, 2, \dots$
- Subject $\rightarrow$ $Subject S(i, t)$, $i=1^{st}$ person or 3^{rd} person view; $t=1, 2, \dots$
- Rules $\rightarrow$ $Rules R(t); t=1, 2, \dots$
- Community $\rightarrow$ $Subject S(j, t)$, $j=1^{st}$ person or 3^{rd} person view; $j \neq i$
- Division of Labor $\rightarrow$ $Division of Labor DL(t)$
- Object $\rightarrow$ $Object O(t), t=1, 2, \dots$
- Outcome $\rightarrow$ Prototype versions $P(n, k), n=1, 2, \dots, N; k=1, 2, \dots, M$ (last version).

As it is apparent, the 2D-ME embeds within its structure a dynamic activity within its constructs that interact and (potentially) are modified across time (t). In particular, the prototype designer is considered as the subject $S(i)$ and subject $S(j, t)$, $j \neq i$, alternating across time (t) between the 1^{st} person and the 3^{rd} person view. The

parameter expresses the different dimensions of prototype (see Section: The Object Outcome (Prototype)). Apparently, the 1^{st} person and the 3^{rd} person view of the subject communicate upon rules $R(i)$ and division of labor $DL(i)$.

As it can be deduced from the aforementioned 2D-ME structure (Fig 3), the flexibility of the AT to project the activity at different levels of analysis is used here to shift from a macro- to a micro-scale approach. More specifically, at the macro-scale approach, the prototyping procedure in the game design provides samples of the evolution of the game design across the time. From a main concept perspective, the 2D-ME framework adopts a micro-scale approach by following the inner iterative prototyping procedure that follows the game designer across the time. Upon this, an AT triangle is defined, where the subject, i.e., the designer of the serious game, is the focus of the approach. The 2D-ME foresees the designer to adopt two perspectives while prototyping, i.e., the 1^{st} and the 3^{rd} person view, respectively. In this way, the 2D-ME follows the internalization/externalization actions within the game designer and provides a conceptualization of the prototype design before its externalization to the others (e.g., collaborators, users etc.). To further explain the main concept, a description of each entity of the 2D-ME follows.

The GTPACK

The GTPACK (Figure 1(c)) is considered in 2D-ME as a tool that extends the TPACK in the area of the necessary knowledge base for the serious game designing. In particular, the GCK refers to the cognitive content of the game i.e., the subject matter of the discipline of reference. GTK refers to the knowledge base relevant to the technology related to the games design and its use. Finally, GPK reflects the knowledge of possible misconceptions, of learning theories and how to apply them in games, of metacognition, etc. Under this perspective, in a game designing procedure, GTCK might be triggered for the representation of the concept to be learned in the game environment, the GPK for the definition of

the game dynamics and the GPTK for the selection of the game mechanics, whereas the GTPACK for the whole game design and aesthetics. The GTPACK serves as a tool that mediates the activity of the subject upon the object towards the outcome. It should be noted that the GTPACK is not a stable framework across the design time, as the designer might interact with resources (either human and/or material) that may alter its load and dynamics across the time.

The Subject

The 2D-ME proposes two points of view of the subject, the 1st and the 3rd person view, respectively, considering transitions from the internalization to externalization processes and vice versa, yet both defined within the same person. In particular, the 1st person view considers the subjective-version of the subject in the activity system that reflects his/her activity following rules of designing a serious game, i.e., the social world. The 3rd person view considers the self-version of the subject that reflects his/her activity according to the object of the activity system that s/he acts upon as designer. The 3rd person view is the agentive self who leads the activity as s/he is engaged with the social world. Under this perspective, the 1st and 3rd person views hold a GTPACK, they both coevolve with the activity, yet the 3rd person view is mainly reflective, in order to actively introduce possibilities, to enhance them by prioritizing other actions, and possibly generate activities that stem from the reality, fantasy and serendipity.

The Rules

In the AT, the rules primarily mediate how the subject acts in relation to the object, including the tools employed and the ways they are used [27,28]. This could include specific and/or well-established patterns of behaviors that could be followed either due to cultural norms and/or other reasons (e.g., professional, legal mandates). In the 2D-ME, the rules refer to the ways of communication between the 1st and the 3rd person view during the subject's communication. Apparently, this interpersonal communication follows some norms (rules) that facilitate the process by which the subject is engaged in unspoken internal interaction and/or dialogue between different and sometimes conflicting attitudes, thoughts, and feelings, all represented by the

1st and 3rd person views. Clearly, these rules are subject-dependent and can be imposed, sustained, redefined, modified, dropped within a dynamic process that, actually, could add to the metacognitive skills of the subject.

The Division of Labor

The main responsibilities (what is being done by whom) that are involved towards the object define the division of labor in AT, taking also into consideration the horizontal division, i.e., across tasks, and the vertical division, i.e., across the power, positions, access to

resources, and rewards [27,28]. In the 2D-ME, the division of labor refers to the contribution of two subject's views, i.e., the 1st and the 3rd persons, towards the object within the interpersonal communication. The concept of horizontal and vertical division can also be transferred at this inner level, by considering the different aspects that could be triggered during the interpersonal communication. For example, the horizontal division could include a systematic definition of a sequence of interpersonal sessions across the prototyping process. Moreover, the vertical division could prioritize the 1st person view in the access to and use of the technological resources (e.g., game developing software), leaving the space to the 3rd person view for reviewing the aesthetics (e.g., rewarding/corrective feedback on game sensation, fantasy, challenges).

The Object-Outcome (Prototype)

The object in AT can be approached by various views, i.e., the object is seen as a thing-to-be-acted-upon, an objectified motive, a desired outcome [32]. The object in 2D-ME is to materialize an idea towards optimizing the outcome, which is a prototype of the game. The prototypes could vary in purpose, as they can refer to a role, an implementation approach, a look, a sense of feeling. These include interaction with the users (role), construction of the game (implementation), users' experience (look and feel) [33]. This multiplicity in roles results in multiple dimensions (denoted with the parameter n , with N being the total number of dimensions). The various versions of the prototype in 2D-ME (i.e., $P(n, k), n=1, 2, \dots, N; k=1, 2, \dots, M$) are tangible externalizations of the development transformations that the

activities undergo between the constructs across the serious game design process.

Prototyping Optimization

vein, its transformation, i.e., $\hat{P}_0(n, k)$, is considered at the next stages of the design process. This transformation could alter specific dimensions of the prototype (e.g., eliminate some, add new ones) and/or the

The proposed 2D-ME conceptual framework considers the prototyping process as an optimization process that converges to the optimal prototype ($P(N, M)$) by minimizing a cost function. This is clearly depicted in Fig 4, where the constructs triangle (Fig 3) is used as an adaptation engine. The cost function per k is the convex function of the mean square error (MSE) between the conceptual (initial, updated) idea of the prototype ($P_0(n), \hat{P}_0(n, k)$) and its current version ($P(n, k)$), given below:

$$MSE(k) = \frac{1}{N} \sum_{n=1}^N [\hat{P}_0(n, k) - P(n, k)]^2, k=1, 2, \dots, M. \quad (1)$$

The adaptation engine provides the convergence, so the whole activity gradually reaches to the optimized outcome, i.e., $P(N, M)$. However, the optimization convergence is not seen within an absolute perspective, but rather from the designer's view and experience. This means that the current optimization process could stop at a point that the $P(N, M)$ will not express the full spectrum of the designer's skills and knowledge, but the process will reach at a point where the designer has already concluded for the validity of the final output and the sufficient use of his knowledge and experience, i.e., his/her current level of GTPACK.

Furthermore, as it can be seen from Fig 4, the initial idea ($P_0(n); n=1, 2, \dots, N$) acts as a trigger to the adaptation engine and, at the beginning of the process, it is considered as static. However, the processes within the adaptation engine (e.g., the interpersonal communication), apart from the update of the version of $P(n, k)$, could potentially affect the initial idea, as well. In this

characteristics of each dimension. Apparently, the frequency of the changes of the $\hat{P}_0(n, k)$ it is anticipated to be low, considering the level of the designer; that is, how clear and solid is the initial idea in his/her mind. To this end, during the optimization process, some versions of the $\hat{P}_0(n, k)$ could be constant across k , e.g., $\hat{P}_0(n, k) = \hat{P}_0(n, k-1) = \hat{P}_0(n, k-2), n=1, 2, \dots, N; 3 \leq k \leq M$. This is, usually, anticipated as the prototype converges to its optimum version, since the designer has already a clear view of its intended and the constructed version.

Capturing of Dynamics

From what it is presented so far, it is clear that the 2D-ME entails dynamics among its constructs and in the prototyping optimization process. In order to capture such dynamics, some sampling tools should be employed. Clearly, the interpersonal communication (between the self-first and the self-third persons) that is involved in the 2D-ME sets the highest hurdle in the dynamics capturing process. One way to infer for the activation of such communication could be the employment of a systematic approach that would include a subject's diary. The latter could be structured on specific contextual factors reflected in a set of statements. A characteristic example of such statements is included in the Activity Checklist [34,35], which is based on AT. As the Activity Checklist provides a "contextual design space" [26], this could be adapted, accordingly, to include statements that could help the designer to describe in his/her diary the employed dynamics between the 2D-ME constructs. In this way, the Activity Checklist itself can serve as a "valuable aide memoir and a tool for reflexivity" [36, p. 31]. Nevertheless, the Activity Checklist contains a large number of items (43 for design and 37 for evaluation) [35] that make its full use quite difficult in practice. As a remedy, adaptation of the Activity

Checklist to the form of interview questions, limited in number, was proposed by [37]. Hence, this interview form of Activity Checklist could trigger reflection and self-talk and could assist in capturing specific dynamics at the various phases of the prototyping process. In this vein, internal questions related with the 2D-ME dynamics that could be self-answered and documented in the diary could be formed, as an internal Activity Interview Script (iAIS), tabulated in Table 1.

An additional source of understanding the dynamics is via the exploration of the alterations across the different versions of the prototype. Apparently, this is a lower quality sampling of the dynamics when compared to the aforementioned approach; it provides, however, a way of monitoring the dynamics, especially when exploring the differences across the dimensions (n) of the prototype versions across the design time. A process of deconvolution is then applied, in order to identify the constructs that were more frequently employed in a current version of the prototype. Projecting this construct activation across the whole prototyping process, the dynamics per construct can be revealed.

Experimental Case Study Setup

An experimental case study was set up as a running example of the realization of the 2D-ME in practice. In particular, the case refers to a preservice teacher (PT) as the designer of a serious game for K-12 students. The motivation for the latter was drawn from the Physics student's exercise textbook for the 5th Grade of the Primary School in Greece (p. 63). In the latter, an exercise related to the light reflection on mirrors presents a situation where a series of mirrors are fixed at different positions in a box. At the perimeter of the box there are four openings where specific objects (compass, scissor, and pencil) and a boy's eye are positioned, respectively. The student is asked to identify and draw the paths of the light reflections on mirrors so as the boy can see the three objects (see $P_0(n)$ in Figure 6). This exercise was presented to the PT as a stimulus for the design of a related serious game on light reflection. PT was at his final semester of his studies at the Department of Primary Education, Democritus University of Thrace (DUTH), Greece, and he already had attended one-semester course concerning serious game design using Scratch (<https://scratch.mit.edu>). In particular, concerning his GTPACK, the PT had GCK about the light mirror reflection, which was the concept to be practiced by the serious game. Moreover, he had an extended GPK due to his studies and a good GTK based on the familiarity with the game prototyping, design and implementation in Scratch. Thus, his current GTPACK was considered adequate for this experimental study. It should be noted that PT already was aware about the GTPACK framework.

The research design foresaw controlled experimental situation that took place at the DUTH's computing lab within a period of one month. PT willingly participated in this experiment and was informed about the experimental process before embarking on it. More specifically, he was asked to express in a diary the conceptualization of his initial idea $P_0(n)$ of the serious game and then to proceed to his prototyping activity and optimization (Figures 4, 5). Moreover, he was addressed with the aforementioned iAIS and was advised to document his relevant thoughts in the diary during the prototyping procedure. It was made clear to PT that the use of the diary should be spontaneous and in no way should hamper his creative impetus. Furthermore, he was informed and consented that an observation documentation would

be made by the SH researcher (first author), in order to capture the explicit prototyping performance of the PT. At the end of the experiment, the PT consented to openly share the diary; a thematic analysis of the diary was manually conducted and combined with the data from the observations along with the outcome of the whole activity.

Results

Conceptualization of the initial idea

PT formulated his initial idea $P_0(n)$ of the serious game, based upon his GTPACK. He wrote in the diary:

I can extend the image in the school textbook where there is a source that produces the light ray and mirrors at stable positions to reflect it so as through successive reflections it can reach a specific point. The students are asked to hypothesize the reflections and then draw a line to depict the path of the light ray as it reflects in this labyrinth of mirrors. Thus, if the student realizes this path once, then there is no interest to resolve it. So, I need to extend this activity towards a more interactive and interesting situation through my serious game. Keeping the analogy with the textbook activity, where it is presupposed that the student already has been taught the light mirror reflection, my educational aim is to involve the students in a serious game, in order to further elaborate the light reflection concept in more dynamic situations than the textbook, e.g., the student can try the mirror reflection towards different lines of the ray and not in a specific labyrinth. Thus, my objective is to move the cognitive effort from the applying level and beyond according to the Bloom's taxonomy. Moreover, I can use depictions from the textbook that the students are acquainted of, i.e., a torch as a source for the light ray, a line for the light ray, top view of a mirror and a top view of a brick as target.

I will elaborate on the well-known K-12 students' misconceptions about the light reflection, concerning the equality of the angles of the light ray as it lands on and reflects from the mirror surface. I will assume that the students had already been taught the light mirror reflection; thus, they have conquered the first two levels of the Bloom's taxonomy, so my serious game will not provide relevant information.

....my objective is to move the cognitive effort concerning the aforementioned concept at the applying level of in the Bloom's taxonomy.

...as a tool I will use Scratch.

I will follow the GDM design framework and I will choose dynamics and mechanics from those presented in the work of [5], combined with additional important elements, namely:

- o *Space and Dynamics: The student should manage to apply the idea of the equal angles that are employed in the mirror reflection, but I do not want to show this; they must hypothesize the light line in a space arrangement that with include three*

sprites, i.e., a source of the light ray, one mirror to reflect upon and one target where the reflected ray should hit, respectively. Thus, I choose the hidden objective dynamic. I also want the student to arrange in a way the game space, so I choose the player autonomy dynamic; yet, with limited actions so as not to be confused. Finally, I will provide feedback to his/her efforts, e.g., a score counting the successive efforts towards the shooting the target with the reflected light ray.

- o *Mechanics: The torch will be at a stable position, but the student could rotate it. The mirror would be horizontally positioned in the bottom of the scene and could be moved in both directions on the x axis and the target will be at a stable position. Thus, I choose move, rotate, for the objects, aiming and shooting for the light ray, allocating for the hypothesized path of the light ray."*
- o *Sprite costumes: I will use depictions from the textbook that the students are acquainted with, i.e., a torch as a source for the light ray, a line for the light ray, top view of a mirror and a top view of a brick as target.*
- o *Aesthetics: I think that the acquaintance of the students with the sprite costumes, the appealing scene, the explicit roles of the sprites and the challenge to target the brick will motivate the students to have fun and keep playing it towards higher scores. All these will contribute to the aesthetics dimensions of my serious game, i.e., its sensation (sense of pleasure), fantasy (make-believe), challenge (obstacle course), discovery (uncharted territory), and expression (self-discovery).*
- o *Programming. I need to program all the needful with Scratch.*

From the aforementioned excerpts, it can be inferred that PT conceptualized his initial idea $P_0(n)$ of the serious game. He also defined the $N=6$ dimensions, where $n=1$ corresponds to the space (sprites: a source of the light ray, one mirror and one target), $n=2$ denotes the dynamics (hidden objective, player autonomy, limited actions and feedback), $n=3$ refers to mechanics (move, rotate, aiming and shooting and allocating), $n=4$ corresponds to the sprite costumes (a torch, a line, a top view of a mirror and a top view of a brick), $n=5$ refers to the aesthetics, and $n=6$ is for the programming dimension.

Dynamics in adaptation engine and prototype optimization

During the activity, PT followed iteration paths through which a series of enhancement of the prototypes that were developed in Scratch resulted in the final output (the game). Here, indicative versions of the prototype are presented to reflect the dynamics and realization of the adopted optimization procedure within the 2D-ME framework. In particular, we follow the $P(n,k)$, $n=1,2,\dots,6, k=1,2,\dots,5$, prototypes in the sequential order that they were developed, cumulatively constructing the serious game aspects. It should be noted that not all dimensions are

simultaneously activated across the prototyping, since the PT placed the effort according to his temporal preferences and focus on specific dimension(s).

Diary-based Sampling

As a first means of dynamics acquisition, excerpts from the PT's diary were used for each version of the prototype. Figure 5 facilitates the presentation at multiple levels that are employed during the application of the 2D-ME framework, showcasing the activity system that the PT was involved in, its dynamics across the triangles' vertices (Figures 3, 5: $\{A,B,C\}, \{a,b,c\}$), and the optimization procedure that took place. The corresponding activated dimensions (separated by semicolon), are described below; SH researchers' external view based on the iAIS is also noted within brackets and included in Figure 5:

- Initial idea: $\hat{P}_0(n,1)=P_0(n)$, Prototype: $P(1;6,1)$
 $a \rightarrow A$: From the 1st person view, I will start by setting the main scene and creating the first sprite; however, my GTPACK is not adequate to achieve this. {Q1.2} I need to enhance my GTK on how to program the reflection of the light ray on a moving mirror. {Q3.2}
 $A \rightarrow C$: I need to incorporate multiple roles within myself to activate a reflective path for my design decisions. {Q1.1, Q4.2}
 $C \rightarrow a$: From the 1st person view, I now feel more confident to start materializing my $P_0(n)$ idea. {Q3.2}
 $a \rightarrow c$: From the 1st person view, I managed to write the Scratch code for the main scene and the first sprite and produce the first version of my object, i.e., $P(1;6,1)$. {Q1.4}
- Initial idea: $\hat{P}_0(n,2)=P_0(n)$, Prototype: $P(1;4;6,2)$
 $a \rightarrow b$: From the 1st person view, I will next put the mirror in the scene. {Q1.2} From the 3rd person view, I realized that I need to revise my initial idea for the size and the way the mirror should look like, to avoid trivial game options. {Q2.1}
 $b \rightarrow B$: The 3rd person view helps me to identify design pitfalls and use one rule, i.e., to be on the shoes of the user, in order to better understand the game. {Q4.1, Q4.2}
 $B \rightarrow a$: From the 1st person view, I keep as a rule to really play the prototype, in order to feel the pitfall that I conceived as such from the 3rd person view {Q1.1, Q4.2} I also follow the rule to distinguish between what remains the same and what should be changed towards optimization. {Q1.4}
 $a \rightarrow c$: From the 1st person view, I understand that the 3rd person view scaffolds my thoughts for the next step towards the implementation of my initial idea and I managed to write the Scratch code for the mirror, selecting the analogous size and view, producing the second version of my object, i.e., $P(1;4;6,2)$. {Q1.4, Q3.4}
- Initial idea: $\hat{P}_0(n,3)=P_0(n)$, Prototype: $P(1;3;4;6,3)$
 $a \rightarrow b$: From the 1st person view, I will next put the brick and the light ray in the scene and adopt the sprite costumes of a line and top view of a brick, respectively. {Q1.2} From the 3rd person view, I realized that I need to revise my initial idea for the fixed angle of the light source to avoid trivial game options. {Q2.1}
 $b \rightarrow C$: I realized that I need to have a more organized sequence of reflections; hence, I have decided to adopt more frequent alternation between the 1st and 3rd person view during my design process. {Q4.2}

- Initial

C→a: From the 1st person view, I now feel more excited to put more degrees of freedom to the torch. {Q1.3}

a→c: From the 1st person view, I managed to write the Scratch code for the addition of the brick, the light ray and the rotation of the torch, producing the third version of my object, i.e., $P(1;3;4;6,3)$. {Q1.4}

• Initial idea: $\hat{P}_0(n,4)=P_0(n)$, Prototype: $P(2;3;6,4)$

a→b: From the 1st person view, I will next include the feedback to the student via a score display; however, I feel that something is missing... {Q1.2, Q2.1} From the 3rd person view, I had the idea of inserting randomness in the game. I find myself a bit strange when I have ideas that I do not know how to implement. It is a contradiction to my general attitude to proceed safely. However, when I follow them, I believe that new possibilities are revealed. {Q1.3, Q2.1, Q2.2}.

b→A: I feel that I need to expand my GPTK towards the motivational and engaging role of the surprises in the game through randomness and its relevant programming. {Q3.2}

A→C: I can use my enhanced GTPACK and identify better the involvement of my different roles in myself for the technology- and aesthetics-related aspects of the prototyping. {Q3.1, Q4.1, Q4.2}

C→a: From the 1st person view, I broke down the move mechanic across my prototyping procedure, in order to realize which object/s it should refer to, and materialize the decided randomness. {Q1.2, Q1.3, Q3.5}

a→c: From the 1st person view, I managed to write the Scratch code for the addition of the score and incorporate movement of the sprites, producing the fourth version of my object, i.e., $P(2;3;6,4)$. {Q1.4}

idea: $\hat{P}_0(n,5)=P_0(n)$, Prototype: $P(5;6,5)$

a→b: From the 1st person view, I feel that, most probably, I have reached the point of satisfaction with the structure of the game so far; but I am not 100% sure... {Q2.1} From the 3rd person view, I visualized a more interesting approach, focusing on the game aesthetics, that incorporated the sense of depth in the main scene. {Q2.2, Q3.4}

b→a: From the 1st person view, I understood that this reflection provides me with many options to increase the sensation and fantasy of the game, using different 3D scene backgrounds. {Q3.4}

a→c: From the 1st person view, I managed to write the Scratch code for the addition of a 3D background in the scene, producing the fifth version of my object, i.e., $P(5;6,5)$. {Q1.4} I believe that, at this point, I have achieved my first higher goal to construct a good prototype of these functionalities and aesthetics of the game, converging to the initial idea conceptualized in the form of $P_0(n)$. {Q1.4, Q1.5}

).

It should be noted that in the excerpt of the optimization process presented above, the initial idea was kept constant across k , as the level of the game designing was of low complexity, trying to conceive and materialize the basic environment and functionalities of the game. As the game advanced, updates of the $P_0(n)$ took place, e.g., through the insertion of more than one mirrors spreading randomly in the scene space; introduction of various game levels with different degrees of difficulty (e.g., random distribution of non-reflecting obstacles, time limitation per level) and so on. Moreover, the GTPACK of the PT was enriched during the prototyping process, showcasing the internal dynamics that are developed across the design time at the GTPACK level, depicted as expanded overlapping spaces in Fig 5 (top). The estimation of the MSE (Fig 5 (bottom)) was based on the comparison (see Eq. (1)) between the current $\hat{P}_0(n,k)$ and the $P(n,k)$ across the n dimensions. As the dimension of programming ($n=6$) is not included in the $\hat{P}_0(n,k)$, this was excluded from the MSE calculation, involving the dimensions of $n=1,2,\dots,5$ in Eq. (1). As at each k , not all dimensions are involved in $P(n,k)$, the highest drop in the MSE is expected when many dimensions of $P(n,k)$ are activated, as it can be seen at $k=3$ ($P(1;3;4;6,3)$

Prototype-based Sampling

At a second, however with lower resolution, sampling of the dynamics, the materialization of the prototypes per optimization version were also analyzed. Figure 6 depicts the sequence of the produced prototypes for $k=1,2,\dots,5$, reflecting the specific dimensions that were examined at each k , visualized at the scene level and the corresponding Scratch code; the stimulus from the exercise textbook used as $P_0(n)$ is also presented. From Figure 6, at $k=1$, there is a very simple output at the scene level (one sprite); however, there is more extended structure at the programming level. This reflects the activation of the GTPACK as a means for extending the gaming programming background. At $k=2$, the work at the programming level is simplified and the scene is extended with the inclusion of the second sprite. The complexity of the programming is increased at $k=3$, since there is the addition of the third sprite and the light ray. This shows higher convergence to the initial idea, revealing that the PT follows an optimization process. In addition, at $k=4$, the experimentation with the light ray and the rotation of the sources (already seen at $k=3$), along with the addition of the user feedback (score) reveal an activation of the GTPACK (to enhance the game programming skills) and of the 3rd person view (also seen in Figure 5). In this way, the PT sees his

prototype from the eyes of the user and tries to accommodate the issues of trivial solutions and lack of feedback, increasing, thus, the game options and aesthetics. The interpersonal interaction about aesthetics continues at $k=5$, where the scene becomes 3D, providing more immersive impression to the user. Again, here, it seems that the dynamics between 1st and 3rd person view are the ones that dominate (also seen in Figure 5), as the enhancement of the external (user's) view of the game is the focus at this stage of prototyping.

Discussion

Principal Findings

The proposed 2D-ME conceptual framework surfaces the roles of the 1st and 3rd person view that challenge the designer to realize aspects of his/her self in this iterative procedure. Being more reflective, the designer may realize that the self may be both a subject influenced by the society norms, e.g., in the aforementioned case the programming rules, but also a driving self that may influence the society through the output of his/her game design. These roles were reflected at the presented case study, which served as a showcase of the 2D-ME framework to reveal the dynamics within the iterative process of the prototype optimization, seen both from the designer's space (diary) and the game design outcome (prototype). This may contribute to more knowledgeable game designers, as it provokes reflection in a fine-grained way of thinking at different levels. It should be noted that, the presented case study did not entail the hierarchy of the activity theory and was kept mostly at the activity system level, focusing on the optimization procedure.

In the presented case study, the user is a PT, who, since he works in the education sector, he had already acquired a basic knowledge of the GTPACK framework. Nevertheless, there is no requirement for someone, in order to use the 2D-ME framework, to have any specific level of prior knowledge; simply, someone who undertakes a prototype design process (in the specific case of game design), most probably will have a basic level of the technology, pedagogy and content knowledge in the field. Even if s/he is not an expert, during the prototyping process, s/he will interact with the knowledge base and would acquire extra knowledge in the area. This is schematically shown in both Fig. 1(c) and Fig. 5 (GTPACK), where the context of the GTPACK is not split in equal sections, but there are different levels of knowledge within it (Fig. 3(c)), which dynamically are expanded during the interaction with the knowledge base (Fig. 5; increased GKC for $k=34$). In addition, the knowledge of the iAIS is not provided as a constrain, but as a guide to help the user formulate the internal reflection on the activities during the prototyping; someone could follow his/her own pathway of metacognitive process stimulation. However, we believe that the proposed iAIS targets all the reflective aspects that could be helpful to serve as a tool of memoir and reflexivity during prototyping.

Apart from focusing on the monitoring of the internal dynamics during the prototype optimization process, 2D-ME can also be used as a means of structure for the designer's skills development in the reflection and creativity. Diary writing itself requires the designer to rethink events and processes, along with thoughts, contradictions, decisions, outcomes, which all have taken place at the various

stages of the prototyping process, and "re-live" it, as many times s/he wants, even after its end. This strategy promotes his/her critical thinking and reasoning skills, i.e., his/her higher order-thinking skills [38]. In addition, the stimulus from the iAIS (Table 1) sets an organized pathway of reflection steps that span across the triangle constructs involved in the 2D-ME framework. In this way, the activity dynamics are scaffolded by the iAIS stimulus and gradually become more imprinted in the game designer's reflection strategy and higher-order thinking. When the narrative information of the diary is transformed into dynamics within the 2D-ME framework (Fig 5), a more externalized representation is achieved that could be visible, apart from the designer him/herself, to others, as well. This can provide information for some characteristics of the designer's personal way of thinking/creating, increasing their explainability, especially when they are not tangible at the prototype level and/or cannot be easily inferred from the final output (e.g., the $P(n, M)$). In this way, the 2D-ME framework could provide more objectified basis for the analysis and comprehension of the expert designer's process, from idea conception to the final output, that can be used for teaching the novice designers, help them to better understand their internal processes and improve their designing skills and outcomes.

In the case study that was presented here, the prototyping process was optimized by taking into consideration the relation between two adjacent versions of the prototype, that is, for the creation of the $P(n, k)$, the $P(n, k-1)$, ($k > 1$), was considered as input to the AT triangle (Fig 5). Nevertheless, additional views could also be adopted, and a higher (>1) order of memory could be employed, e.g., for the creation of the $P(n, k)$, the $\{P(n, k-3), P(n, k-2), P(n, k-1)\}$, ($k > 3$) can be used as a sequence of inputs. Moreover, this sequence could also vary across the whole process, both in the number of the previous versions used and/or in their continuity, e.g., $\{P(n, k-3), P(n, k-1)\}$, ($k > 3$). This depends on the scale of the focus that is used at each k , providing the opportunity to the designer to shift from the micro- to the macro-scale of the prototyping process [39,40]. This influence of previous prototype version(s) within the creation of the new one materializes the convolution of the dynamics adopted in the past with the dynamics shaped in the current version, in an effort to create a new, more enhanced prototype. This blending of dynamics in a macrostructural approach showcases the causalities that are created across the prototyping process that, in a way, contribute to the personal characteristics of the designer's style. For example, sequential use of the prototyping versions (e.g., as in Figs 5 and 6) could reveal steadier design style, where each step is cumulatively constructed from the previous one. A more discontinued use of past prototyping versions could express more diffusion of the design ideas at various time instances of $k-l$ ($l=1, 2, \dots \vee k-l > 0$), revealing a distributed way of materializing the design ideas, where different parts of them gradually are synthesized and construct a more integrated prototype version at the k th time instance.

The adopted bilateral sampling of the dynamics in the 2D-ME, i.e., via the analysis of the diary notes and the prototype versions, provides both the internal and external view of the prototyping dynamics and outcome, respectively. Additional means of dynamics sampling could also be foreseen, by incorporating other sources of relevant information, such as biosignals. In fact, the biological-

signal data from multiple biological-signal sources, e.g., electroencephalography (EEG), electrocardiography (ECG), electromyography (EMG), electrooculography (EOG), and electrodermal activity (EDA), can be combined with artificial intelligence (AI)/machine learning (ML)/deep learning (DL) to provide additional queues of the developer's state (e.g., stress, relaxation, hyper/hypoactivity) during the design of the game and the creation of a series of prototypes [41,42]. In this way, the projection of the creative thinking onto the physiological signals and testing of the same protocol to game users, could reveal the transferability of the designer's intentions to the gamers, via the similarity of the related acquired signals. This could be used as a measure to optimize the game design and create a dynamic co-creation process [44-47], that could adapt to the specific characteristics of the designer and the target group of the serious game users [48-52].

Limitations and Further Research

The proposed 2D-ME conceptual framework provides new insights into the internal dynamics of the game designer's prototyping process. Clearly, the presentation here of one case study with five prototype versions cannot express the whole range and magnitude of such dynamics. It serves, however, as a good example of the potentialities the 2D-ME framework could provide, both to the game designers, educators and researchers. In addition, the adoption of MSE (Eq. (1)), as a cost function for the optimization process (Figure 4), could also be further explored, as alternative and/or a combination of metrics could be involved. The selection of such cost function(s) should take into consideration the acceptable variation that relates with the context of a particular applied game design problem and should clearly express, as much as possible, the gains from its minimization under the game design problem's particular circumstances [53]. Extensive experimental application of the 2D-ME framework (e.g., in educational settings of game design), could further validate its efficiency to monitor the dynamics evolved within the game design prototyping process, not only under the controlled settings, as presented here, but also at more naturalistic environments, e.g., designers' workplaces/labs.

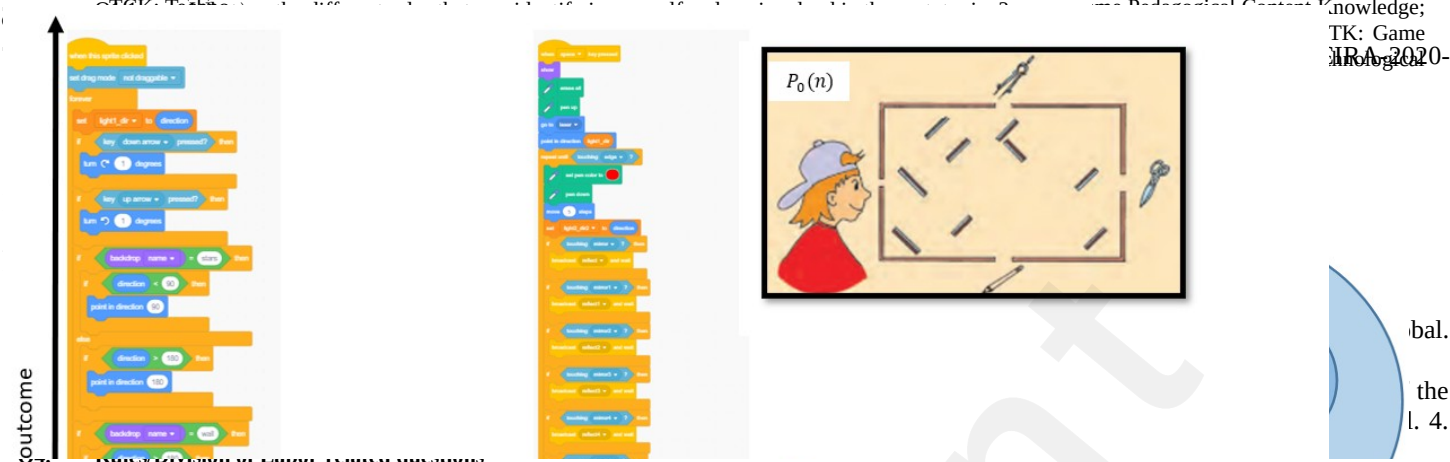
The 2D-ME conceptual framework attempts to explain the self-first and self-third person views of prototyping dynamics in serious games design. Nevertheless, as it combines TPACK and AT in a dynamic way, it shows many potentialities to be extended further to various design problems, additionally to the area of game design. In this vein, in our future plans, we foresee 2D-ME to be applied into the areas of arts, where the game design is replaced by art design. In many areas of art, e.g., painting, sculpture, literature, architecture, cinema, music, theater, the design dynamics is the driving force for the creativity and the development of the art work through prototyping. Clearly, the 2D-ME framework can easily embrace and explain such dynamics. Furthermore, sharing of the prototype version at specific k time instances to an external group (e.g., experts, colleagues, mentors, educators), could provide an additional level of external input to the internal world of the designer, extending the role of the community. In this vein, the current 2D-ME framework can be extended to the 2D-ME-ALL one, embracing external inputs/dynamics during the prototyping process, enhancing, thus, the social and collaborative aspects in the use of the AT objects, extending to runaway ones with even broad societal ramifications [54]. Clearly, during the development of the

prototype versions, externalization and projection, from the "inner" to the "outer" world is possible and, under a co-creation perspective, wishful, in order to arrive to an optimized version. Moreover, this externalization does not have to be for the whole prototype, but it could be associated with specific parts (processes) of the prototyping, where external feedback is needed, upon the personal decision of the designer. In addition, it could happen during one or many iterations, providing a dynamic interplay between the inner and outer worlds. Approaching this as interconnected AT systems (constellations) [55], mainly shifts the locus of attention to the multitude of such internal activities, as externalized via their relationships, rather than the interplay between the self-first and self-third person within the game designer's mind. In this sense, the selection of the scale is important and the inclusion of interconnected AT systems could explain a concept of collective contribution (i.e., transition from the person to the group and, further, to society). Apparently, this can happen in the case of complementary contributions by different experts participating in the game prototyping, e.g., directors, graphic designers, composers, light experts, character creators. It also can be expanded to an interdisciplinary context where the experts come from distant backgrounds, e.g., health and technology. However, even in such cases, the 2D-ME framework could be adopted by each expert to describe the steps that s/he undertook to arrive to his/her final contribution to the game design. Finally, there are some creative processes that are lone by nature, e.g., music composition, painting. In such cases, it is important to focus on the internal dynamics that take place in the artist, as, in this way, we can identify personal traits and idioms that finally characterize the personal artistic style. In this kind of cases, the constellation of AT systems could, probably, be adopted if we want to model the audience interaction with the artistic outcome, especially in cases where there is an interactive part in it, for example, music installations or interactive spaces (e.g., Xenakis' polytopes). These views and extensions of the 2D-ME, along with the addition of biosignals' input by incorporating AI/ML/DL tools, sets the forthcoming research goals; work has already embarked towards such endeavor.

Conclusions

A new conceptual framework, namely 2D-ME, that provides insights upon the dynamics that evolve during a serious game designer's prototyping process has been presented here. Combining information from both the games space, TPACK and AT, the 2D-ME framework provides explainable representation of, somehow, intangible processes, most of them not easily identifiable in the externalization of the prototyping process, that is the prototype itself. With the use of dynamic constructs, the 2D-ME framework incorporates the alternations from 1st person to 3rd person view and vice versa, stimulated by an organized way of internal self-interview (iAIS), providing dynamics monitoring that drive the prototype optimization process. A paradigm of the practical implementation of the 2D-ME framework in the case of a game design on light reflection exemplifies its potentialities and efficiency to capture the fine-grained dynamics involved during the production of the prototype version across the design timeline. Due to its generic structure, the 2D-ME framework has high transferability to other areas of designing, e.g., arts, and could be used both as a means of exploration of the expert designer's creative process and training of the novice ones, providing explainable representations of the underlined higher-order thinking.

Figure 6. The internal Active Interview Script (AIS) optimization process in DEM framework. The consistent knowledge (K) is provided as the initial seed, $P(0)$, and the inconsistent knowledge (K) is provided as the initial seed, $P(0)$. The AIS optimization process in DEM framework is also depicted.



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Abbreviations

TPACK: Technological-Pedagogical-Content Knowledge

CK: Content knowledge

PK: Pedagogical Knowledge

TK: Technological Knowledge

PCK: Pedagogical Content Knowledge

TPK: Technological Pedagogical Knowledge

TCK: Technological Content Knowledge

AT: Activity Theory

GTPACK: self-first/self-third person Games TPACK

iAIS: internal Activity Interview Script

MSE: Mean Square Error

Supplementary Files

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Figures

Schematic representation of the dynamics across the prototyping optimization for $k=1,2,\dots,5$. At the top, the GTPACK alteration across k are displayed, where the dynamics affect its internal set (at $k=1,4$). The constructs dynamics are denoted with arrows, accompanied with the related iAIS questions (Table 1). The optimization process is depicted for each prototype, whereas the estimated MSE is depicted at the bottom, showcasing its reduction as the game design evolves.

