eLuna

A Co-Design Framework for Mixed Reality Narrative Game- Based Learning

Fredrik Breien

Thesis for the degree of Philosophiae Doctor (PhD)
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Scientific environment

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Abstract

Increased focus on out of school learning over the last decades has led to extended use of science centres as learning arenas for pupils in primary and secondary education. A learning trail is a form of embedded learning environment in which the learners themselves, physical exhibits, and digital companions are elements that promote learning content and goals. When used in science centres, learning trails can combine different sets of exhibits and emphasize various aspects of their content to support learning goals inside a broad range of curricular plans and programs. Being comprised of physical exhibits and digital companions, science centre learning trails are mixed reality systems in which learner interaction occurs in both the physical and virtual domains. Research has shown that narratives and game mechanics are among the most effective components for science centre learning trails to achieve increased focus on the learning content, and to induce flow and engagement in learners. With an aim to contribute to improving science centre learning, the main objective of this research is *to develop a co-design framework for mixed reality narrative game-based learning trails that enforce positive effects on engagement, motivation, and learning.*

Narratives have been used in learning and instruction since prehistoric times, and games for learning have been theorized and applied in human culture for centuries, increasingly so with the advent of the computer, and opportunities provided by digital games. While both narratives and games are shown to have the ability to positively affect learning, research on the effects from narrative game-based learning has shown mixed and contradictory results. The lack of a common model to categorize narrative games has led to a knowledge gap regarding how and under which conditions narrative games have effects on learning. Whereas most studies of narrative game-based learning neglect mentioning a narratological model at all, the ones that do mainly refer to models adapted from different media that lack the capabilities to properly categorize the event flow of many digital games. An exception is the ludo narrative variable model (LNVM), a narratological model that can properly categorize all games as narratives. Building on the LNVM, this research fills this gap with the development of the

extended LNVM (eLNVM), a common model to categorize and isolate narratives in digital game-based learning.

Narrative game-based learning trails comprise interactive exhibits and digital companions and promote learning goals inside curricular programs. Therefore, they require participation from educator and developer stakeholders to be properly designed and brought to learners. Research has shown that there is a lack of models, methods, or frameworks that empower educators and developers to co-design game-based learning, something which results in either the learning content being lost in the engaging mechanics of the game, or the fun of the games becoming inferior to the learning goals. Furthermore, to be applicable in science centres, such a co-design framework must also distinguish between physical and digital elements in mixed reality environments.

Applying an information system research framework as a design science methodology, the eLuna co-design framework for mixed reality narrative game-based learning trails that enforce positive effects on engagement, motivation, and learning was developed. A systematic literature review identified 15 studies that self-reported effects of digital game-based learning systems on engagement, motivation, and learning. These were categorized on the eLNVM and sorted by their self-reported effects to identify what characterizes narrative digital game-based learning systems that positively affect engagement, motivation, and learning. Using an iterative design-based research process these characteristics associated with positive effects were then applied in a co-design framework comprising a method and a visual language, which was later extended with the capabilities to distinguish between physical and virtual elements in mixed reality learning trails. Throughout the process the framework was tested in co-design workshops with stakeholders and evaluated through mixed methods, including focus groups, semi-structured interviews, questionnaires, thematic analysis, and heuristic usability inspection.

The research presented in this PhD dissertation contributes the eLuna co-design framework for narrative game-based learning, which empowers educators and developers in the creation of both narrative digital game-based learning and mixed reality narrative game-based learning trails that optimize the potential to induce positive effects on engagement, motivation, and learning.

Sammendrag

De siste tiårs utvidede fokus på læring utenfor skolen har bidratt til økt anvendelse av vitensentre som læringsarena for barn i grunnskole og videregående utdanning. En læringsløype er en type integrert læringsmiljø der de lærende, fysiske installasjoner, og digitale hjelpemidler bidrar til å fremme læringsinnhold og mål. På vitensentre brukes læringsløyper som pedagogisk støtte innen et bredt spekter av pensumplaner og programmer, gjennom å kombinere forskjellige sett av installasjoner og ved å vektlegge forskjellige aspekter av installasjonenes innhold. Siden de er sammensatt av både fysiske installasjoner og digitale hjelpemidler, er læringsløyper blandet virkelighet systemer, der de lærende interagerer med elementer i både den fysiske og virtuelle virkeligheten. Forskning har vist at både narrativ og spillmekanikker er blant de mest effektive komponentene som kan ligge til grunn for at læringsløyper skal kunne oppnå økt fokus på læringsinnhold, og for å engasjere de lærende ved å sette dem i en tilstand av flyt (av engelsk flow). Forskningen som presenteres i denne avhandlingen har som hovedmål å forbedre læring på vitensentre, gjennom å bidra med et co-design-rammeverk for blandet virkelighet narrative spillbaserte læringsløyper som underbygger positive effekter på engasjement, motivasjon, og læring.

Narrativ har vært brukt til læring og instruksjon siden forhistorisk tid, og spill for læring har vært teoretisert og anvendt i mennesker i århundrer, i enda større grad etter oppfinnelsen av datamaskiner, og mulighetene bragt på banen gjennom digitale spill. Selv om bade narrative og spill har vært vist å kunne ha positive effekter når anvendt for læring, har forskning på effekter fra narrative spillbasert læring vist variable og motstridende resultater. Mangelen av en felles modell for kategorisering av narrative spill medfører manglende kunnskap relatert til hvordan og under hvilke forutsetninger narrative spill har effekt på læring. På tross av at de fleste studier av narrativ spillbasert læring unnlater å nevne narratologiske modeller, og de som gjør det primært refererer til modeller lånt fra andre media som mangler de nødvendige egenskapene til å kategorisere hendelsesflyten som benyttes i mange spill, finnes det en ludo narrativ variabel modell (LNVM), som er en narratologisk modell som kategorisere alle spill som narrativ. Denne forskningen videreutvikler LNVM, og presenterer en felles modell

for kategorisering av narrativ spillbasert læring; eLNVM (fra engelsk: The extended LNVM).

Narrative spillbaserte læringsløyper består av interaktive installasjoner og digitale hjelpemidler som belyser læringsmål innenfor pensumprogrammer. Det er derfor nødvendig med deltakelse både fra pedagoger og utviklere når slike læringsløyper skal designes og presenteres til lærende. Forskning viser at det er mangel av modeller, metoder, og rammeverk som myndiggjør pedagoger og utvikleres felles design av spillbasert læring, noe som enten resulterer i tapt fokus på læringsinnhold til fordel for engasjerende spillmekanikk, eller i at underholdningspotensialet i spill blir underordnet læringsmålene. Slike rammeverk må videre kunne skille mellom fysiske og virtuelle elementer for å være anvendbare i blandet virkelighet omgivelser.

Forskningen presentert i denne avhandlingen benytter et rammeverk for informasjonssystemer som vitenskapelig metode til å utvikle eLuna co-design-rammeverket for blandet virkelighet narrative spillbaserte læringsløyper som underbygger positive effekter på engasjement, motivasjon, og læring. En systematisk litteraturstudie identifiserte 15 studier som rapporterte effekter fra digitale spillbaserte læringssystemer på engasjement, motivasjon, og læring. Disse systemene ble kategorisert med bruk av eLNVM og sortert basert på deres rapportering for å identifisere karakteristikker av narrative digital spillbasert læring som har positive effekter på engasjement, motivasjon, og læring.

Denne forskningen benytter en iterativ design-basert forskningsprosess der karakteristikkene assosiert med de positive effektene legges til grunn for et co-design-rammeverk bestående av en metode og et visuelt språk. Co-design-rammeverket blir deretter utvidet med kapasitet til å separere mellom fysiske og virtuelle elementer i blandet virkelighet omgivelser. Rammeverket blir gjennom prosessen testet i deltakende co-design workshops og evaluert med bruk av varierte metoder, inkludert fokus grupper, intervjuer, spørreskjemaer, tematisk analyse, og heuristisk evaluering.

Forskningen som blir presentert i denne doktoravhandlingen resulterer i eLuna co-design-rammeverket for narrative spillbasert læring, som kan bli brukt av pedagoger og utviklere til å lage både narrative digitale spillbaserte læringssystemer, og blandet virkelighet narrative spillbaserte læringsløyper som optimaliserer potensiale for positive effekter på engasjement, motivasjon, og læring.

List of Publications

Article 1:

Breien, F. S. & Wasson, B. (2021). Narrative Categorization in Digital Game-Based Learning: Engagement, Motivation & Learning. *British Journal of Educational Technology*, 52(0), 91-111. DOI:10.1111/bjet.13004

Article 2:

Breien, F. & Wasson, B. (2022). eLuna: A Co-Design Framework for Narrative Digital Game-Based Learning that Support STEAM, *Frontiers in Education*, 6:775746. DOI: 10.3389/feduc.2021.775746

Article 3:

Breien, F. & Wasson, B., Greiff, S. & Hauan, N.P. (2022). The eLuna mixed reality visual language for co-design of narrative game-based learning trails, *Frontiers in Education*, Special Section on Digital Learning Innovations. DOI: 10.3389/feduc.2022.1061640

The research behind the work presented in the articles was carried out by Breien under the supervision of Wasson and Hauan. Articles 1 & 2 were written by Breien and main supervisor Wasson, who contributed with substantial feedback on the organisation of the paper, prodding on details of the presentation of the results and language editing. The work distribution on article 3 was the same with the supervisors Wasson and co-supervisor Hauan contributed with substantial feedback to the background, and Greiff contributing with discussions of the method and targeting of the research objectives and commenting on the next final version of the article.

Contents

List of figures

List of tables

List of abbreviations

STEM	Science, Technology, Engineering, and Mathematics
STEAM	Science, Technology, Engineering, Arts and Mathematics
GBL	Game-Based Learning
DGBL	Digital Game-Based Learning
ELE	Embedded Learning Environment
LNVM	Ludo Narrative Variable Model
LEAGUÊ	Learning, Environment, Affective-cognitive reactions, Game factors, Usability, UsÊr
LM-GM	Learning Mechanics–Game Mechanics
DSVL	Domain Specific Visual Language
ISRF	Information Systems Research Framework
IS	Information System
eLNVM	extended Ludo Narrative Variable Model
DBR	Design-Based Research

Part 1 – The extended abstract

1. Introduction

Since the 1970s and 80s, international organizations of science centres such as the European Network of Science Centers and Museums (Ecsite)[1] and the Association of Science and Technology Centers (ASTC)[2] have been formed around the world. As can be seen from their strategic reports and statements[3,4], these organizations have consolidated and grown over the last years in terms of member entities, as well as numbers of visitors to, and offerings of, learning programs that are increasingly tied to formal national learning plans and curriculums. In the Nordic and Baltic regions, the Nordic Science Centre Association (NSCA)[5] is an example of a regional science center organization, which count a total of 40 science center members[6]. Most of the NCSA members are also members of Ecsite. Similar regional associations structures exist worldwide, and regional association members are often also members of their continental organizations. When creating learning programs for school visits, science centres typically consult national learning and competence goal descriptions for elementary and high school curriculums, with focus on Science, Technology, Engineering, and Mathematics (STEM) subjects. These STEM subjects are further tied together across curriculums among themselves and can also be interdisciplinary by including subjects from Social Sciences and the Arts[7], referred to as STEAM. This focus on cross-curricular relationships makes the science center learning programs STEAM (Yakman, 2008) compliant educational programs. STEAM education allows for cross-curricular study of subjects based on their naturally occurring relationships with one another through holistic and integrated methods. Through STEAM education science center learning programs, the visiting pupils not only explore the STEM subjects isolated and alone, but also how they affect one another, and furthermore, their

[1] https://www.ecsite.eu/about/
[2] https://www.astc.org/about/
[3] https://www.ecsite.eu/sites/default/files/annual_report_2019_final_version_0.pdf
[4] https://www.astc.org/wp-content/uploads/2019/09/ASTC_StrategicDirection_SUMMARY.pdf
[5] http://nordicscience.net/about
[6] http://nordicscience.net/members (retrieved April 5th, 2022)
[7] Like e.g., Loop https://www.vilvite.no/opplev/utstillinger/loop (in Norwegian), a biodiversity exhibition founded in two interdisciplinary subjects in the Norwegian learning plan, one about Sustainable Development, and another about Democracy and Citizenship https://www.udir.no/lk20/overordnet-del/prinsipper-for-laring-utvikling-og-danning/tverrfaglige-temaer/2.5.3-barekraftig-utvikling?lang=eng and https://www.udir.no/lk20/overordnet-del/prinsipper-for-laring-utvikling-og-danning/tverrfaglige-temaer/demokrati-og-medborgerskap/?lang=eng

culture, society, and the world in which they live. In Norway it is the Directorate for Education (UDIR) that updates and upholds learning plans and the competence goals[8] contained therein.

As can be read on various flagship science centers' public presentations of themselves, terms such as 'inspiring engagement', 'playful involvement', 'exiting and fun exploration', 'joyful discovery', and 'curious creativity', are prolifically used in their self-descriptions[9]. Over the last decade, a wide variety of narrative game-based learning trails, embedded learning environments that tie together semantically related exhibits on science center floors through interactive and multimodal narratives (Hauan and DeWitt, 2017), have emerged. Examples of these are Antilantis, The Adversaries of Waste, and Vilde Vite, as described by Breien, Wasson, Greiff, and Hauan (2022), and EgoTrap as described by Kahr-Højland (2011).

A science center that is part of NSCA and Ecsite, and that offers learning programs in conjunction with Norwegian national learning plans across subjects, is the Bergen Science Centre *VilVite*. As can be seen on their website, VilVite offers their programs to schools at various levels[10]. VilVite is a typical example of science centers that can be found across Europe, North America, and other parts of the world.

As shown by Nils Petter Hauan in his PhD thesis (Hauan, 2017), science center embedded learning environments have the potential to increase both engagement and flow (Csikszentmihalyi, 1990; 1995) in learners, and furthermore provide grounds for cross-curricular learning of STEM subjects in social scientific context related to how they affect our society and the world around us. Furthermore, Kahr-Højland (2011), writing about a Danish science center, shows how narrative game-based learning trails improve the attention span of pupils interacting with individual exhibits when they are used, thereby increasing the learning outcomes from science center visits. As both

[8] https://www.udir.no/in-english/curricula-in-english/

[9] E.g., https://www.vilvite.no/, https://www.heureka.fi/, https://www.experimentarium.dk/, https://www.kopernik.org.pl/ - The exact phrases were all found on these pages by clicking through links and profiled articles on their frontpages on September 6th, 2022. These front pages offer news and rotating offers, is part of the ongoing marketing of centres, and change with a high frequency. Although these exact phrases may not be part of profiled text upon the next visit, there will very likely be similar ones.

[10] https://www.vilvite.no/laeringstilbud (in Norwegian)

authors discuss, these narrative game-based learning trails can be developed as app-based companions on mobile phones or tablets, which carries the narrative from exhibit to exhibit. The apps become digital game environments that are naturally and logically related to the exhibits, and trigger narrative events that occur to tie the exhibits together in a greater whole. The integration of both digital companions alongside the exhibits, which are often physical and analogue in nature, defines narrative game-based learning trails as mixed reality (Milgram & Kishino, 1994) systems, comprising elements that exists both in the physical and the virtual world. As Kahr-Højland (2011) puts it, such narrative game-based learning trails consists of three elements: "The already existing *hands-on exhibits* at the science center [..], the visitor's *mobile phone* and a *narrative*." (p. 67). The overall aim of the research presented in this PhD dissertation is to contribute to improving learning at science centres.

1.1 Science centre narrative game-based learning trails

In conjunction with the growth of science centers' offerings to learners over the last decades, increased emphasis has been placed on out-of-school learning in elementary and high-school education (Drotner, 2008; Henriksen & Frøyland, 2000). As venues for such learning contexts, science centers have become an important area of focus in formal school visits (e.g., Kahr-Højland, 2011; Solis, Hutchinson, & Longnecker, 2021; Hauan & Kolstø, 2014; Drotner, 2008; Henriksen & Frøyland, 2000). Rising to the challenging mandate of providing educational content that meets with the stringent requirements of formal learning for the new generation, Hauan (2017) explored the concept of science center embedded learning environments. In Hauan's work, science centre embedded learning environments are multimodal collections of semantically related exhibits, in which the exhibits themselves, narratives, digital game companions, the pupils, their teachers, and science center educational staff all participate as active entities to induce a state of flow (Csikszentmihalyi, 1990) and engagement in the learners. In embedded learning environments, learners can follow trails of exhibits that are made available as game elements based on learner progress. Completion of game elements opens narrative chapters pointing to new exhibits to visit, while also offering new game elements. Thus, embedded learning environments can be labeled as learning trails; a trail that someone follows to learn something. Central components of learning trails that Hauan shows to induce flow and engagement, are *game elements* and *narratives* embedded in the learning environment. The research presented in this dissertation follows up on the work of Hauan. Focusing on the narrative and game-based components of science centre learning trails, the research explores the categorization of digital game-based learning (DGBL) in a narratological framing and identification of the characteristics of DGBL that are best suited to induce positive effects on engagement, motivation, and learning outcomes. These results form the foundation for the eLuna framework that can be used by educators and developers to create narrative DGBL blueprints that are ready for development and subsequent deployment to learners.

1.2 Empowering stakeholders through co-design frameworks

Narrative game-based learning systems are complex applications that require the empowerment of educators and developers alike to participate in their creation. This should indicate the application of methodologies that enables the positive influence of their professional expertise in narrative game-based learning design. However, in conducting a systematic literature review on design approaches in serious games, Gurbuz and Celic (2022) found 7084 peer reviewed articles about game-based learning published between 2002 and 2022. Of these, 2466 were about game design, however, only 32 provided a design approach with specific steps in form of a method, framework, or model. As Gurbuz and Celic's work does not identify participating stakeholders, it is not possible to derive how many of the 32 approaches included both educator and developer roles in design and development of the methods, frameworks, or models. A wide research community in the field of games (e.g., Hunter-Doniger et al. (2017), Milara et al. (2020), Finch et al. (2018), Finch et al. (2018), MacDonald et al. (2019), Silva (2020), Marchiori et al. (2011), Arnab et al. (2015), Lameras et al. (2017), Carvalho et al. (2015)) point out that there is a lack of common tools, methods, and frameworks to support educators and developers in co-designing game-based learning.

Whereas the afore mentioned researchers all have their own perspectives and stances on the matter, their cumulative conclusion reveals that educator's lack of technical competence, alongside developers lack of understanding of pedagogical taxonomies and methods, often leads to either the learning content being lost in translation to the games, or to the games being overpowered by a focus on the learning methods. The former becomes something fun to play with little focus on learning, the latter becomes learning software that does not capitalize on the affordance of games as entertaining and thus engaging systems. This realization is further reinforced in the 3rd paper, Breien et al. (2022), which shows that the stakeholders in the design of science centre learning trails are even more diverse. Furthermore, science centres not only comprise games and learning materials, but also physical exhibits, which further introduces a wide range of stakeholders in their development. Not only does the creation of science centre narrative learning trails need to be informed by the characteristics of games and narratives that induce positive effects in the learners, there is also a demand for co-design frameworks that truly empower educators, developers, and other stakeholders to properly follow the process of development from beginning to end, resulting in systems that are fun to use, and that also conserve the learning content by placing it front and center in accordance with formal goals in learning plans and curriculums.

1.3 Narrative game-based learning trails as mixed reality systems

With few notable exceptions, such as e.g., Hauan (2017) and Kahr-Højland (2011), the core research foundation on narrative game-based learning focuses on digital experiences, that is, digital game-based learning (DGBL), systems that provide materials to learners in fully virtual environments, screen-based games mimicking entertainment games explored in a fully virtual world (e.g., Tsai & Tsai, 2020; Clark et al., 2016; Connolly et al., 2012; Novak, 2015; Dettori & Paiva, 2009). However, as shown by Hauan (2017) and Breien et al. (2022), science centre narrative game-based learning trails encompass elements spanning beyond the virtual domain. Such components always include 1) physical exhibits that communicate with 2) virtual game companions via sensors or a pupil's transmission of data through solving of physical world tasks, and often include 3) other physical elements, such as physical world position data, time data, or 4) enactments by physical world actors (science centre staff or teachers) playing vital roles in the learning games' narrative experiences. This positions narrative game-based learning trails as mixed reality (Milgram & Kishino, 1994) systems that include interaction with, and communication between, physical and virtual elements in a holistic whole. Central to science centres, mixed reality embedded learning environments are important as these include both physical world (exhibits) elements, and digital companions used in exploration of STEAM concepts.

1.4 Research objective and supporting research questions

Development over the last decades has shown that science centres have become increasingly important for out of school learning. A narrative game-based learning trail, as a form of a cross-curricular, interdisciplinary, embedded learning environment offered at science centres, includes narratives and games as important elements to induce flow and engagement in learners. With an aim to contribute to improving science centre learning, the main objective of this research is *to develop a co-design framework for mixed reality narrative game-based learning trails that enforce positive effects on engagement, motivation, and learning.*

To reach the core research objective, the research formulates three research questions addressed in the papers enclosed in this dissertation:

> RQ1: What characterizes narrative digital game-based learning systems that positively affect engagement, motivation, and learning? (Article 1)
> RQ2: How can a co-design framework empower educators and developers in the creation of narrative game-based learning that is based on characteristics that positively affect engagement, motivation, and learning? (Article 2)

RQ3: How can a co-design framework for narrative game-based learning distinguish the physical[11] from the virtual in mixed reality learning trails? (Article 3)

The research first explores what characterizes narrative digital game-based learning systems that self-report positive effects on engagement, motivation, and learning and develops the extended ludo narrative variable model that can be used to categorize and isolate narratives in DGBL (Article 1; Breien & Wasson, 2021). Based on this model, the research subsequently develops, evaluates, and presents a co-design framework that empowers both educators and developers to co-specify narrative game-based learning systems that adhere to the characteristics that have been shown to induce the positive effects (Article 2; Breien & Wasson, 2022). Finally, realizing that narrative game-based learning trails are mixed reality systems, and that their design specifications should enable co-designers to distinguish the physical-world elements from the virtual elements of the trails, the research extends the co-design framework so that it properly distinguishes physical from virtual (Article 3; Breien, et al., 2022).

1.5 Research design

With the end goal of contributing a co-design framework for mixed reality narrative game-based learning trails, the research presented in this dissertation commences with a literature review (Kitchenham & Charters, 2007) rapid evidence synthesis (Catalá-López, et al., 2017) to uncover characteristics of narrative games that are associated with positive effects on engagement, motivation, and learning and model development to account for these characteristics. The eLuna co-design framework, comprising a method and visual language, was developed through two design-based research (Nieveen & Folmer, 2013*)* studies inside an information system research framework (Hevner, et al., 2004). The first study iteratively developed and evaluated the method and visual language with participants in a series of co-design activities. The second

[11] In article 3, the dichotomy real and virtual was used. Acknowledging that virtual elements may also real, the text in this dissertation replaces real with the more precise term physical.

study extended and evaluated the eLuna co-design framework's visual language with capabilities to distinguish physical elements from virtual ones, making it effective in use for designing and developing learning trails at science centres.

The three articles build on one another in a sequential manner, as shown in figure 1.

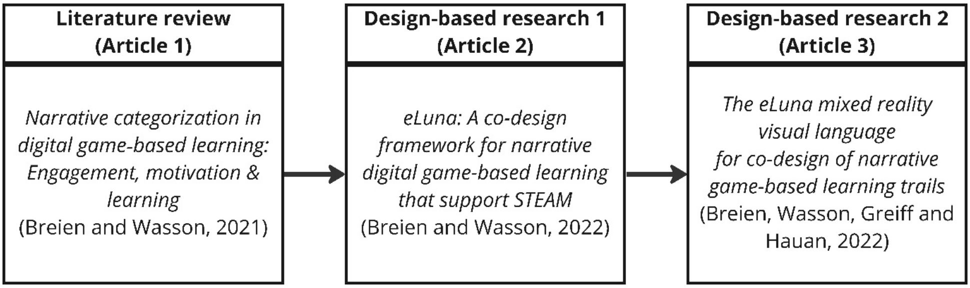

Figure 1: Relationship of the three articles included in the dissertation

The literature review (Breien & Wasson, 2021) obtained and applied a dataset of game-based learning systems to a narratological model to categorize them before sorting them based on self-reported effects. The first design-based research study (Breien & Wasson, 2022) applied the characteristics of the categories that had shown the most positive effects to a co-design framework and iteratively evaluated and developed it consulting experts and end-users. The second design-based research study (Breien, et al., 2022) extended the co-design framework's visual language with capabilities to distinguish between physical and virtual elements in learning trails.

The literature review follows the process of evidence synthesis (Catalá-López, et al., 2017) in systematic literature reviews as described by (Kitchenham & Charters, 2007) and places the systems with self-reported effects on an extension of the ludo narrative variable model (Aarseth, 2012). The first design-based evaluation study iteratively evaluates the co-design framework using mixed qualitative methods following best practices described by Oates (2005) and Belanger (2012). The second design-based evaluation study applies semi-structured interviews as described by Oates (2005), organizes the interview output using thematic analysis Braun and Clarke (2006), before making the required extension applying usability heuristics (Nielsen & Mack, 1994).

1.6 Audience for the work

This dissertation is an information science contribution with application in museum science and game studies. It has both academic contributions (theoretical and methodological) in the fields of game-based learning, human-computer interaction, and system design and a practical contribution for co-designing narrative game-based learning trails usable by educators, game-developers, and museum and science centre planning, development, and educational staff.

1.7 Dissertation structure

This PhD dissertation is divided into two parts, the Extended Abstract (part 1) and the Articles (part 2). The Kappa (extended abstract) informs on the process and decision making of the PhD research, links the studies to the main research objective and supporting research questions, and provides a broader view of the findings and contributions to the fields of narrative game-based learning and co-design of mixed reality learning trails for use in science centres.

Part 1 comprises six chapters, including this introduction. Chapter 2 presents previous research on relevant topics and identifies research gaps. It includes sections about learning trails in museums and science centres, narratives in the history of learning and instruction, game-based learning in both digital and analogue domains, narratological models, co-design frameworks, and effect studies on narrative game-based learning. Chapter 3 introduces the methods used in the research, first in terms of the research paradigm found in information science, then in further detail related to the methods of evidence synthesis, design-based research, mixed qualitative methods, thematic analysis, and heuristic inspection as relevant for the research studies. Chapter 4 discusses the main research objective of the PhD research, using the three supporting research questions as basis for presenting the results. Chapter 5 discusses the contributions of the research, and, reflecting on both the research limitations and the research data that is already collected, describes potential further work, some of which is in progress. The final chapter, Chapter 6, concludes the dissertation.

Part 2 comprises the three papers on which present the research (Article 1, Breien & Wasson, 2021; Article 2, Breien & Wasson, 2022; Article 3, Breien, Wasson, Greiff & Hauan, 2022). All papers in this research were co-authored with the PhD candidate and author of this dissertation as first author, indicating main contribution.

During the doctoral scholarship, 2 papers were published in addition to the 3 included in this dissertation. A spin-off study (Breien & Gkini, 2021) revisits the dataset from the literature review, and, organizing them by the degree of linearity found in their event structures, explored the differences in learning effects between linear and non-linear games. The second, Palmquist, Gunnars, Njå, Gkini, Breien and Jedel (2021) explores shared concepts in the emerging fields of learning analytics and gamified education.

1.8 Reflections on personal motivation

When writing academically, I mostly prefer to do so in third person. However, in this sub-chapter, which is of a personal nature, I stray from this preference, since it seems more natural to describe my background and motivation for the PhD work in first person, talking about myself.

When writing this, it is almost exactly 30 years since I first formulated my thoughts on games as a valuable resource and asset for motivating learning. I remember the setting well. It was the spring of 1992, I was 17 years old, and like many Norwegian high school students, I was enjoying a year of exchange study—for me this was conducted in France, where I attended a lycée in Paris focusing on language studies in a class full of international students. Close to school, there was a café which we frequented practically every day after classes. I was there with two boys from Italy, a girl from Canada, a girl from Japan, and a boy from the Dutch Antilles when I first expressed my thoughts, based on my long run of being a gamer since the early 1980s (the Commodore 64, Amiga 500, and pen-and-paper role playing games, mainly focused on Warhammer Fantasy, my weapons of choice). My ideas were naïve, I admit, but my fellow students were full of encouragement, and it became something I started to ponder seriously, to the point of which I in 1993 applied to Ringerike Municipality (where I grew up in Norway) to write a book about games and learning. They turned me down, of course, and I think that it was right of them, my ideas were far from mature, and it would have been a waste of funds. Sometimes, however, I wish I had that application at hand, just to see what I wrote, and to compare it to where I am today. The talk we had at the café that afternoon stuck, and it's safe to say it formed my career onward in a major way.

While doing my bachelor's degree in informatics and information science (I merged courses from two higher education institutions, one more technical, the other social scientific), I kept thinking about games for learning, and as far as possible tried to revolve all assignments around it. While a master's student, I was fully focused on games for learning, and while taking courses in Computer Supported Collaborative Learning, Artificial Intelligence, and Human-Computer Interaction, I made everything relate to games. My Master thesis, submitted in 2004, was entitled the Situated Educational Environment (SEE), and in it I worked with Adobe, who invited me in as a beta-tester of their Atmosphere 3D[12] system in which I created and evaluated a prototype for game-based history learning. Atmosphere 3D later became extinct when Adobe bought Flash[13] from Macromedia. As history shows, Flash was later practically killed by Apple, when they stopped supporting it[14], but now I digress, it's an interesting story for anyone interested that can be followed in the footnotes.

After getting my master's degree, I worked in academia for a few years, where I became involved with the Bergen Science Centre, for whom I helped develop parts of their opening exhibitions in 2007-08. By the time this was completed, I realized that the time was ripe for game-based learning in a real way, and, having made a network for myself, I co-founded a game developer company that focused on learning games and game-based installations, and entertainment games; with my workload divided approximately 50/50 between the two. From 2008 to 2018, I developed five

[12] https://en.wikipedia.org/wiki/Adobe_Atmosphere
[13] https://en.wikipedia.org/wiki/Adobe_Flash
[14] https://www.howtogeek.com/805605/this-is-how-steve-jobs-killed-adobe-flash/

entertainment strategy games, the last of whom was a licence for Warhammer Fantasy, something which achieved a long-time ambition of mine as that was the very system that got me into gaming in the first place, way back in the early 1980s. Through those 10 years, I also designed and developed more than 40 serious games and game-based learning systems, large and small; many of them for science centres and museums, but also for industry, academia, schools, the public sector, and other institutions in culture and art. The company grew, and I became more and more of a manager, getting dis-attached from the development that I loved. By the end of 2017, I wanted to get back to being hands on, and, spurred on by accumulated curiosity about the actual effects of all that I had done so far, I turned to the VilVite Science Centre and SLATE at the University of Bergen, applied for an industrial PhD position through the Research Council of Norway, and got funded to do the research presented in this dissertation. The rest is history. As I write this, it is with great satisfaction that I look at the publications produced, the framework created, and, not least, the confirmation that it is a good contribution to learning across many sectors for diverse demographics. I am now again at a crossroad and look forward to what lies ahead. One thing that is certain is that I will continue to work practically and carry out research based on learning with games. I cannot see myself ever doing anything else. My course has been set for the last 30 years, and so it is for the next 30 if anyone will let me.

2. Background

The research presented in this PhD dissertation places emphasis on science centre learning environments and contributes design methods for design and specification of narrative game-based learning trails for such venues. This chapter starts with and in-depth presentation of learning trails in museums and science centres, before briefly presenting narratives' place in learning, the concept of game-based learning, and modern perspectives on co-design.

2.1 Learning trails in museums and science centres

As shown in seminal research on pioneering science centres (Piaget, 1970), contemporary science centres (Gardner, 2006), and museums (Csikszentmihalyi, 1995), all such venues used for science communication have the potential to be engaging learning environments. A learning trails (e.g., Walker, 2006A and Walker, 2006B; Leister et al., 2019) is a form of learning environment that guides visitors on tours related to topics in museums and science centres. The term *Learning Trail* is self-descriptive, indicating a *trail* that can be followed with the goal of *learning* something. Not all relevant research on learning trails uses the phrase learning trail in their self-description. Hauan and Kolsø (2014) for example used embedded learning environment (ELE) to name that which is a trail to be followed in learning. In this dissertation the term learning trail is used to encompass such systems. The research presented herein has focused on narrative game-based learning trails, a sub-category of learning trails which applies narrative games as part of the experience, something that not all learning trails do.

2.1.1 Learning trail science and practical application

In the learning sciences, the *learning trail* term was initially defined in research on interactive and multimodal learning in digital distributed environments (Jih, 1996) and advanced to virtual courses by Seehusen et al. (2000), which capitalized on new technologies and the opportunity for learners to travers material in accordance with their own abilities, interests, and goals. Walker (2006A; 2006B) proposed extending interactive and multimodal affordances from learning trails, and to bring them to museum contexts, and to use location tracking and mobile technologies for visitors to generate their own narrated learning trails that can later be shared with others. This can be applied in science centres as well. In first presenting EGO-TRAP (Quistgaard & Kahr-Højland, 2010), that use a combination of exhibits, flexible narrative structure, and communication technologies to emphasise social and individual learning processes, the authors show that learning trails, due to their structure and flexibility, foster both personal and social learning processes as well as critical reflection. Learning trails exist worldwide and Kahr-Højland (2010) shows practical examples from the countries of Sweden, Denmark, The United Kingdom, Ireland, The USA, and Israel. Other examples can be found in Norway, among them the Bergen Science Centre's Antilantis, Vilde Vite, and Adversaries of Waste learning trails (Breien, et al., 2022). Another example is the Bergen Aquarium 'Make your fish'[15] mobile learning trail, where visitors collect fish based on personal preferences through the exploration of relevant aquariums and solving challenges related to what they learn there. A third is The Norwegian Museum of Science and Technology's 'Tele and Data Exhibition'[16], where visitors input relevant data about themselves, and are then guided through the exhibition in an individual sequence where, depending on the visitor's selected topics, a different focus is placed on, and information received from, individual exhibits. In developing a learning concept where school class groups of learners perform a series of thematically related experiments with exhibits named *learning trails*, Leister et al. (2019) propose the use of an Engagement Profile (Leister et al., 2016) to translate exhibit properties into both media forms and generic learning outcomes.

2.1.2 Narrative game-based learning trails' effects on young learners

As shown by Kahr-Højland (2010) the narrative game-based learning trail named EGO-TRAP positively affect young learners, because it "*scaffolds pleasurable engagement and counteracts the tendency of 'random button pressing' that often occurs in classical science centre exhibitions*" (p. 66). According to Kahr-Højland this is because of the narrative game-based learning trail's quality as a digital narrative, and

[15] https://www.akvariet.no/nyheter/lag-din-egen-fisk (retrieved 12th July 2022, in Norwegian)
[16] https://www.tekniskmuseum.no/ikt (retrieved 12th July 2022)

because it, through the narrative on the mobile phone, offers an experience which young people describe as both personal and flexible. Presenting the Embedded Learning Environment (ELE) framework, Hauan and Kolsø (2014) show that narrative game-based learning trails induce flow and engagement in young learners, that educational activities with clear goals and appropriate rules facilitate curiosity and interest, and furthermore that games, which are rule based systems with clear goals, allow for exploration and playful action in science learning. They also show that narratives are promising instruments for facilitating engagement in science learning, since they help students stay focused, while at the same time allow for personal choices and actions within the narrative frame (Hauan & Kolsø, 2014). Hauan's ELE are multimodal learning trails balancing structure and free exploration, in which the game and the narrative are important elements. The research described in this dissertation builds on the work of Hauan (2017) and seeks to categorize narrative game-based learning trails, searches for characteristics of narrative games that positively affect learning, and then develops a co-design framework for development of narrative game-based learning trails that, through use of Hauan's ELE induce flow together with categorical characteristics of games and narratives, enforce positive effects on engagement, motivation, and learning.

2.1.3 Museum and science centre structure: Collections, exhibitions, and exhibits

Normally, museums and science centres maintain a *collection* or a set of *collections*[17] inside a broad topic, such as *contemporary* or *classic art*, *photography*, *natural history*, *culture history*, *science*, and so on. In public presentation, collections are typically divided into *exhibitions* that are organized as subtopics, such as for example 'Dinosaurs' or 'Volcanoes' in a natural history museum, 'Expressionism' or 'Modernism' in an art museum, or 'Energy' or 'Robotics' in a science centre. Inside the exhibitions, there are several elements that each Inform on the subtopic. These

[17] Whereas single museums usually refer to a singular collection, there are museums that have several. An example is the Bergen Art Museum KODE https://kodebergen.no/en/about-kode-0, which constitutes seven individual museums with diverse art ranging from handcrafts via photography and painted art, to cultural historical buildings and architecture. As such, KODE 1 to 7 hold individual collections. When seen individually, however, each museum has a collection.

elements are referred to as an exhibition's *exhibits*[18]. In a natural history museum Dinosaurs exhibition, exhibits can, for example, be dioramas of dinosaurs in natural environments from the eras in which they lived, or dinosaur bones and fossils mounted for display. In an art museum, exhibits will often be the paintings, pictures, photos, or other individual pieces of art, such as installations and sculptures, that are exposed on the walls and floors around the museum space. In a science centre, exhibits can be a set of physical or virtual interactive experiments that all showcase a STEM principle, such as how energy is produced using different raw materials and methods, how the energy is distributed, and what it is used for, and so on. Figure 2 shows a typical museum and science centre structure.

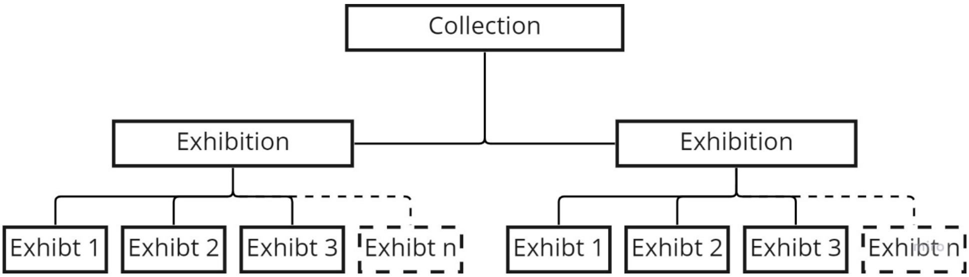

Figure 2: A collection, separated in two exhibitions with many exhibits in each

The possible topics of museum collections are too numerous to mention of course, *toys*, *trains*, *national costumes*, *flags*, *planes*, and *paintings* comes randomly to mind, all of which can be organized into exhibitions made up from sets of exhibits. In the city of Bergen, with approximately 275 000 inhabitants, the local government webpage lists 43 museums[19], however, when looking through the list and applying local knowledge, it is possible to identify several that are missing. Looking at a world metropolis like London, doing an Internet search for '*How many museums in London*', and opening the first handful of links show the generally estimated number of museums in London to range between 200 and 300, Wikipedia states 250 registered in 2016[20]. The official

[18] Exhibits can be referred to as objects, installations, items, and several other terms inside various artistic and museum communities. At the Bergen Science Centre VilVite, the word exhibit is consciously and uniformly used, and since this research is related to the collection and learning trails at VilVite, the term exhibit will be used throughout this dissertation.
[19] https://en.visitbergen.com/things-to-do/attractions/museums (retrieved 13th July 2022)
[20] https://en.wikipedia.org/wiki/List_of_museums_in_London (retrieved 13th July 2022)

site Visit London does not provide a count, however, using their booking tool[21] and setting the search parameters to visit 'any museum' in 'London' at 'any time in the future', gives 164 results, which should be the full list limited to the ones that visitors can book admittance to through Visit London; presumably there are many for which one cannot. Generalized examples of much profiled topics and subtopics in a museum can be:

- Art from a particular artist, or artistic tradition or period, in a classic museum
- Presentations in one way or another of specific species, evolutionary eras, or geographic or temporal regions, in a natural history museum
- Details about the workings of a scientific discipline or specific scientific achievement, or about how scientific traditions or discoveries affects our world and society, in a science centre or a technical museum

2.1.4 Museum and science centre structure: Spatial distribution and aspects of learning interests

Museums and science centres show their collection in exhibitions spatially distributed in physical locations, museum buildings. In museum and science centres visitors can move from one exhibit to another and receive information about them through various modalities. As is usual in science centres, but not so much in museums, visitors can also often interact with and manipulate the exhibits to solve challenges or to explore topics based on information received in the surroundings.

While individual exhibits are part of single exhibitions, a single exhibit can still be interesting due to many different and coexisting aspects of its artistic qualities or descriptive capabilities. The same photography in a photo museum can, for example, be of interest as a portrait photograph, a black and white photograph, and a photograph that depict a particular political or cultural event, or era at the same time. An example of such a photo is Yousuf Karsh's 1941 portrait of Winston Churchill[22], which is part of the collection of The National Portrait Gallery[23] in London, England's *20th Century*

[21] https://www.visitlondon.com/things-to-do/sightseeing/london-attraction/museum/1 (search done 13th July 2022)
[22] https://www.npg.org.uk/collections/search/portrait/mw07205
[23] https://www.npg.org.uk/

Portraits exhibition. It is also a black and white photo and can be found as one in the museum's subjects and themes section[24], which visitors can use to guide their visit through what is essentially a learning trail for black and white photography. Furthermore, Karsh's portrait is part of the museum's *Icons Trail*[25], a learning trail with a subtopic related to '*people who changed the 21st century*', among them Winston Churchill. The photograph of course, remains stationary on a wall in the museum, or, if it is moved, can certainly not occupy more than one space at any one time. In such situations, learning trails are useful, since they allow visitors to traverse a museum based on subtopics that are not necessarily linear inside the museum exhibition spaces, but which may lead from one exhibit inside e.g., the portraits exhibition, to another in a different exhibition altogether, which is semantically related to the previous exhibit in the given perspective on learning goals. The portrait of Winston Churchill can, for example, lead to the painting Statesmen of World War I[26], if the subtopic is war history, or to the painting of Margaret Thatcher[27], if the subtopic is prime ministers of Great Britain. Moreover, in these two examples, the information presented for the Churchill portrait would differ from one to the other, wherein the first could inform about Churchill's career in the military and his contributions in the wars in which he participated, and the second could inform on his political affiliation, and the political roles he filled in his life, up to and beyond becoming prime minister. Figure 3 extends museum collection structures with learning trails and illustrates how learning trails can be created across topics and exhibitions, using museum exhibits across them to inform on different curricula.

[24] https://www.npg.org.uk/collections/explore/subjects-and-themes/
[25] https://www.npg.org.uk/visit/icons-trail
[26] https://www.npg.org.uk/collections/search/portrait/mw00301/Statesmen-of-World-War-I
[27] https://www.npg.org.uk/collections/search/portrait/mw07953/Margaret-Thatcher

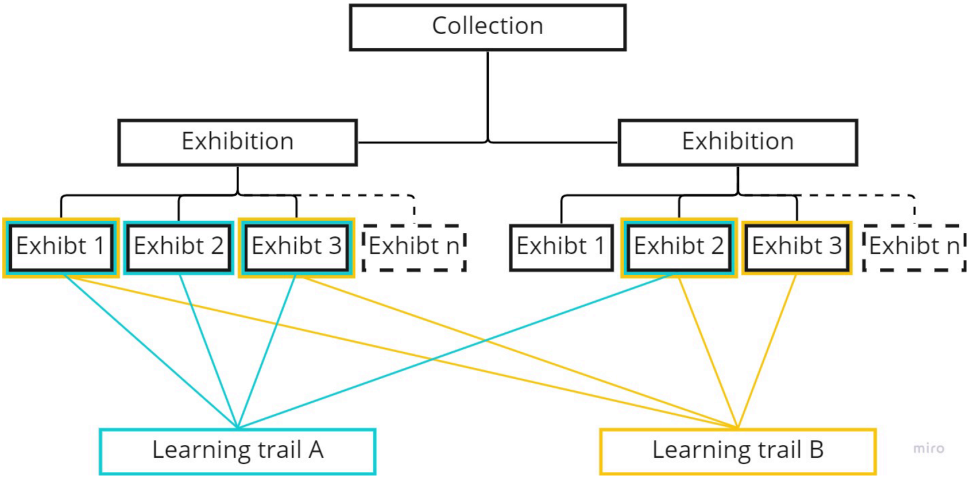

Figure 3: Museum and science centre learning trails' use of exhibits across exhibitions in collections

Two of the afore mentioned learning trails at the Bergen Science Centre VilVite, Antilantis and Adversaries of Waste, are examples of narrative game-based learning trails that used exhibits across exhibitions. Antilantis comprised 14 exhibits, Adversaries of Waste across eight. The science centre at that time had three exhibitions and with an average of 10 exhibits each. Figure 4 shows Antilantis and Adversaries of Waste and a subset of the exhibitions they employed, to illustrate a practical example of the structure in Figure 3.

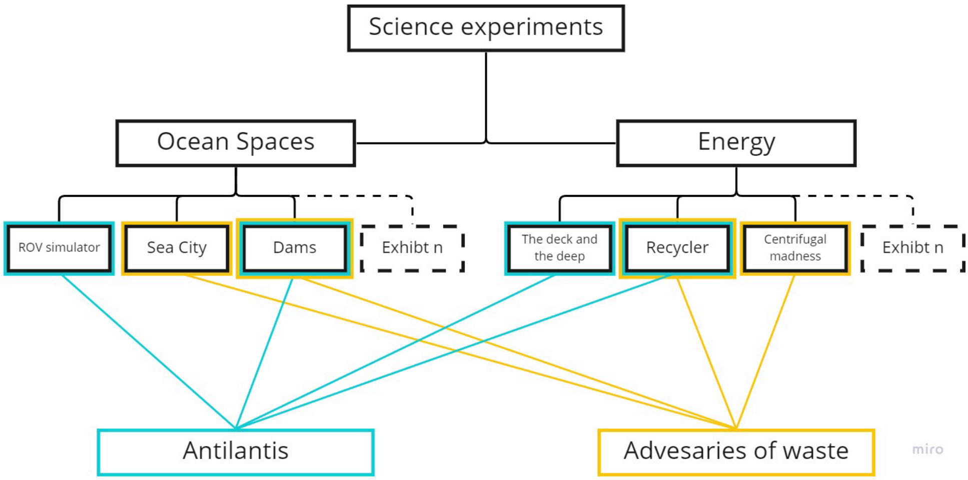

Figure 4: Examples of learning trails at VilVite

As figure 4 shows, VilVite has a collection of science exhibits that are divided into three exhibitions, two of which are Ocean Spaces and Energy. Among the exhibits shown, each of the learning trails use four exhibits, two from each exhibition. The Recycler and Dams exhibits are used in both learning trails.

2.1.5 Potential of narrative game-based learning trails

As shown, learning trails are a form of a learning environment that has the potential to positively affect learning in museums and science centres. Learning trails that utilize game-based and narrative elements can induce flow and engagement young learners. Furthermore, learning trails reduces button mashing in science centre exhibit settings, allowing for completion of more scientific experiments and increased potential for understanding them. Museum and science centres organize exhibits into exhibitions, still, many times, learning objectives dictate that exhibits from different exhibitions be used together, and the information focus of a particular exhibit can differ widely depending on which aspect is relevant. Learning trails may thus transcend exhibitions in physical locations when used in museums and science centres.

2.2 Narratives in the history of learning and instruction

Lucarevschi (2016), conducting a literature review of storytelling in language learning, and Koenig (2002), exploring approaches for using storytelling as means to teach diverse students, inform us that storytelling is one of humanity's oldest methods of communication. According to Zipes (2012), people started formulating narratives alongside developing speech, and narratives since prehistoric times have enabled humans to learn about themselves and the world in which they live. According to the Oxford Dictionary, prehistory is "*the period of time in history before information was written down*"[28]. This section informs on theories about narratives as information mediator alongside the development of human culture and society, and presents current

[28] https://www.oxfordlearnersdictionaries.com/definition/english/prehistory

theories related to how storytelling has been instrumental in development of the intelligence of our species.

2.2.1 Storytelling to entertain, inform, and educate since prehistoric times

The National Geographic Educational Resource Library encyclopedia entry on Storytelling[29] informs that stories are typically told for three reasons – to *entertain*, to *inform*, and/or to *educate* and, that, in accordance with Zipes, while it is impossible to prove, it is likely that storytelling developed not long after language itself. The encyclopedia entry explains that storytelling initiated as visual and oral traditions across all cultures, referring to cave drawings in Lascaux in France (as described by e.g., Curtis, 2006) as an example of the former, and The Tale of Gilgamesh (analysed by Damrosch, 2007) and Aesop's Fables (translated alongside a biography about Aesop by Anthony et al., 2006), both stories that existed for centuries before being written down, as examples of the latter. The encyclopedia entry points to three main reasons for why people, as they say, are drawn to stories.

1. Because stories help us feel in control, enabling us to find order in what happens to us, and to make sense of events in the world
2. Because stories allow us to understand the perspectives of others, building empathy and community between people
3. Because stories share information about cooperation and survival in a memorable way, allowing ancestorial details to be remembered more clearly than when recited as pure fact

While the encyclopedia entry is a learning resource for teachers of 5th to 8th grade social science and history pupils, and not a scientific publication, the observations therein resonate well with classic and recent research on narratives in learning. Piaget (1965) asserts that storytelling enables children to learn moral values at levels appropriate to their cognitive maturity level. Moral values are founded in our culture, and are thus part of the reasoning for, and our sense-making of, the world around us. Likewise,

[29] https://education.nationalgeographic.org/resource/storytelling (Retrieved 18.11.2022)

community building, the seed of society, is based on culturally dependant moral values. Cooperation with the intent to survive is achieved in society, which is based on moral values, all of which are effectively learnt and understood through storytelling. In prehistoric times informative tales were told to, as Zipes (2012) puts it, "*mark an occasion, set an example, warn about danger, procure food, or explain what seemed inexplicable. People told stories to communicate knowledge and experience in social contexts*" (p. 2). Their memorable aspect allows stories to become bridges to our past, memories that have been conserved by recital through centuries before the origin of written language, as exemplified by aboriginal stories that have never been written down, but that geographical ocean level studies have shown to be accurate, and probably over 7 000 years old (Nunn & Reid, 2016).

2.2.2 Storytelling, abstraction, and the development of human intelligence

In exploring storyworlds (a form of interactive storyline) development as an educational activity for children, Detorri (2016) points out that reasoning on non-predefined paths and on activation conditions (e.g., making stories in fantasy or reflecting on experiences to properly recite factual events in hindsight) is a powerful exercise of abstraction. According to Wing (2006; 2008), abstraction is at the core of computational thinking, which is recursive reasoning based on analytical problem solving and parallel processing applied in mathematics, engineering, and scientific method alike. Computational thinking was not new with the advent of computers, Wing informs, it was rather accelerated and made available in the computer age, much like the printing press accelerated access to the core analytical abilities reading, writing, and arithmetic, a list to which Wing (2006) advocates adding computational thinking. Explaining how storytelling structures of problem-chain-resolution is at the core of both mathematics and scientific method, allowing human evaluation of what is valid and what is misleading, Coen (2019) suggests that a major factor in the development of language and intelligence has been the ability to differentiate between truth and deception in storytelling, and moreover, to use storytelling to gain reproductive and thus evolutionary advantages. Effective storytelling in the origin of human society was a way of portraying the world to one's own advantage, and the memorable structures of storytelling became a way to conserve one's world view through generations, ensuring the survival of one's genes. The power of narratives in human development as shown by Coen is resonated in David Herman's defining work in narrative cognition (Herman, 2013), a categorical term for cognition that applies or works with narratives. Hermans presents five core functions from narratives on human cognition:

- Sense-making by segmenting experience into useful chunks
- Causally linking events
- Typifying phenomena to determine norms
- Sequencing actions (including planning)
- Distributing intelligence across time and space, including the function of communication.

Narrative intelligence (Sengers & Mateas, 2003), a form of narrative cognition based on narrative comprehension (Brewer, 1982) that exists at the confluence of narratives, artificial intelligence, and media studies, describes human ability to interpret experience in narratives. Narrative intelligence based on the core functions of narratives on human cognition as provided by Herman, alongside Detorri's and Wing's individual works on abstraction, may shed light on what cognitive properties in individuals allowed them to portray the world to their own advantage, and how these properties are manifested as a core analytical ability through computational thinking.

2.2.3 Games as narrative media

People have been reciting narratives since pre-historic times, and with the advent of society, culture, and science, humans have developed narratological models to categorize and analyse the stories around them. The Greek philosopher Aristotle, who lived from 384 BC to 322 BC, formulated that a narrative must have a beginning, a middle, and an end (Aristotle, c. 335BC/1996), and thus initiated work on act structures in narratology. In the Freytag Pyramid (Freytag, 1886), Freytag evolves on the act structures, increases the number of acts from three to five, and describe them more in depth, both with regards to their content, as well as their role and relationship to other parts of the story. Act structure narratology is suitable to categorize books and plays from his time up onto our own, as well as works from other media, like most films and many games. With the growth and professionalization of the film industry came stories with more focus on humans than sequences of events, and to contribute a narratological model for those changes, Campbell (1949) introduced the Monomyth, a narratological model focused on the development of the individuals in the story, and how their abilities and change drives the narrative onward. Many stories on many media formats, including games, can be categorized by both act structures and monomythical narratology, which together can be labelled classical narratology. However, as shown in Breien and Gkini (2021), there are many games that break with the descriptive premise of linearity in classical narratological models, and that simply cannot be categorized meaningfully using neither act structures, nor monomyth. Initiating the debate on games as narratives, Aarseth (1997) introduced the term Ergodic literature, from the two Greek words *ergon*, which means “work”, and *hodos*, which means “path”. Ergodic literature is any story which requires the observer’s non-trivial action to proceed, indicating that the story is a game, in which mental or motoric challenges must be overcome before the narrative will advance. In 2012, realizing that games had become a dominant cultural form alongside e.g., movies, literature, music, and painting, Aarseth cautioned against simply adapting processes from other media, like classical narratological models, when examining games as narratives, and contributed the Ludo Narrative Variable Model (LNVM). The LNVM is a narratological model for games that can describe all games and narratives using a set of ontologies that are categorized from high author agency, in which the designer of the game has much freedom to dictate a story, reducing the player’s ability to interact with and manipulate it, to high ludic (game) agency, in which the player has wide opportunity to alter and direct the flow or content of events, at the sacrifice of the designers control of the recital.

2.3 Game-based learning

When someone refers to game-based learning (GBL) in our modern day and age, our minds quickly jump to the digital world. Digital Game-Based Learning (DGBL), a term coined by Prensky (2001), a concept that is often linked to Malone (1981) and the theory of intrinsically motivated instruction, and to Abt (1970), introducing the concept of serious games. However, games used for learning purposes have a much longer history than the implementations found in the digital age and, as shown by Wilkinson (2016), may even be linked to the early development of human culture and society, not all the different from narratives and storytelling. DGBL is a sub-set of GBL; the text in this dissertation uses the GBL term throughout, and only resort to the term DGBL when the context requires the specification. In this sub-chapter, game-based learning is first introduced in a historic perspective before a discussion about games as narratives is provided.

2.3.1 Prespectives on the origin of games for learning

In his exploration of the pre-history of serious game, Wilkinson (2016) informs that serious games are contemporary manifestations of theories and practices that are centuries, even millennia old. Starting all the way back at Plato, who lived almost 2500 years ago, Wilkinson show how the Greek philosopher observed that reinforcement of behaviours in play, could reinforce those behaviours through to adulthood, suggesting that games can have educational purposes. Starting in the 19th century, it has been assumed that games can be imperative to learning (Cohen, 2018). As described by Cohen (2018), Piaget mapped the development of play in his children, noticing that there is a continuity between children's play and work on which they later embark, arguing that play consolidates skills through repetition, and develops sense of mastery.

Many articles written on game-based learning and serious games (e.g., Djaouti, et al., 2011; Squire & Linn, 2011) indicate that the ancestry of serious games commences with the MECC[30] game Oregon Trail[31]. However, in the world of analogue games, there are earlier examples, both of games made for entertainment that have been used for learning, and games that have been made solely with the intent to instruct, educate, or teach someone something. An early entertainment game that was used for learning

[30] https://en.wikipedia.org/wiki/MECC
[31] https://en.wikipedia.org/wiki/Oregon_Trail

is The Landlord's Game[32], a 1903 precursor to modern day Monopoly[33] that in from 1906 to 1915 was used in teaching at the economics department at the University of Pennsylvania Wharton School of Economics[34]. Another much older example is the entertainment game Mancala[35], a 7th century abstract arithmetic game that according to Laamarti, et al., (2014) was used as an accounting tool in trading of animals and food. Mancala is a precursor for the modern-day entertainment game Kalah[36], which has been used in mathematics teaching in schools since the 1960s (Haggerty, 1964; Gorman, 1997). Approaching pioneer academic work in analogue games developed with an intent to teach and instruct, one needs to look to military circles, and more particularly to the Reisswitz Kriegsspiel[37], a configurable board game created to instruct on executions of plans on realistic terrains in a multiplicity of situations (von Müffling, 1824). The Kriegsspiel, as it is referred to, gave rise to the concept of wargaming, which, particularly in the navy, has become a much-applied method of learning and instruction, as described by McCarty Little (1912), and much later by Mouat (2022) as a focused effort with relevance to learning outcomes. Perla (2022) describes wargaming as an effective tool for military staff under training to understand ranges of possible outcomes of conflicts in safe environments. In fact, Lillard (2016), who describe western approaches to wargaming during the second world war as proper tactical learning environments where decisions could be tested without casualties, is one of many sources who shares the famous words of Admiral Nimitz, who in 1960 informed that the naval war with Japan had been re-enacted by so many people in so many ways in game rooms before it started, that nothing that happened during the war came as a surprise[38].

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32 https://en.wikipedia.org/wiki/The_Landlord%27s_Game
33 https://en.wikipedia.org/wiki/Monopoly_(game)
34 As documented in the Landlord Game's history webpage: https://landlordsgame.info/games/lg-stryker/lg-stryker_history.html (retrieved 20.12.2022)
35 https://en.wikipedia.org/wiki/Mancala
36 https://en.wikipedia.org/wiki/Kalah
37 https://en.wikipedia.org/wiki/Kriegsspiel
38 Fleet Admiral Chester Nimitz speech to U.S. Naval War College, 10 October 1960. Recorded by the U.S. Naval Institute to be stored in Folder 26, Box 31, RG15 Guest Lectures, 1894–1992, Naval Historical Collection, Naval War College, Newport RI, https://www.usni.org/magazines/proceedings/2017/january/war-gaming-must-get-red-right (retrieved 20.12.2022)

2.3.2 Classifications of learning games: Game-based learning, serious games, COTS games, and gamification

In their overview of serious games, Susi et. al. (2007) summarize terminology associated with learning games as edutainment, e-learning, serious games, game-based learning, and digital game-based learning. Presenting the growth of serious games in academia and industry, Laamarti et. al. (2014) add gamification as a type of learning game, and others (e.g., Van Eck 2008) add Commercial Off-the-Shelf (COTS) games used in education.

As pointed out by both Susi et. al. (2007) and Van Eck (2008), edutainment is mostly associated with educational video games and is defined as any education through entertainment (Michael & Chen, 2006) employing any media that can otherwise be used to entertain. Thus, edutainment can be games for learning, and it can also be non-games such as films or animations, or simply books with entertainment value provided through techniques like humour, drama, or suspense. Van Eck (2008) comments that edutainment is more like a tutorial than a game, however, by strictly applying the definition by Michael and Chen (2006) it is hard to see how serious games, COTS games, and gamification are not commonly classified as edutainment if they are used for education. Other application areas for serious games, COTS games, and gamification outside of learning are healthcare, training, public policy, communication, defence, corporate training, politics, religion, art, well-being, and advertisement (Zyda, 2005; Michael & Chen, 2006; Susi et. al., 2007; Laamarti et. al., 2014).

A reason why edutainment is often associated with digital games and media, pointed out by both Susi, et. al. (2007) and Van Eck (2008), is that the term itself is often associated with screen-based multimedia phenomenon and initiatives from the 1980s and 90s. Defined as education through entertainment there is nothing that hinders analogue games from being defined as edutainment. Whereas a digital COTS game used for learning, such as Minecraft (e.g., Nebel, et. al., 2016) constitutes digital edutainment, a work from literature used in education (e.g., as suggested for nursing education in Stowe and Igo (1996)) constitutes analogue edutainment. An example of edutainment in form of a digital serious game is America's Army (as described by

Nieborg (2004)) that has its ancestry in military learning applications dating back to the Krigzspiel (von Müffling, 1824), which is an example of analogue edutainment.

Serious games are made for a variety of reasons beyond learning and educational use, examples of which are Darfur is Dying[39] (politics / communication), an awareness game about humanitarian crises (described by e.g., Peng et. al. 2011), EndeavorRx[40] (healthcare / well-being) the world's first health game to be approved for medical professionals to prescribe for patients — in this case young ADHD patients as described by Canady (2020) — and CoronaQuest[41] (healthcare / public policy), a game designed to raise awareness of children returning to school after the pandemic lockdown, described by Bouroumane et. al. (2020). Similarly, gamification is used for many purposes beyond learning, such as to onboard a new employee in their work environments (e.g., Heimburger et. al., 2020), or to motivate work processes through game-based awards systems (e.g., Mauroner, 2019). COTS games are not developed for learning at all, but for entertainment, and the use of COTS games for learning is a very narrow category of games, notably apparent in many usages of Minecraft, but also in other games such as Where in the World is Carmen Sandiego?[42], used in geography and cross curricular learning (Wilton, 1997), Valiant Hearts: The Great War[43], used in advanced history education, and Spore[44], used in biology education the latter two both described by Rüth and Kaspar (2021), and The Walking Dead[45], used in ethics learning (Staaby, 2020).

Definitions exists that categorize game-based learning as a special form of serious games under the argument that serious games can be used for many purposes, and that they become game-based learning when used for education (Susi, et. al., 2007). However, as shown by Breien and Wasson (2020), both gamification, which uses select game mechanical elements, and COTS games can be game-based learning systems. This makes it problematic to agree that game-based learning is a special form of serious

[39] https://games4sustainability.org/gamepedia/darfur-is-dying/ retrieved 24.05.2023.
[40] https://www.endeavorrx.com/ retrieved 24.05.2023.
[41] https://coronaquest.game/about retrieved 24.05.2023.
[42] https://en.wikipedia.org/wiki/Carmen_Sandiego_(video_game_series) retrieved 24.05.2023.
[43] https://en.wikipedia.org/wiki/Valiant_Hearts:_The_Great_War retrieved 24.05.2023.
[44] https://en.wikipedia.org/wiki/Spore_(2008_video_game) retrieved 24.05.2023.
[45] https://en.wikipedia.org/wiki/The_Walking_Dead_(video_game) retrieved 24.05.2023.

games, since that would mean that all gamification systems, as well as COTS games, if used for learning, inherently categorize first as serious games. Other definitions argue that game-based learning and serious games are two names for what is essentially the same thing (Corti, 2006). The initial search protocol of the first article presented in this dissertation (Breien & Wasson, 2020) revealed that the number of results from a search for learning games in articles abstracts through scientific databases, greatly decreased if omitting either of the terms serious games or game-based learning. While this is an indication that the terms serious game and game-based learning are at least used interchangeably in the study of learning and games, one could argue that this is more the result of a lack of proper common definitions, than the redundancy of one of the terms in favour of the other. If one were to substitute one of the terms with the other, one would be left with either serious games or game-based learning, alongside gamification, and COTS games as three separate entities with no common classification for discussing game elements used in learning systems at a high level. The term Game-Based Learning, however, comprises COTS games, serious games, and gamification, when used for learning. Thus, the research presented in this dissertation used Game-Based Learning.

Game-Based Learning can be applied both through digital and analogue systems in both virtual and physical surroundings. Whereas Spore, The Walking Dead, and Minecraft, for example, are representatives of digital game-based learning sub classified as COTS games, Monopoly and Mancala are examples of analogue COTS games used in analogue game-based learning. Duolingo[46] uses gamified unlockable learning topics to award high learning rates in language learning, thus classifies as digital game-based learning. A Norwegian mathematics initiative Math Marathon[47], a school activity in Norwegian schools in which pupils receive accolades for covering physical distance while solving analogue math puzzles, is an example of gamification in a physical environment, classifying as analogue game-based learning. Famous digital serious games used for learning include America's Army[48] (Nieborg (2004)),

[46] https://en.wikipedia.org/wiki/Duolingo retrieved 24.05.2023.
[47] https://mattemaraton.no/ (in Norwegian) retrieved 24.05.2023.
[48] https://en.wikipedia.org/wiki/America%27s_Army retrieved 24.05.2023.

Dragon Box[49] (Siew, et. al., 2016), and the Crystal Island games series (Rowe, et. al., 2009; Cloude, et. al., 2020), which all classify as digital game-based learning. Analogue serious games used for learning are represented in military tabletop wargaming such as Reisswitz Kriegsspiel (von Müffling, 1824), and for other learning purposes in analogue learning trails embedded learning environments at science centres, as described in Hauan (2017), both classifying as analogue game-based learning. Furthermore, there are game-based learning that mix the two, such as Kahr-Høyland's (2010; 2011) research on using handheld devices for story driven game-based learning trails using physical exhibits, and Hauan's extended work on modern embedded learning environments, using learning trails on tablets to guide pupils in exhibitions (2014; 2017).

Figure 5 shows a classification of game-based learning, acknowledging that all the systems contained therein can exist both in physical and virtual environments, and that links between the environments can be applied to create mixed-reality (Milgram, 1996) game-based learning systems.

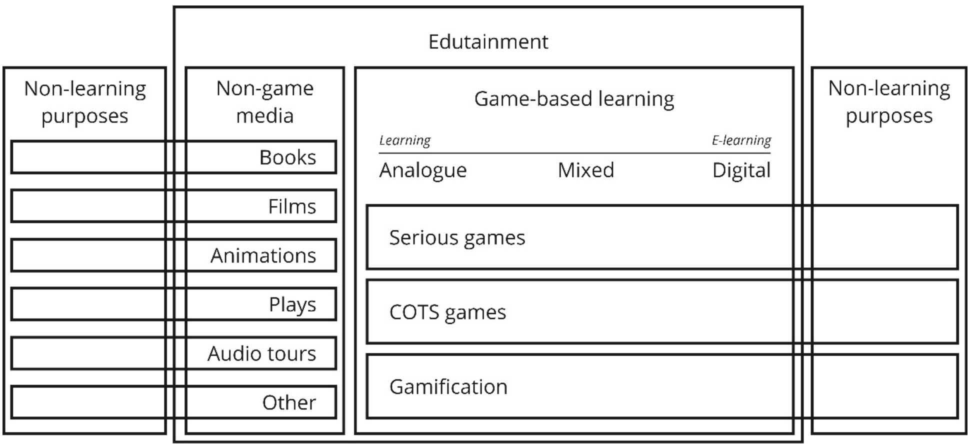

Figure 5: Situating game-based learning with respect to edutainment and learning

If one accepts the premise that education facilitates learning, and that learning environments, tools, and artefacts are provided as part of education, then game-based

[49] https://dragonbox.com/ retrieved 24.05.2023.

learning is part of edutainment, and comprises serious games, COTS games, and Gamification used for learning. Furthermore, they can all exist in analogue and digital forms, or derivates thereof, with varied emphasis on physical and virtual element combinations. The figure also shows the larger picture, where edutainment also includes non-game media (e.g., books, films, etc.). Both non-game media and game-based learning can also be used for non-learning purposes.

The LNVM (Aarseth, 2012) is a model to categorize games as narratives inside four ontologies that have been shown to be part of all games and narratives. Games conforming to different categories and category combinations can be analysed based on their characteristics and how they affect some parameter or other, such as, engagement, and motivation, or business and market related parameters such as player retention over time, or costs of bandwidth and storage for types of players. The LNVM is usable to categorize serious games and COTS games. Gamification, however, is defined by using a few select game mechanics and does not necessarily employ a full set of ontologies, something which is a premise for meaningfully categorizing games using the LNVM. A gamification system may, for example, amount to giving accolades upon successful completion of a certain number of tasks over time, or for someone to visit a certain string of places in a sequence. This separates gamification from games and renders incomplete data from gamification systems for them to be meaningfully categorised using the LNVM. If one finds a gamified system that can be categorized on the LNVM, one may ask if it is a game. Likewise, if one cannot categorize a game on the LNVM, it might not be a game at all, but rather a gamified system resembling a game, for example through addressing many of the categories on the LNVM, but not all, or from being perceived as a game for placing much emphasis on the selected game element(s) when in use.

2.3.3 Game-based learing and effects on engagement, motivation, and learning

Whereas the scientific research presented in this dissertation emphasises effects from narrative game-based learning on engagement, motivation, and learning, causality for effects on those three parameters have been explored based on several other mechanisms and components found in games (e.g., Connolly et. al., 2012; Bellotti et. al., 2013; Laamarti et. al., 2014; Landers, Armstrong, & Collmus, 2017; Ullah et. al., 2022). This subchapter first presents the scope of the research on game-based learning and effects on engagement, motivation, and learning as it has developed over the last 20 years, before summarizing reviews of these effects as the field of research has matured.

Historic research on game-based learning, engagement, and motivation

To gain an overview of the extent and development of studies related to engagement and motivation in games used for learning, training, or education since 2000, the following search string:

Title/Abstract/Keywords: (Game) AND (Learning OR Training OR Education) AND (Motivation OR Engagement)

was used to search for publications between 2000 and 2022 on the ACMDL, IEEExplore, PsychINFO, Science Direct, and Web of Science (as used in Breien & Wasson (2021)). The search resulted in 7501 studies, see figure 6 (NOTE the dip in 2022 is most likely a result of not all studies from that year being registered and indexed yet).

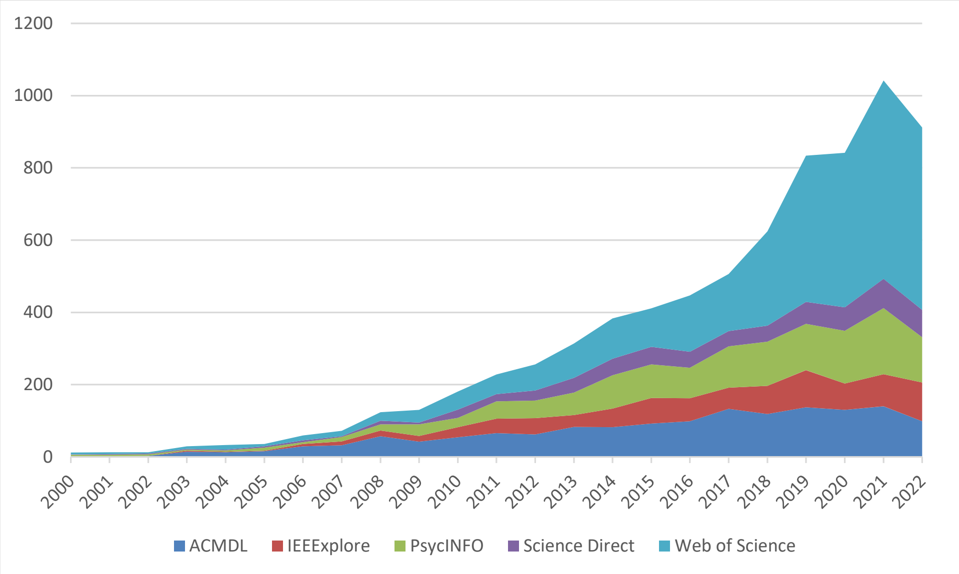

Figure 6: The growth in studies of learning games, engagement, and motivation since the turn of the century

Figure 6 shows how the area of study emerged with very few studies before 2005, and that the ACMDL was the foremost proponent of the discipline in the beginning, indexing almost half of all studies in 2008 (57 out of 124). From about the turn of the last decade, publications gained traction on PsycINFO and Web of Science. PsycINFO contributed equal amounts as ACMDL down to single digits differences from 2014 to 2019, steadily surpassing and increasing the difference to 183 studies from PsycINFO and 140 studies from ACMDL in 2021. Publications on Web of Science surpassed those from ACMDL in 2012, with 72 versus 62 studies, and the gap increased steadily, to 2021 where Web of Science contributed 549 studies, which is over half of the 1042 total from all databases combined.

In the review by Breien & Wasson (2021), 61 scientific publications between 2009 and 2019 were obtained, a number which was reduced by one third, to 40, after removal of duplicates and false positives. Since the intent of the study was to find empiric studies of game-based learning that self-reported effects on engagement, motivation, and learning, while also providing a sufficient description of the game itself for it to be categorized on the LNVM, the results were further reduced by 65% (from 40 to 14).

Using an estimation technique called Fermi Question (e.g., Miranda, 2014), a method for approximation of numbers for further study of an effect, a trend, or phenomenon when it is impractical or impossible to calculate them exactly, like famously done for the force of a nuclear blast by Enrico Fermi (documented by e.g., Weinstein, 2012), or, in this case, the approximate extent of studies on engagement and motivation in game-based learning, this indicates that the number of studies from 2000 through 2022 is right around 5000, and that, among those, approximately 1750 should be empirical studies on effects accompanied by game descriptions sufficient for them to be categorized on the LNVM.

To complete the picture of the growth of game-based learning, and to explore the extent to which engagement and motivation are addressed in game-based learning publications, the search string is reduced, omitting the parameters related to engagement and motivation:

Title/Abstract/Keywords: (Game) AND (Learning OR Training OR Education)

Table 1 shows the total studies obtained about game-based learning from the same five databases from 2000 through 2022, and the percentage of those studies that are also related to engagement and motivation.

Table 1: Studies on learning games and percentage related to engagement and/or motivation

	ACM DL	**IEEE xplore**	**Psyc INFO**	**Science Direct**	**Web of Science**	**Total**
Studies on game-based learning	5,834	9,146	9,206	5,703	27,059	56,948
Percentage of studies that are also about engagement and motivation	25.80	9.80	14.86	11.47	11.38	13.17

As can be seen from table 1, 13% of research on game-based learning since 2000 addressed engagement and motivation, at least to the extent where one of the two terms are found in the title, abstract, or keywords of the publications. Whereas IEEExplore is an outlier with less than 10% of research published mentioning the terms, ACMDL is at an opposite trajectory, with almost 26%, the double of the average, of the studies relating to engagement and motivation. When seen in relation to figure 6, this diminishes the accumulated contribution of ACMDL to the study of game-based learning, while making the database highly targeted at obtaining research on engagement and motivation in learning games. Web of Science indexes more than 50% of all studies on game-based learning from 2000 until today.

Assuming that the number of false positives and duplicates are like the search done in Breien and Wasson (2021), thereby removing one third from the total number of studies found on game-based learning arrives at an estimated 37 500 unique and relevant publications since 2000. As table 1 shows 13 percent of these, 1 750 publications, are expected to be about some aspect of the game and its effect on engagement and motivation, where the publication or referenced material provides a description of the game sufficient to categorize it on the LNVM. In the original review by Breien & Wasson (2021), 22% of studies about effects on engagement and motivation were removed due to the lack of descriptions for categorization. It is thus likely that another circa 350 studies among the 37 500 evaluate such effects, but do not describe the game, bringing the probable number of such studies to approximately 2 100. This amounts to 5,6% of all studies of game-based learning, implying that study of effects on engagement and motivation is important in the field of game-based learning.

As with any emerging area of research, game-based learning and more particularly effects on engagement and motivation, has been the subject of study in literature reviews and meta-analysis. To inform on the reported effects and how the effectiveness of game-based learning has changed over the last two decades, one can look at reviews and analysis in what one can call three phases of study of game-based learning effects: 1) the founding years, from 2000 through 2012, when the number of studies were low, 2) the maturing years, from 2013 through 2017, where the amount of studies grew steadily and doubled compared to the first phase, and 3) the modern years, from 2018 until today, a period over which the number of studies appears to have tripled, if one accounts for the trend of the graph in figure 6.

The theory of intrinsically motivated instruction, and engagement in entertainment games

Having shown how research on instructional design has mainly focused on cognitive structure changes and learning processes for academic skills, Malone (1981) argues that motivation in learning has been neglected. Furthermore, Malone informs that external reinforcement may deteriorate learners' intrinsic motivation, degrading the quantity of performance of certain tasks. Realizing that intrinsically motivated learners spend more time and effort on learning activities, and that video games are a media that intrinsically motivates play because it is fun, Malone asks what captivating features of video games can be used to make learning interesting and enjoyable. After conducting a series of experiments using available video games, Malone proposes a theory for intrinsically motivating instruction, based on three categories: challenge, fantasy, and curiosity. Challenges comprise a series of goals that are personally meaningful for the learner, that can be easily generated, and on which encouraging feedback can be provided. The uncertainty of outcomes keeps learners engaged and motivated. The theory of intrinsically motivated instruction presents variables for uncertain outcomes and a framework for how to model and approach them in instructional design. These include methods for attuning difficulty to motivate learners, score keeping and responses when engaging in multi-level goals, leveraging hidden information and randomness, and building learner self-esteem by constructively supporting their successful reaching of goals. Malone makes a distinction between extrinsic fantasy, which has low dependency to usage of skills in a game, and intrinsic fantasy, which is fully integrated with the learning content and intimately related to the use of skills. Intrinsic fantasy engages learners and positively affects memory building, through supporting learners to learn skills in meaningful contexts and to satisfy their emotional needs. Curiosity is separated into 1) sensory curiosity, the audio visual and other sensory stimulus of the game, which in modern times (after the publication by Malone in 1981) would include VR, haptics, location maps, and other sensors used, for example, in museum learning trails, and 2) cognitive curiosity, which presents opportunities for learning by providing complete, consistent, and parsimonious knowledge structures while providing surprising and constructive feedback.

Whereas Malone’s work has become seminal in defining what makes games captivating and how they may provide intrinsic motivation in instruction and learning, Sweetser and Wyeth (2005) point out that while enjoyment is the most important goal in computer games, there was still no accepted model of player enjoyment in games. Sweetser and Wyeth contribute the GameFlow model — an eight-element model based on existing heuristics uncovered by the authors — for evaluation of player enjoyment in games. The eight elements — concentration, challenge, skills, control, clear goals, feedback, immersion, and social interaction — include sets of criteria for measuring if enjoyment has occured. After its introduction, the GameFlow model has been augmented with tools for designing and evaluating enjoyment in games, such as the application of GameFlow across different game genres and platforms (Sweetser et. al., 2017), detailing of GameFlow heuristics (Sweetser et. al., 2012), and evaluating individual issues using GameFlow by different stakeholders (Sweetser & Johnson, 2017). GameFlow is based in flow (Csikszentmihalyi & Csikszentmihalyi, 1990), see also chapters 1.1 and 2.1. While GameFlow is rooted in entertainment gaming, it has also become used in game-based learning. For example, to create learning games that are both engaging and educational, Shabalina et al. (2014) suggest new ways to combine GameFlow and learning objectives using learning analytics measures to counter effects in which the entertainment value of the games and the learning content negatively affects one another.

Cruz et. al. (2017) has shown that many games offer extrinsic motivation in the form of award systems, something which they, in concurrence with Malone (1981), suggest may harm players intrinsic motivation. However, in accordance with several of the categories in Malone’s framework for intrinsically motivated instructions, Cruz et. al. (2017) found that earning rewards associated with meta-games promotes different ways of playing the games, and that giving positive feedback to successful gameplay boosts self-esteem, boosts online and offline status, and promotes completionism (the desire to engage in the game to earn all the rewards), all of which indicates that the extrinsic reinforcement contributed by award systems may induce intrinsic motivation in the context of the game. Awards systems are often applied in gamification, of which Duolingo[50] is an example that may capitalize on double effects thorough their awards systems: one in accordance with the findings of Cruz et. al. (2017), and another in making the awards increase the scope of the learning content, by providing in-depth learning categories that are otherwise hidden. The findings in Cruz et. al. (2017) was preceded and strengthened by the findings of Wang and Sun (2011), which shows how extrinsic rewards foster intrinsic motivation in game players by providing social meaning, enhanced status, and social tools in gaming societies.

An important approach to personalizing games to individual preferences and what engages them, is that of player types, one of which is the BrainHex model (Nacke, et. al., 2014). The BrainHex model presents seven different archetype player types and what they enjoy:

- Seeker (interest and curiosity)
- Survivor (horror and controlled experiences of panic)
- Daredevil (thrill seeking and risk taking)
- Mastermind (strategy, puzzles, and efficient decision making)
- Conqueror (battling adversaries and defeating difficult foes)
- Socializer (talking to and helping people)
- Achiever (goal orientation, long-term achievements, and perseverance)

A significant difference between entertainment games and learning games, is that the entertainment games can target customer demographics defined as one or more player types, engage, and entertain them, and get their revenues in their market[51]. Learning games may not have that luxury, in that the defining learner demographic that is targeted can be expected to be comprised of representatives of all player types, especially when used by broad learner demographics in formal or public education.

[50] https://www.duolingo.com/

[51] Examples: God of War (https://en.wikipedia.org/wiki/God_of_War_(franchise)) is targeted at conquerors, Star Craft (https://en.wikipedia.org/wiki/StarCraft) is targeted at masterminds, and Need for Speed (https://en.wikipedia.org/wiki/Need_for_Speed) is targeted at daredevils

Trying to accommodate for all archetype player types in a single game is not a good idea, and whereas making separate games for different player types may provide a solution, it is impractical and time consuming, and very costly. Player types may still have its place in effective Game-based learning. Iten and Petko (2014) show that it is the expectancy to learn, and not to have fun that influences intent to use learning games. While an individual may have preferences associated with a player type, that does not imply that the individual may not react positively to games for learning that is more attuned to other player types. Moreover, when developing learning games that are informal, or that is intended as supplement to other instruction, player types have the potential to be a decision parameter for game type to target a narrower demographic with particular forms of learning. One example of such is EndeavorRx[52], a prescription game for 8 to 12 year old ADHD patients which targets the daredevil player type, and leverages adjustable difficulty to ultimately focus the player.

Overview of review literature examining effects on engagement, motivation, and learning from game-based learning

Looking at reviews and meta-analysis of serious games between 1997 and 2005, Clark (2007) failed to find evidence that games can teach anyone anything that cannot be taught more effectively and at a lower cost using other media and methods. Moreover, no evidence is uncovered showing that games motivate more to learn than other instructional programs. Countering arguments that there is a research gap in the study of serious games, Clark shows that there had already been contributed several well-designed studies of effects from serious games, which all revealed similar negative results. Whereas Clark arrives at the conclusion that games cannot teach anything quicker or more economically than using other methods, he still concludes that games can augment education and training as an ongoing practice of transfer.

A year before Clark's meta-review, Van Eck (2006) presented a more optimistic, and somewhat contradictory view, informing that several reviews and meta-analysis of digital game-based learning since the advent of the video game genre in the 1970s consistently show that games promote learning and that they may reduce required

[52] https://www.endeavorrx.com/

instruction times across disciplines and demographics. Van Eck observes a surge in the attention given to games for learning in the early 2000s, attributed to three factors: 1) a steady stream of books and publications about games for learning, 2) the preferences of digital natives, a young generation of learners that disengage from traditional instructions, requiring instead streams of information and interactions that matches game-based learning, and 3) the increased popularity and subsequent growth of the gaming media in general. Pointing out the danger in creating an impression that all games are good for all learning and learners, Van Eck called for research on why learning games are engaging and effective, and for guidance to inform when, for whom, and under what conditions games should be integrated in learning to maximize their instructional potential. The latter point resembles Armstrong and Landers' (2017) call to identify the same conditions for the subset of games that are related to narratives.

The same year as Van Eck, Vogel (2006) provided a meta-analysis of games and simulations for learning, concluding that using games and interactive simulations report higher cognitive gains, better learning attitudes, and increased motivation and learning outcomes compared to other teaching methods, but that the research base was insufficient to draw this conclusion with confidence, since several studies were omitted due to methodological and reporting flaws, lacking inclusion of statistical data, demographic data, and in-depth descriptions of programs and activities used in interventions.

In a BJET editorial, Rushby (2012) continues to point out that while there is evidence to support that people can learn from serious games, there was still little evidence regarding how they do so. Looking at submissions to the journal at which he worked, Rushby observed what was mostly anecdotal evidence that people learn from games, and that they enjoy learning from them. Arguing that games — including serious games — will become technically and graphically better, Rushby asks whether parameters related to e.g., colour and perspective are really related to learning, or if there are other parameters to explore.

Examining the literature about the impact of video games and serious games on learning, skill enhancement, and engagement, Connolly et. al. (2012) identified 129 papers reporting on one or more of those parameters. Indicators and measures used in the papers reveal that playing games, serious or not, is linked to a range of perceptual, cognitive, behavioural, affective, and motivational impacts and outcomes, with outcomes and impacts on knowledge acquisition/content understanding and affective and motivational outcomes being the most reported. Sorting the papers by the quality of the evidence, Connolly at. al. (2012) found that 70 of the 129 provided high quality evidence, suggesting that the previous lack of evidence about effects from games was now being challenged. Focusing on game genres, the study finds that while a wide range of genres are shown to engage and motivate in entertainment games, serious games, games for learning, and game-based learning, however, rarely sorted outside the genres of role-playing games and puzzles. Whereas some of these also exhibited positive effects, Connolly et. al. encourages exploration of other game genres for learning, and that to do so, a better understanding of what tasks, activities, skills, and operations are offered, and how they can be employed to match with intended learning outcomes, is needed. Connolly et. al. also calls for more random control trials to rigorously inform on the effectiveness of game-based learning, and more qualitative studies to inform about the nature of engagement in games. Finally, they also underline the importance of considering details about how games can be integrated into holistic learning experiences.

The year after, Wouters et. al. (2013), contributing a meta-analysis to investigate the assumption that serious games provide more effective learning and increased motivation, showed that that learners learn more from serious games when the game is a supplement to, or is supplemented by, other instructional methods. The results of the meta-analysis further revealed that serious games are more effective in terms of learning and retention when compared to other instruction methods. However, there was no evidence to support that games are more motivating. Wouters et. al. explored a wide range of game genres and found that, for example, a sophisticated 3D adventure game contributed the same effect in mathematics learning as a basic simulation game, warranting further study of game genres and their ability to affect learning and motivation in various domains. Furthermore, the authors encourage analysis of specific features of serious games (e.g., graphics fidelity, motoric challenges, mental challenges, interactions, sound feedback, narrative, and so on) that determine effectiveness.

While acknowledging that several studies had questioned the effects from game-based learning, Bellotti et. al. (2013) still considers there to be a wide consensus in research showing that video games have educational potential. The authors argue that many of the studies showing negative or neutral effects were already old at their time of writing, and that the decade leading up to their publication had seen unprecedented development within the field of games in general, and even more in educational games. In stark opposition of Clark (2007), who six years earlier argued that games for learning were more expensive to produce than any other instructional material, Bellotti et. al. rather found that serious games safely and cost-effectively help learners to acquire skills and attitudes that are hard to obtain using other methods, and furthermore that learning through gameplay may last longer. The authors provide several examples of how well-designed learning games produce learning through engagement. However, concurring with previous studies, Bellotti et. al. points out a shortage of studies that assess learning through gameplay. Whereas the authors show that games can teach factual information, albeit not necessarily better than other methods, the study still shows that students prefer simulations and games to other instruction, and that gamed simulations can affect their attitudes to concepts such as education, career, marriage, and children. Pointing to several specific application areas, the study defines healthcare as an example of a domain in which games have provided particularly positive effects. They give the examples of using virtual reality to treat phobias, and games to distract patients during burn treatment and chemotherapy, something which MRI has shown to make a difference in brain activity, indicating pain reduction. Furthermore, the study shows that games can motivate behavioural change, by for example enhancing self-esteem by implementing classical conditioning. The study also shows how mini games used in study of cultural heritage capitalize on the visual properties of games, something which, compared to reading text, forces learner to focus on problems, and thereby accommodating favourable knowledge acquisition and retention. Bellotti et. al. concludes with two prerequisites for future assessment of effects from games, one being formal characterization of player's activities, tasks, and profiles in games, and the other being better integration of assessment structures in the games themselves.

In proposing a taxonomy for digital serious games, Laamarti et. al. (2014) begins to bridge the gap of measuring effects of game elements by classifying reviewed serious games by 1) application area (education, well-being, training, advertisement, communication, health care, and other), 2) activity (physical, phycological, and mental), 3) modality (visual, auditory, haptic, smell, other), 4) interaction style (keyboard/mouse, movement tracking, tangibles, brain interface, eye gaze, joystick, and other) , and 5) environment (social presence, mixed reality, virtual environment, 2D/3D, location awareness, mobility, and online). Focusing on modalities, the study shows how providing visual feedback to players throughout the day can be a success factor in serious games, that music in games is among the most important factors to motivate the use of training games, and that integrating haptic feedback can enhance the learning experience via tactile perception of objects.

Observing the general notion in research that games make learning fun, but that the relationship between fun and learning through serious games has not been clarified, Iten and Petko (2014) found that while the perceived entertainment value of a serious game led to increased interest levels in subject matters, making learning games well suited to increase motivation in learning processes, it is not primarily the anticipation of having fun, but rather the anticipation of easy achievement of learning benefits that influence children's intent to use learning games. Iten and Petko also question whether fun is an adequate construct in exploring motivation to use serious games, and advice taking other aspects of engagement such as emotional, cognitive, and behavioural, into account in further study of learning game motivation. While learning research ties fun to learning processes and content as a mediating variable, media studies define fun as aspects in their own right, such as (in games) technological capacity, game design, aesthetic presentation, game play experience, narrative, challenge, and competition, warranting further study of the relationship between fun and learning through serious games.

On reinspecting his own work (Van Eck, 2006) from a decade earlier, Van Eck (2015) reinforces his stance that digital games have the potential to teach. He presents several advances in the field in multiple disciplines since his first publication and shows that well-designed games on average improve learning between 7 and 40 percent when compared to lectures, and that game-based instruction allow learners to perform one full letter grade better than the performance achieved through non-game-based instruction. Thus, the question, Van Eck proposes, should no longer be whether games can teach, but rather, what they can best teach, and why. 21st Century Skills are observed by Van Eck (2015) as well addressed by learning games, and among these, he defines problem solving as one of the most important, and as one of the hardest to teach through traditional instruction methods. Problem-based learning is an effective strategy to teach problem solving, however, it is time consuming and difficult to teach. Echoing many of the reviews of effects from game-based learning, Van Eck calls for further study of the mapping of game design elements and how they affect learning, noting that, unlike a decade before, game design competence had become available to academics through the advent of formal game design education. Hung and Van Eck (2010) began this work by mapping problem types in problem-based learning to gameplay types based on what knowledge and cognitive processes are always and sometimes required to teach problem solving strategies.

The year 2016 saw a surge of articles that discussed game-based learning, and effects from game design, game mechanical elements, and genres. Examining 29 studies that targets 21st century skills, Qian and Clark (2016) found that learning games can effectively facilitate learner development, and — emphasising that little is known about how games influence acquisition of 21st century skills — provide insights, based on a range of measures, indicators, and outcomes, into how game design elements and learning theories impacts such acquisition. Qian and Clark reveal constructivism as the predominant learning theory used in games, in 13 of the 29 studies, with the remaining 16 studies divided over an additional nine learning theories. The authors identify 28 game design elements used in the studies. Their findings show that whereas games using simple and few mechanics, primarily modelled after quiz, or drill and practice materials does not engage learners, more elaborate game design elements, such as collaboration, competition, complexity, exploration and discovery, role play, self-expression, and interactivity work well with constructivist learning of 21st century skills. These elaborate game design elements are recommended emphasised in game-based learning development, since they are all predominantly associated with large effects sizes when implemented in game-based learning. Hamari et. al. (2016) show that while engagement in a game has clear positive effects on learning, immersion in a game does not show similar significant results. A particularly strong predictor of learning from games was found to be challenge, which both affected learning directly, as well as through increased motivation. Hamari et. al. (2016) suggest that challenge in games should be kept in alignment with the learners' growing abilities when designing game-based learning environments. Clark, Tanner-Smith, and Killingsworth (2016) synthesise comparisons of game and nongame conditions and show that games can significantly increase learning relative to other conditions. The authors observe that this also applies to gamification, albeit possibly primarily on lower order learning outcomes, something which was the focus of most gamification studies in the selection. The study reveals that rich narratives and visual complexity has a small but significant negative correlation to learning, a reason for which may be that such elements may distract learners from the learning content, and even engage them in alternative goals that do not improve measures that are to be assessed. If so, the findings speak towards collaboration between educators and game developers to align graphics fidelity, narrative evolvement, and game environment to optimally support assessed learning objectives.

Building on the theory of gamified learning (Landers, 2014), Landers, Armstrong, and Collmus (2017) isolates game elements, links them to behavioural, motivational, or attitudinal outcomes, and in turn learning outcomes, to explore how the game elements individually can support learning. While the study is about gamification, systems in which a limited amount of game elements are applied to reach some learning objective, the elements are all derived from game design, and the study is as such also of interest to improve the effectiveness of game-based learning using a larger set of game elements. The authors find that, while rules and goal setting should not be targeted at the learning itself, since particularly performance goals often interfere with learning goals, goal-theory seeking to maximize effective feedback on progress towards goals, naturally coincides with rule/goal elements in games, making it an easy element to leverage in game-based learning. Learners that receive feedback on their progress to a goal, are better equipped to understand the problem represented by the goal, and to focus their learning efforts as needed. Furthermore, rules help illuminate a learning concept and theoretical boundaries. Reaching goals are closely associated with conflict and challenge game elements, related to aspects of difficulty and attainability of success in goal reaching. If a goal is too easily obtained, learners may perceive it as trivial, and if a goal is too hard to obtain, it may be perceived as impossible or unfair, neither of which will lead to learner motivation towards reaching the goal. Therefore, a balance must be reached, something which may be difficult in situations where learners skills and preparedness varies. Games, however, being an interactive and adaptive medium, have the power to adjust these goals, and to provide experiences that attunes the challenge to the individual learner through design, and thus capitalizes on motivational effects of different learners through the same instructional tool, the game. The testing effect (Roediger & Karpicke, 2006) is a phenomenon showing that learners that are tested retain learning material better, even if they do not receive feedback on their performance. Thus, Landers, Armstrong, and Collmus (2017) argue that testing can be incorporated in game-based learning to improve retention. Assessment structures in games that enforce the testing effect include points accumulation, badge awards, and leader boards, often in the form of rewards as a summary of performance, the marking of an accomplishment, or the accumulation of points based on activity. Whereas assessment rewards in games can promote completionism behaviour, motivate friendly competition, provide feedback for further learning, and provide grounds for reflection through debriefing, learners may find little value in assessment and rewards if it lacks the appropriate context, and learning game structures require conscious design to provide relevance for learning, and not to only be accumulations of accolades and numbers with no apparent meaning and relevance to the learning content and situation. A games action language represents players' communication with the game and can induce a state of presence, which in turn may induce learning through a subjective experience of concentrated existence in a game. Presence is again closely tied to flow (Csikszentmihaly & Csikszentmihaly, 1990), which like presence requires concentration, adding interest and enjoyment. Action languages (Landers, 2014) may encompass interaction structures such as keyboard and mouse, buttons and sticks on game controllers, touch-interfaces on mobile devices, or sensors and positioning technologies found in interactive virtual reality sets, to mention a few. Whereas action languages may induce a sense of presence and thus promote learning through games, a concern about them is that users must also learn how to use the action language, and that competencies for such use may vary among learners (Landers, Armstrong, & Collmus, 2017). Given the momentum of video games in our culture, however, such obstacles are expected to be less and less challenging in the future. Another game element that induces presence, according to the authors, is immersion. Immersion is embodied in the player representations, such as the player avatar in a video game, or pieces that exists on a board game, the sensory stimuli of the experience. Examples include the game visuals and sound, haptic feedback from controllers, or other, such as heat and smell in more experimental systems applied, for example, in science centre learning trails, and the sense of safety, which in a video game may include the ability to safely test actions without suffering real world consequences, as experienced for example when playing and educational wargame. Immersion can be conceptualized as a player's temporary acceptance of the presented reality, something which is closely related to the concept of suspension of disbelief (as described by e.g., Muckler, 2017). Using attributes of the game that contribute to immersion has the potential to contribute to presence, which can in turn contribute positively to learning. While Landers, Armstrong, and Collmus (2017) explain how realistic and relevant representation of the player improves presence, the authors also note that higher fidelity games may be distracting to learning, and therefore advice to improve fidelity of games as much as necessary to meet the requirements of the learning objectives. A third and final game element that affects presence is the environment representing players' locations in games. The environment affects the rules and expectations of a game and may have varying relevance to the learning context; an environment that induces presence may contribute positively to learning when the relevance is high. Another aspect to consider when promoting learning in the environment is learners' preferences, whereas some prefer a practical and others a theoretical approach to learning and thus the environment in which learning occurs, the environment contributes positively to learning if well attuned to the individual learners' preferences. Self-determination theory (Ryan & Deci, 2000) is based on the psychological needs for autonomy, competence, and relatedness. According to Landers, Armstrong, and Collmus (2017) control over those needs approaches intrinsic motivation, which is again tied to positive learning outcomes. Increased freedom related to what and how someone learns leads to motivation, something which can be leveraged by providing autonomy in learning games through learner control; allowing the learner to affect the learning experience through alteration of the features in the learning environment. Whereas the evidence of the effects of learning control is mixed, since certain types of control may motivate learners but not be attuned to supporting the learning objectives, there are several ways in which to utilize learner control in game-based learning while still guiding the experience to underline the learning content. Landers and Reddock (2017) provide nine methods for control in web-based instruction, which are transferable to learning games. These nine methods are "allowing learners to skip material they already know, to add material for extra study, to change the order of learning material that they experience, to add or skip knowledge/skill assessments, to receive guidance and determine a course of action in response, to change the stylistic details of the learning environment, and to control when and where they complete their learning" (Landers, Armstrong, and Collmus, 2017 p. 18). The narrative hypothesis (Graesser, et. al., 1980) suggests that narrative (storytelling) texts are better learnt and retained than expository texts. The observed effects of the narrative hypothesis on learning are mixed. Whereas field studies show that narratives are more satisfying to learners overall, there is little evidence of differences in learning between text genres. According to Landers, Armstrong, and Collmus (2017), narratives, as game element, are represented as game fiction describing the game world as well as the story contained therein. According to the authors, game fiction can affect learning outcomes both directly, through satisfaction and enjoyment, and indirectly, as a mediating process whereas the game fiction motivates learning in general. Game fiction can, as observed by the authors, affect variables such as learning engagement, and distraction. As such, game fiction and the narrative hypothesis become a double-edged sword when applied to learning games. If the narrative itself has relevance to the learning objectives and increases engagement in the learning content, learning outcomes should improve. However, if the game fiction leads learners to engage in content that is not relevant to the learning objectives, the game fiction becomes a distraction that may deteriorate the learning outcomes.

Motivated by the increased interest in serious games shown by increased numbers of publications, Zhonggen (2019) conducted a meta-review of positive and negative effects from a decade of learning game research between 2009 and 2018 spanning 39 articles. Eight positive findings and three negative findings were reported.

Serious games were reported effective to (Zhonggen, 2019, p. 4):

1. facilitate learners' holistic understanding of scientific conceptions,
2. obtain cognitive abilities,
3. increase positive affect of learning and improve teaching in the sciences,
4. provide flexible learning,
5. improve learning outcomes,
6. facilitate socio-cultural learning in terms of cognitive and motivational effects and team opinions,
7. improve cross cultural communication competence,
8. improve script collaboration based professional learning and learner satisfaction.

The three negative findings were (Zhonggen, 2019, p. 4):

1. The nature of serious games negatively influenced the relationship between mental workload and learning effect.
2. No significant differences in in-depth learning were found among learners.
3. Some serious games aggravated the mental workload and decreased the learning effectiveness.

A recent literature review about research trends in serious games used in science education (Ullah, et. al., 2022), also discusses the positive and negative aspects on learning from serious games. Ullah et. al. (2022) finds several positive aspects related to the use of serious games in science education, summarized as follows:

- Serious games make it easier for learners to comprehend science.
- Immersion in games is associated positively with learning science literacy.
- Serious games effectively improve cognitive abilities.
- Serious games constitute pedagogy that offers learners who is unattuned to, or wants to step beyond the boundaries of, conventional learning.

A negative association reported by the study is that games can be complicated and difficult to use, adding to the cognitive load during learning, and thereby reducing the learning effects.

This subchapter has shown how far the field of study of effects from game-based learning has come since Van Eck (2006), Vogel (2006), and Clark (2007). It has shown that research on game-based learning and their effects have grown from a few articles per year in the beginning of the millennia, to over a thousand published studies per year in the early 2020s. Based on a larger corpus of work, the reports of the effects from learning games, and how and under what condition they occur, have become more nuanced. Whereas the early reviews of the literature reveal few positive effects and a media that has difficulty in growing it's reach, more recent reviews show a mix of positive and negative effects, and provide a consciousness about why these effects occur, when, and to whom, leading to refined suggestions about how to integrate games in learning to capitalize on their positive affordances. Many of the studies investigated here call for more research on game mechanics, elements, and designs, and how they practically affect engagement, motivation, and learning. Whereas some of the studies from the last decade also initiates such research, there is still a lot of ground to be covered, not only for the narrative aspect of learning games, as is the initiating factor of this PhD dissertation, but also for other elements of the game, whether that being the graphics, sound, and other modalities, the interaction and mental and motoric challenges posed by games, games awards systems, or other relevant game related phenomenon.

2.3.4 Narrative game-based learning

There seems to be a consensus in scientific communities that narrative is a central component in games. Ermi and Mäyrä (2007) defines games as comprised of rules, space, and narrative, Esposito (2005) define game elements as game, play, interactivity, and narrative, making a distinction between game and play based on Caillois (2001) in which playing (paidia) is a freeform, expressive, and improvisational recombination of behaviours and meanings, and gaming (ludus) are the rule structures that afford competitive strife towards a goal. In a review of educational game design, Dondlinger (2007) finds distinct game designs elements to consist of narrative context, rules, goals, rewards, multisensory cues, and interactivity, and Qian and Clark (2016) see narratives as one of 28 game elements, comprising elements such as collaboration, and exploration, alongside genre typologies like role-playing, and strategy. Ludology (e.g., Eskelinen, 2001) acknowledges narratives to potentially be a part of games, albeit with a game being something requiring an involved player who cares about what will happen, rather than external observers that apprehend what has occurred (Frasca, 2013), something which, as described by Simons (2007), leads to the ludologist stance that narrative theory simply cannot describe the forms and formats of new media, like games. A ludology vs. narratology debate thus spurred in the early 2000, a debate that was somewhat stained with strong language (Simons, 2007). Procedural authorship (Murray, 1997), procedural rhetoric (Bogost, 2007) or simulation rhetoric (Frasca, 2013), perspectives on how games as new media are concerned not with what has happened or is happening, like traditional narratives are, but rather what may happen, is often referenced in ludology. These concepts that are inert and unique to games and similar new media structures fall akin to the definition of emergent narratives (Jenkins, 2004), something which has been labelled narrativism by Aarseth (2004) and has been problematised as to whether is a narrative at all (Aarseth, 2012). Breien & Gkini (2021) show how ludological systems encompass all games as well as narrative games, and that the LNVM (Aarseth, 2012) can be used to categorize all of them.

To illustrate the above, one may look at chess. An instance of a game of chess may employ procedural rhetoric and a narrative may emerge. After and even during a game, a player may recite a story about the pieces and their actions. In a game in which a rook played a particularly vital role, one may imagine a narrative about that rook, how it bravely positioned itself in the centre of the battle to protect its queen and lesser officers, led a charge that successfully opened up the opposing player's king side, and ultimately was instrumental in placing the king in checkmate, in a daring and sacrificial raid. Chess can be categorized on the LNVM. It has a single room world, confined to the playing board. It has objects, which could arguably be discussed to be the 8x8 tiles on which pieces can stand, or to be the tiles, as well as all the pieces except the kings, which use them to keep safe, in any event categorizing as destructible objects (which also makes them useable, as per the linearity of the objects ontology in the LNVM). It has agents, which could be only the kings, the main characters of the game which uses all the pieces as objects, or all the pieces, characterized as what they are, using the sole object of the playing tiles to move around, regardless categorizing as stereotypical, given that their different move patterns probably elevate them from bots. Finally, it has events, all the things that can happen in a game of chess, which is fundamentally restricted to moving and removing playing pieces. A game of chess contains no kernels, though, as the concept of kernels dictate that they are occurrences that must happen for a story to be itself. In chess, there is nothing that must happen. No one piece must be moved anywhere, anytime, or even, at all, for a game of chess to happen. Not even checkmate must happen, since a game of chess can, and often will, end in a remis. Even if games of chess can spur narratives, chess itself still categorize as no kernels, not a narrative on the LNVM. It is important to separate procedural and emergent narratives from the narratives that arise from them. The example about the heroic rook above may well become a book, a play, or a game which is in turn not chess, and that story may well categorize something else than no kernels on the LNVM. But in such an instance, chess would have been a tool or an inspiration for the resulting narrative, like emergent narratives are tools and inspirations for future stories that can later categorize as narratives on the LNVM. Before a concrete story has emerged, it will categorize as not a narrative even if the system includes definitions of both world, objects, and agents in compliance with the narrative theory for games.

As Hauan (2017) has shown, narratives and games are powerful components in embedded learning environments that foster engagement and flow in learners. As shown in Breien and Wasson (2021) although there are several empirical studies and literature reviews that point towards positive effects from narrative DGBL, the results are mixed, with studies showing both neutral and negative effects. As observed by Armstrong and Landers (2017) there is a scarcity of studies that isolate narratives in DGBL, and there is a lack of a common model to properly categorize their narratives. Thereby it is difficult to conduct research related to how, and under what conditions, narratives have effects in DGBL. To illustrate the degree of understudy of narratives in DGBL, a final search was done across the five databases used in study 1 in this dissertation altering the original search string once again by removing references to engagement and motivation and changing the field restriction from title to abstract for narrative and story[53]. This resulted in a total of 1 735 publications between 2000 and 2022, which is a mere 3 percent of the 56 948 studies about game-based learning that was published in the same timeframe. Given that so many descriptions of game elements recognize narratives as central components of games, one could expect the focus on narratives to be higher overall.

In Ermi and Mäyrä’s (2005) perspective, narratives in games are identified as something running parallel to interactive mechanics of the game, the rules, in a defined game environment, the space, and in Qian and Clark (2016), narratives are found to be the third most applied game element in DGBL. None of these, however, say anything about how the narrative in the game is structured in terms of narratological models, which Breien and Wasson (2021) identified as a shortage in the study of narrative DGBL. The research presented in Article 1 (Breien & Wasson, 2021) aims to fill this gap.

[53] (Game) AND (Learning OR Training OR Education) AND (Narrative OR Story)

Breien and Gkini (2021) separates narratology into classical (Aristotle, c. 335BC/1996; Freitag, 1886; Campbell, 1949) and ergodic (Aarseth, 1997) models and distinguish them by linearity, with classical narratology, being adapted from media like theatre, books, and films, being linear in structure, and ergodic narratology, while also allowing for linear structures, also offer categorization for non-linear storytelling. Whereas the research presented in Breien and Gkini (2021) shows that non-linear narrative DGBL outperform linear narrative DGBL in terms on learning effects, another equally important takeaway is that ergodic narratology has the capacity to categorize all games' narratives, whereas classical narratology can only properly categorize a sub-set, namely the linear narratives. An important premise for the research presented in this dissertation is thus that a common model for categorization of narrative DGBL must be an ergodic model. The Ludo Narrative Variable Model (LNVM) (Aarseth, 2012) is such a model, which can, as shown by Breien and Gkini (2021), categorize all games, linear, non-linear, and even games that are not narratives.

2.4 Co-design

The creation of games for learning is a multidisciplinary activity in which educators and developers must be empowered to participate and communicate effectively to make game-based learning that is both educationally efficient and fun to play (Silva, 2020). As uncovered by Arnab et al. (2015) there is a lack of enabling tools for learning game development that allows educators to understand how they can be implemented in education. Concurring with Arnab et al., Lameras et al. (2017) call for pedagogically driven and inclusive processes for learning game design that enable educators. Taking the perspective of the developers of learning games, Carvalho et al. (2015) uncover a gap between idea and implementation, due to a lack of models, methods, and frameworks enabling developers to understand how pedagogic requirements are satisfied. Thus, the design of games for learning needs to be seen as a co-design activity where educators specify curricular goals, learning goals, demographics, and the learning situation, developers provide expertise on game design and development, and both must be empowered through the process to ensure educational quality and entertainment value. This sub-chapter explores co-design process types, the main stakeholders in learning game co-design, and the reach of co-design frameworks in game-based learning development.

As Zamenopoulos and Alexiou (2018) show, co-design is a practice in which people with different knowledge, skills, and resources connect or collaborate to carry out design tasks that no one person has the understanding to solve. Co-design can involve users as participants in design processes (Chesbrough, 2003). The range of products, concepts, and services that can result from co-design is wide. It can, for example, involve user-participation in modelling of health services, or a musician aiding a musical instrument model construction, or, more related to the research presented in this dissertation, it can be science centre educators coming together with technological developers and domain experts to create exhibits, exhibitions, and learning materials for them, in the form of mixed reality narrative game-based learning trails, as shown in Breien et al., (2022).

2.4.1 Types of co-design

The co-design prefix can mean collaborative, cooperative, collective, and connective (Zamenopoulos & Alexiou, 2018), and while the nature of a particular co-design project to reach some goal may include many of these meanings at the same time, there is an important distinction between the collaborative variant and the other three. In *collaborative design*, participants work towards a shared goal, such as creating a learning trail using a set of exhibits for education in a science centre. In *cooperative design*, on the other hand, one finds participants with essentially different goals and interests that find opportunities for synergies in a part of processes that ultimately leads to widely different objectives. Imagine a hydro electrical power company wanting to increase production in a local community where the population is working towards making a bridge over a stream. This may result in a dam-bridge across the stream, designed in cooperation to ensure both power production and movability from one side to the other, two widely different goals, which are both solvable if both interest groups participate. *Collective design* involves mobilizing groups and individuals to elicit knowledge, values, and ideas in solving challenges for themselves or for groups and individuals external to themselves that has requirements. Interest groups and organizations are good examples of collective design efforts, such as organizations promoting accessibility in society, where participants with varied skills come together to, for example, create and implement accessible entry points to buildings, or to argue for new legislation to improve conditions for groups. Finally, *connective design* addresses projects or communities in which people pool the results of their actions or their resources and build on each other to reach a variety of individual and sub-group goals. This is exemplified in many open source and open access movements, such as open software development communities in which, for example, a freely available database structure, or a library of code that represents generic objects may be re-used and applied in many different programs and services, most often with a requirement that any extension of the original asset shall be returned to the community for further use by others. Whereas cooperative and connective design is typified by individuals or groups contribute independently, collective and collaborative design is typified by participants working together at the same time (Zamenopoulos & Alexiou, 2018).

Games for learning are co-designed by individuals with different knowledge, skills, and resources working together towards a common main goal; to create games that create conditions for learning in some manner of efficiency. Thus, the co-design of learning games means collaborative design.

2.4.2 Main stakeholders in learning game collaborative design

As seen in Silva (2020), Arnab et al. (2015), Lameras et al. (2017), Carvalho et al. (2015), and other studies detailed in the background section of Breien and Wasson (2022), the main roles in learning game co-design are the educators, having expertise about subject matters, curriculums, learning objectives, demographics, etc., and the developers, having expertise about game mechanics and game design, programming, graphics, implementation, distribution, upkeep of game systems, etc. As shown in Breien et al., (2022) creation of science centre learning trails can have an even wider range of stakeholders (e.g., engineers, construction workers, area planners, actors, or creative writers, to mention a few). Learning trail co-design, however, is based on existing exhibits and their affordances as learning tools and the digital companions.

The educators working with the educational programs based on the exhibits have the overview of their functions and learning capabilities, and the developers have the competence to technically create the games, something which make these two roles the most important co-design participants even in science centre learning arenas.

2.4.3 A call for co-design frameworks

Co-design frameworks for game-based learning exist. The LEAGUÊ framework (Tahir & Wang, 2020) is a card-based design toolkit in which stakeholders brainstorm, ideate, and design educational games for different learning domains and users, applying game genres and technologies. The Learning Mechanics–Game Mechanics (LM-GM) model (Arnab, et al., 2015) consists of predefined game mechanics and pedagogical elements, while the Domain Specific Visual Language (DSVL) authoring tool (Marchiori, et al., 2011) offers a visual language for non-technical personnel learning game design (for others, see Article 2, Breien and Wasson (2022) and Rabail Tahir's PhD dissertation (Tahir, 2021)). There is, however, a need for inclusive co-design methods for learning games. After investigating 165 papers about planning, designing, and implementing learning games, Lameras et al. (2017) conclude that the lack of design approaches inhibits the integration of learning elements in learning game design, something which creates misconceptions, discrepancies and uncertainty related to how learning activities may be designed and applied. Exploring the use of design approaches in 2466 papers on learning game design, Gurbuz and Celik (2022) uncover that only 32 of them mention any form of design approach in form of a model, method, or framework.

2.5 Summary

This chapter has shown that learning trails in science centres can create Embedded Learning Environments (ELEs) transcending exhibitions to target wide varieties of STEAM learning goals and objectives. Learning trails are mixed reality ELEs, consisting of the physical exhibits and digital companions, and research has shown narratives and game mechanics to be important elements of learning trails to foster engagement and flow. Narratives have been used to educate since pre-historic times and are speculated to be closely tied to the development of human intelligence and society. Games are a form of narrative media that require their own types of descriptive tools to be properly categorized using narratological models, however, research shows that insufficient models are often adapted from other media, if narratological models are applied at all. Thus, there is a need for a model that can categorize games. The research discipline of game-based learning has grown over the last two decades, and several reviews has been conducted that informs on engaging factors for positive learning outcomes from games. Engaging factors are also found for games that targets entertainment, some of these factors may transfer to game-based learning. The main stakeholders in co-design of game-based learning are educators and developers, for whom research points to a lack of enabling models, methods, and frameworks. The research reported in this dissertation aims to contribute to these two gaps.

3. Methods

This research presented in this dissertation applies design science research with mixed qualitative methods. This chapter presents the methods used in the research. First, the adopted research paradigm, design science, and the information science research framework is described. Next, the methods used to conduct the studies are detailed including a rapid evidence synthesis (Article 1), and design-based research (Article 2 & Article 3). Then the data collection methods including focus groups, semi-structured interviews, a questionnaire, and the analysis methods included thematic analysis and heuristic usability inspection are described. The chapter ends with the research ethics section.

3.1 Design science and the Information Science Research Framework

As opposed to routine design, system building, that applies an existing knowledge base using well known best practice artifacts to solve organizational problems, design science addresses previously unsolved challenges in unique and innovative ways (Hevner et al., 2004). Thus, design science provides the overarching methodology for the research presented herein, which addresses the unsolved challenge of designing and developing mixed reality narrative game-based learning trails that promote positive effects on engagement, motivation, and learning.

The Information Systems Research Framework (ISRF) as presented by Hevner, is adopted as the design science methodology. ISRF is a framework in which people and technologies in organizations provide relevance to the research, where theories and/or artifacts are developed or built, and in which foundations and methodologies in a knowledge base are applied to rigorously assess, then iteratively refine, the theories and artifacts. The development or building of the relevant theories or artifacts, the utilities, lays at the core of the design science, whereas the justification and evaluation, the truths, comes from behavioural science. The justification and evaluation ensure the theories or artifacts appropriate application in the environment, and feed relevant additions back to the knowledge base.

Whereas design science provides a foundation for innovative approaches to solving unsolved challenges in a community of relevance — such as a science centre exploring design methods for game-based learning trails that enforce positive effects on the learners — an information systems research framework facilitates the practical and iterative design and development of artefacts that can be iteratively tested and evaluated using ethnographic-oriented methods to get feedback from the relevant environment. The synergies of design science paired with an information systems research framework allows for defining the challenge, and, using the knowledge base, enables the environment consisting of the educators and developers, the organization to which they belong, and the technology they have available, to iteratively refine and assess innovative solutions for mixed reality narrative game-based learning trail co-design that enforces positive effects on engagement, motivation, and learning.

Figure 7 shows how the ISRF was applied in the research identifying 1) the environment, 2) the knowledge base foundations and methodologies, and 3) how the IS research informs and underpins relevance and rigour, which iteratively develops, assesses, and refines the theories and artefacts resulting from this research and shows how these were justified and evaluated.

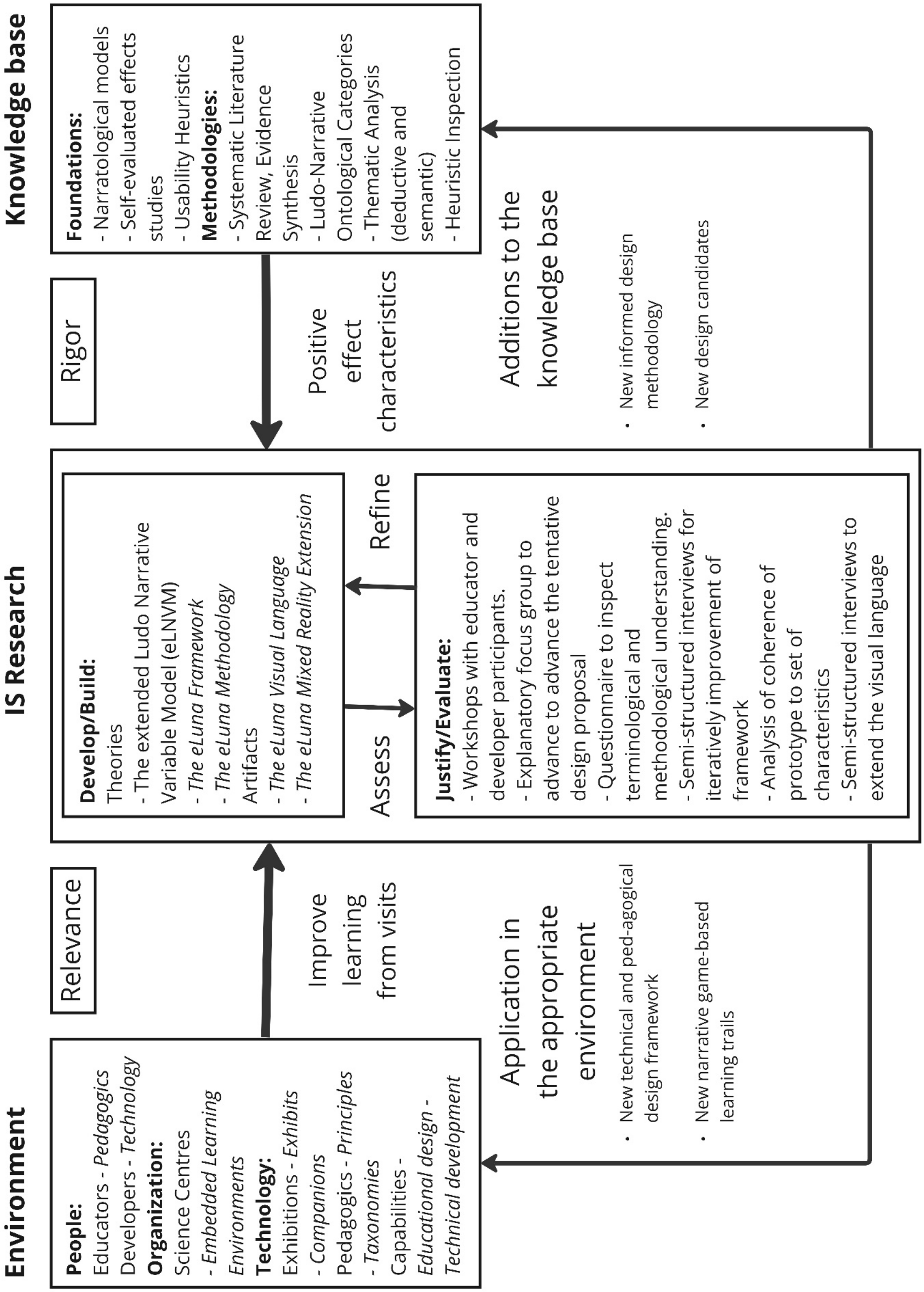

Figure 7: ISRF for development of eLuna theories and artifacts (adapted from Hevner, et al., 2004)

As can be seen in figure 7, the roles of the people in the environment are educators and developers. Their business need is to improve learning from formal visits to science centres through the development of mixed reality narrative game-based learning trails. These roles have different capabilities of relevance and importance in reaching the goal, capabilities that are characterized by their respective competences inside pedagogics and technological development. The organizations in which the roles operate are the science centres, which are organizational cultures that strategically apply embedded learning environments as part of the processes to provide learning to visitors. The technologies of relevance in the environments are the scientific exhibits and exhibitions, the companions used in learning trails, alongside pedagogic principles, and the capabilities of educational and technical personnel.

The knowledge base that provides relevant applicable knowledge to create the theories and artifacts is founded on 1) narratological models, 2) historic narrative game-based systems that have been evaluated according to self-report on their effects on learners' engagement, motivation, and learning outcomes, and 3) usability heuristics. The methodologies include 1) the evaluated systems are identified using a systematic literature review process, a rapid review of evidence synthesis, 2) the ontological categories of the eLNVM which reveals categorical system characteristics that can be organized based on their effects, 3) thematic analysis, and 4) heuristic inspection.

In the IS Research, presented in the remainder of this chapter, the main artefacts, the eLNVM and eLuna Framework (including the eLuna method and visual language) are developed.

3.2 Overview of the studies

To reach the overarching objective of this research as detailed in figure 7, three studies were conducted to develop and build the co-design framework theories and artifacts, and subsequently iteratively justifying and evaluating the components. Table 2 summarizes these three research studies and their methods as presented in the three articles included in this dissertation.

Table 2: Overview of iterative research per article

Overall aim	To contribute to improving science centre learning.		
Main research objective	To develop a co-design framework for mixed reality narrative game-based learning trails that enforce positive effects on engagement, motivation, and learning.		
	Article 1	*Article 2*	*Article 3*
Title	Narrative categorization in digital game-based learning: Engagement, motivation & learning	eLuna: A Co-Design Framework for Narrative Digital Game-Based Learning that Support STEAM	A Mixed Reality Visual Language Extension for Narrative Game-Based Learning Trails Co-Design using the eLuna Framework
Research question	What characterizes narrative digital game-based learning systems that positively affect engagement, motivation, and learning?	How can a co-design framework empower educators and developers in the creation of narrative game-based learning that is based on characteristics that positively affect engagement, motivation, and learning?	How can a co-design framework for narrative game-based learning distinguish the physical from the virtual in mixed reality learning trails?
Method(s)	Systematic literature review (rapid review for evidence synthesis), model development	Design based research	Design based research
Sample/ participants	Peer reviewed articles from five databases and hand searches published between 2009 and 2019	6 Science centre teachers, 5 High school teachers, 6 Serious game developers, and 6 Technology enhanced learning academics	6 Science centre teachers, and 2 Serious game developers
Data	Database search string keywords, inclusion / exclusion criteria	Focus group, questionnaire, semi-structured interviews,	Semi-structured interviews
Analysis	Narrative categorization, self-reported effects clustering	Thematic coding and categorization	Thematic coding and categorization, heuristic usability inspection

The following sections describe the methods, data, and analysis as used in the three studies.

3.3 A common model to categorize and isolate narratives in DGBL

The development of a model for categorizing and isolating narratives in digital game-based learning (Article 1) comprised three steps: 1) A systematic literature review; 2) the extension of a ludo narrative variable model, and 3) narrative categorization and clustering. This section describes the methods involved in these steps.

3.3.1 Systematic literature review: Rapid evidence synthesis

Advancement in knowledge must be built on prior knowledge, and to push the knowledge frontier further, we must first understand where the frontier is (Xiao & Watson, 2019). As Xiao and Watson write: "*By reviewing relevant literature, we understand the breadth and depth of the existing body of work and identify gaps to explore. By summarizing, analysing, and synthesizing a group of related literature, we can test a specific hypothesis and/or develop new theories.*" (p. 93). One tool available to researchers for uncovering and exploring the historic body of research in a field or topic of interest is a systematic literature review, widely applied based on the guidelines set forth by the Cochrane Institute, in the Cochrane handbook for systematic reviews (Higgins, et al., 2019). However, as pointed out by Kitchenham and Charters (2007), systematic literature reviews are work and time-consuming undertakings that are not fitted for the scope of the research that can be completed by a single candidate completing a PhD. Kitchenham and Charters contribute comprehensive guidelines for systematic literature reviews appropriate for PhD students that presents a fair evaluation of a research topic, applying a trustworthy, rigorous, and auditable methodology (Kitchenham & Charters, 2007), defining evidence as the synthesis of the best quality scientific studies on a topic or research question (Kitchenham, et al., 2009). Furthering the methodology provided by Kitchenham and Charters, Catalá-López, et al. (2017) limited the development of the search protocol in their *rapid review for evidence synthesis* to three comprehensive steps, adopted in study 1:

1. **The unstructured initial informal search** across 10-fold databases to test different combinations of search words and database results,
2. **The test protocol**, to develop search string and criteria, and to select the final databases to use, and

3. **The main protocol**, in which the actual search protocol was conducted using the search query and inclusion criteria.

To ultimately contribute to the co-design framework these steps were adopted to identify the articles that were used to initially uncover characteristics from empirical studies of the self-reported effects of digital game-based learning on engagement, motivation, and learning, and then they were categorized and clustered in the extended Ludo Narrative Variable Model (eLNVM).

As presented in Article 1, Breien and Wasson (2021), a search protocol was defined through a preparation phase, uncovering an effective search string and databases to search, before it was applied as a main protocol. The resulting dataset obtained from the main protocol was initially filtered to remove duplicates and false positives, further compared to three rounds of inclusion criteria, and finally an evaluation of the system description. Table 3 provides an overview of systematic literature review rapid evidence synthesis as conducted in the initial study (Article 1).

Table 3: Overview of systematic literature review rapid evidence synthesis

Phase	Step	Description
Preparation	Unstructured informal search	Searches across 10 databases using different search strings and keywords, then manually getting an overview of results and their relevance to the research questions, in terms of overall numbers of results and results per database
	Test protocol	Selecting 5 databases with the most relevant results, then refining the search string to increase the percentage of relevant results
Main protocol	Search string:	Title: (Narrative OR Story) AND Title/Abstract/Keywords: (Game) AND (Learning OR Training OR Education) AND (Motivation OR Engagement)
	Search timeframe:	2009 — 2019
	Databases:	ACM Digital Library, IEEE Explore, PsychINFO, Science Direct, Web of Science
	# Of studies identified:	61
Dataset filtering	Removal of duplicates	Same study found in different databases
	Removal of false positives	E.g., return of title word ‘history’, or reference to ‘narrative evaluation methods’
Inclusion criteria	Abstract	The study must be about the design or evaluation of a fully or partially interactive digital tool, system or process that teaches or trains someone in a subject matter, skill, trait, or process
	Full text 1	(1) The study does not target users with special assistive needs or medical conditions, (2) The study is targeted at school children, students, or adults in professional or academic settings, and (3) The study provide results, observations, comments, recommendations, practices, or other relevant information about narratively obtained motivation and/or engagement and learning outcomes from the learner or practitioner
	Full text 2	Classify by (1) Study type, (2) Sample size, (3) Demography, (4) Method, (5) Subject matter, (6) Game type/genre. Study removed if problematic
	System description	Confirm that the evaluated DGBL systems were qualitatively sufficiently described to meaningfully categorize them (by reading the papers, but also by following links to on-line resources, playing games, watching academic videos of game play sessions, and/or by following reference links to previous papers in which the DGBLs were further described)
	Result	15 Empirical studies (across 14 studies) of categorizable narrative DGBL systems with self-reports of effects on engagement and/or motivation as well as learning outcomes

3.3.2 Extending a ludo narrative variable model

A gap in the field of narrative game-based learning (Chapter 2.3.2 & Article 1) is the lack of a common model to categorize and isolate narratives in DGBL to enable an analysis and comparison of how, and under what conditions, narratives have effects on learning in DGBL systems. The ludo narrative variable model (LNVM) that has been used to isolate and categorize narratives in research on commercial video games was a candidate to fill this gap. The LNVM was selected after exploring four perspectives on narratology and determining their appropriate fit with narrative games as media. The four perspectives are classical act-based narratology, as presented by Aristotle (c. 335BC/1996) and Freitag (1886), monomythical narratology, focusing on character development in narratives (Campbell, 1949), alongside Ludology as described by e.g., Juul (2011), and Frasca (2003), and the ergodic narratology (Aarseth, 1997), a modern perspective on narratives in which observers needs to apply non-trivial actions to evolve the storyline. The LNVM sorts under the ergodic perspective and has the capability to categorize all games as narratives under four ontologies that are shared by all games and narratives.

The LNVM was extended to clarify terminology and to distinguish between two forms of events structures in narrative games. The extended Ludo Narrative Variable Model (eLNVM) that can be used to categorize and isolate narratives in DGBL was developed to account for the identified characteristics. Categorization is done by determining narratological and game mechanical properties of games under four ontologies, World, Objects, Agents, and Events, and placing them under categories that describe the properties. Isolation is done by sorting the narrative DGBL studies by their characteristics, then inspecting their self-reported effects.

3.3.3 Narrative categorization & clustering

To arrive at the characteristics that are empirically associated with positive effects on engagement, motivation, and learning, the 15 studies obtained from the literature review were categorized on the extended Ludo Narrative Variable Model (eLNVM) (Breien & Wasson, 2021), resulting in 4 characteristics (see Chapter 4 & Article 1).

The categories of the eLNVM and their characteristics are further described in Article 1 (Breien & Wasson, 2021).

3.4 Design based research

Seeking to construct a systematic science of how to design educational environments so that new technologies can be successfully introduced in learning situations, Collins (1990) introduced design science research in education. According to Collin's initial contribution, design science in education consists of systematic methodologies for conducting design experiments, and design theory to guide implementation of innovations. Design science research is conducted by involving teachers and other stakeholders, enabling the comparison of innovations with no vested interest in the outcome.

The term Design-Based Research (DBR) was first introduced by Brown (1992). DBR is at the core of the research of the second and third article of the PhD research presented herein. In an analysis of original and emerging DBR definitions since Brown, Anderson and Shattuck (2012) shows DBR to be defined by eight characteristics. Table 4 lists these eight characteristics and show how they relate to the research presented in this dissertation.

Plomp (2013) identify two possible purposes of DBR: *Development studies* and *validation studies*. Focusing on the former, Nieveen and Folmer (2013) formulate development DBR studies as "*the systematic analysis, design and evaluation of educational interventions with the dual aim of generating research-based solutions for complex problems in educational practice and advancing our knowledge about the characteristics of these interventions and the processes of designing and developing them.*" (p. 153).

Table 4: Characteristics of DBR and relevance for the research

Characteristic of DBR	**Relevance for the research presented**
Is Situated in a Real Educational Context	The research presented was performed in the context of a physical-world science centre and throughout focused the crux of the work towards co-designing learning trails revolving around exhibitions and exhibits presented at the centre, thereby effectively informing and improving practice.
Focus on the Design and Testing of a Significant Intervention	The research presented commences with an assessment of the local context (the science centre affordances, the resources allotted for teaching and learning programs, and previous research on embedded learning environments), is further informed by relevant theory from other contexts (the characteristics of game-based learning that induce positive effects on the learners), and is designed specifically to meet the challenge of improving learning outcomes from science centre learning trails during school visits. Furthermore, the researcher carefully documented the time, commitment, and contingencies of creating and implementing the intervention, which is the learning trail itself.
Use Mixed Methods	The research, in accordance with practices in DBR, select methods of research that are practical to applying the findings to a reality that is plural and unknown, focusing on meaningful and authentic issues in the context. The various methods applied through the research are summarized in the remaining sub-chapters under this one.
Involve Multiple Iterations	The research is conducted through several iterations, both to shed light on particular details of the intervention (the co-design framework) before refining and applying them, and to improve the methodology in iterative steps; proposing a procedure, testing it, consulting the participants, refining it, and testing it with both new and recurring participants.
Involve a Collaborative Partnership Between Researchers and Practitioners	The research was conducted consulting the main stakeholders in learning trail design and development; educators and developers. The researcher participated in a hands-off, facilitating role, allowing all participants to focus on and apply the knowledgebase wherein lays their core professional expertise. For the educators, these are pedagogics and particularities around constraints and affordances in science centre teaching to school classes, for the developers these are game design and development, and for the researcher these are scientific methodological work and rigorous documentation.
Evolve Design Principles	The research focuses on the actual conditions in which it operates; the science centres' exhibitions, the learning objectives targeted in the programs, and the situation of learning in science centres, including practical logistics, available technology, times of visits, and staff available to facilitate the programs, evolving practical design principles allowing the context and the intervention to maximize learning.
Compare to Action Research	The research, like most DBR projects, has similarities to action research in being pragmatic, being derived from theoretical models, but restricting itself to practical and specific contexts for instruction. What ultimately places the research as DBR is construction of theories, artifacts, models, and prototypes, foci that is not (necessarily) part of action research.
Has Practical Impact on Practice	The research directly focuses on the critical importance of implementation and adaption of its results in the context; emphasising the real-world constraints and affordances of the participants expertise and resources, and the physical-world setting of the science centre, taking both logistics, planning, and time into account throughout.

The type of research Nieveen and Folmer informs has twofold yields: the first being high-quality, research-based interventions designed to solve complex problems in educational practice; and, the second being well articulated design principles providing insights into: 1) the purpose and function of resulting interventions, 2) the key characteristics of resulting interventions, 3) guidelines for designing resulting interventions, 4) the resulting interventions' implementation conditions, and 5) theoretical and empirical arguments for characteristics and procedural guidelines for resulting interventions' design. The core objective of the research presented in this PhD dissertation is to shed light on design principles for effective learning trails in science centres. Yet, as auxiliary results, the research also provides, to various stages of completion, a set of concrete interventions that were co-designed throughout the work to iteratively evolve the co-design framework and methodology.

Nieveen and Folmer (2013) further define DBR development studies to consist of three phases: 1) the preliminary research phase, in which researchers gain insight into the existing problem situation, then explore possibilities for improvements and innovation, 2) the development and prototype phase, during which several prototypes are developed to various stages of completing, then evaluated and revised, to help develop both the intervention and the accompanying design principles, and 3) the summative evaluation phase, in which the outcomes of the study is evaluated towards its original intent. In the research presented herein, the first phase concerns the exploration of the research of Hauan (2017), and his definition of components for and structures of embedded learning environments. This was carried out alongside the literature review and categorization of game-based learning systems, presented in Article 1, and using the characteristics shown to induce positive effects as a basis for the co-design framework development. The second phase concerns most of the research conducted and presented in Articles 2 and 3, in which a series of prototypes are co-designed by stakeholders based on the current version of the framework, methodology, and the visual language. The third phase concerns the work between the iterative prototype development phases, in which the framework and its components are refined based on the98econd9898on of the previous co-design session, and the participants responses and feedback using mixed methods. The second phase, development and prototyping, Nieveen and Folmer (2013) informs, is founded in formative evaluation, providing empirical data for the increased quality of the next intervention and the design principles. As Nieveen and Folmer (2013) puts it: “The function of formative evaluation is ‘to improve’. It focuses on uncovering the shortcomings of an object during its development process with the purpose of generating suggestions for improving it.” (p. 158). Plomp (2013) shows how a DBR project requires several iterations before a solution to a complex educational problem can be reached, and how each cycle contains its own formative evaluation with specific research objectives which require a potentially unique research design. Following up on this realizations, Nieveen and Folmer (2013) goes on to propose a cyclic model for development and prototyping in DBR, shown in figure 8.

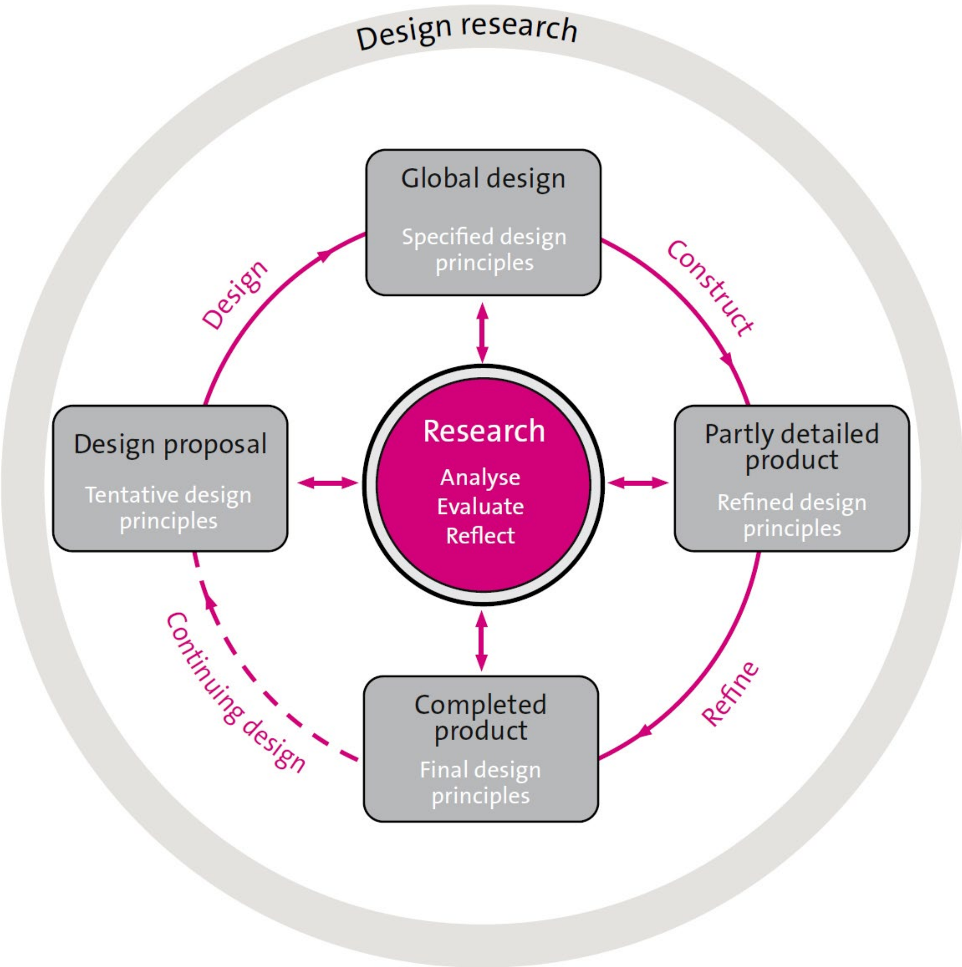

Figure 8: Development or prototyping phase in an educational design research study (from: Nieveen & Folmer, 2013)

3.5 A co-design framework for mixed reality narrative game-based learning trails

The contribution of a co-design framework for mixed reality game-based learning trails were divided into two studies, presented in articles 2 and 3 respectively. In study two, the categories associated with the positive effects identified in study one, the literature review, were used as basis for a co-design framework for narrative game-based learning, and the framework was brought through the four phases in DBR. In study three the DBR phase bringing the framework from specified to refined design principle was reiterated, adding capabilities to distinguish physical from virtual elements, allowing the framework to be used in mixed reality learning trail environments. Both studies' data were analysed using semantic and deductive thematic analysis, the third study also applying heuristic usability inspection.

In the next two subsections, the methods applied, and participants involved in the two studies are detailed related to DBR phase. Then the methods are summarized, before data analysis is described.

3.5.1 A co-design framework for narrative game-based learning

Using mixed methods, study two brought the co-design framework through the four DBR phases from tentative to final design principle. An initial design was proposed by the researchers and was then brought to experts and end users in a series of workshops which were afterwards evaluated to bring the framework to global design, refined principle, and final principle through four iterations. Table 5 shows the DBR phase, workshop format, method, and participants numbers and backgrounds involved in study two.

Table 5: DBR phases, workshop, methods, and participants of study 2

DBR Phase	Workshop	Method	Participants
Design proposal	15 min instruction 90 min co-design 10 min presentations	Focus group (30 minutes) with e-mail confirmation and follow up	6 PhD / PhD candidates in Technology Enhanced Learning fields
Global design	15 min instruction 90 min co-design 10 min presentations	Questionnaire (eight question Likert scale)	5 High School teachers 2 Developers
Partly detailed product	35 min instruction (15 minutes at start, four 5 min instructions before each ontology) 90 min co-design 10 min presentations	Semi-structured interviews (60 minutes, 10 headlines with two questions each)	6 Science Centre teachers 2 Learning Science academics 2 Developers
Completed product	N/A	Prototyping (co-design, co-specification, blueprint, implementation)	1 Educator 2 Developers

As table 5 shows, a co-design framework proposed by the researcher (Design proposal phase), was evaluated by expert participants through a design session and subsequent explanatory focus group (Belanger, 2012), designed to provide further insight and validation to the co-design framework, which is based on the characteristics found in the literature review, and needs to be made comprehensible for end-users. The resulting refined framework (Global design phase) was then presented to educators and developers through design sessions, after which the participants responded to questions about their understanding of the applied terminology, alongside the sequence of work during the practical sessions. Adjusting the terminological use and presentation, and the sequence of work based on the feedback, the refined design next version of the framework (Partly detailed product phase) underwent a series of design sessions, after which participating educators and developers participated in audio recorded semi-structured interviews (following best practices by Oates, 2005) to further improve it in a broad perspective. Finally, a final design was conducted and brought to a functional prototype. A verification of whether it is possible for educators and developers to co-design a narrative DGBL that can be implemented and brought to target audiences and evaluating the framework's output for its compliance to the original characteristics that was intended reached in interventions resulting from the use of the framework, is the final step to bringing about the final design principles (Completed product phase) for the framework.

3.5.2 Visual language mixed reality extension

In study three (Article 3), the final design principles from the previous article were revisited and laid to ground for another study, in which two groups of educators and developers made alterations to the visual language of the framework. The goal of the study was to extend the framework's visual language with capabilities to distinguish physical from virtual elements in mixed reality learning trails. Since the framework remained unaltered, and it had already been verified in the previous study, and because the intention was not to make a new visual language, but rather to keep the existing one, and giving it new expressive abilities, this study cannot be said to commence at the design proposal phase. Rather, it is already past the global design phase, ready to commence partially detailed product phase, bringing about the refined design principles for the mixed reality visual language. Study three was therefore a reiteration of the partly detailed product phase and followed the method from the same phase in study 2. Table 6 shows the single DBR phase conducted in study three.

Table 6: DBR phase, workshop, method, and participants of study 3

DBR Phase	Workshop	Method	Participants
Partly detailed product	30 min instruction 90 min co-design 24-hour comment period	Semi-structured interviews (60 minutes, categories as topics, shared screen of co-design)	6 Science Centre teachers 2 Developers

As table 6 shows, the visual language extension DBR phase was based on workshops like those in study 2, only in this study accompanied by a 24-hour comment period on a shared co-design document. During the semi-structured interviews, this co-design document was made available on a shared screen, and the categories from the eLNVM applied as topics for discussion. The shared screen and the audio were recorded, and subsequently transcribed and analysed.

3.5.3 Data collection

To gather data and feedback from participants throughout the research, mixed methods were applied. These were all modelled as individual experiments following DBR in which participant stakeholders co-designed game-based learning trails following the practices which at the time of the interventions applied for the framework that is the main contribution of the PhD research. These methods are all tried and tested, and in accordance with the pragmatic approach promoted by DBR, as well as the rigour demanded for contributions arrived at through the ISRF.

Explanatory focus group

Focus groups are qualitative data gathering techniques in which respondents participate in planned discussions of scientific topics of interest to researchers (Krueger, 1994). According to Oates (2005), labelling focus groups as group interviews, focus groups work best with participants of similar status, to negate the disadvantageous effect of peoples' worry of speaking up to someone they consider their superior. This is reinforced by Krueger (1994), establishing an effective focus group to be in a permissive, non-threatening environment. Upon the establishment of an inclusive environment for the participants, focus groups have many advantages. As Krueger (1994) informs, focus groups allow participants to share reactions, ideas, and opinions through interaction, what Morgan (1997) refers to as collaborative construction, rather than consensus and negotiation. The first iteration of study two involved obtaining direct feedback from experts in technology enhanced learning related to the proposed design principle, regarding any relevant comments on the framework itself, and alterations or modifications that should be done for it to become usable for educators and developers. As all the respondents were academic peers, and a safe environment was provided, a focus group was conducted.

Belanger (2012) show how focus groups can provide significant insights in a variety of situations, among them in developing theoretical models for information system phenomena to be tested. Belanger (2012) differentiate between exploratory (e.g., to obtain a global picture of a phenomena of interest) and explanatory (e.g., generate constructs or items for an existing model, or to test a model). The focus group method applied in study two was explanatory, since the eLNVM characteristics are prerequisites for the co-design framework, and the iterative step is to generate it's constructs and validate its applicability for end users. The focus group discussion was transcribed by the researcher, and the transcripts were approved by respondents after a 24-hour feedback and discussion period.

Likert scale questionnaire

A Likert scale questionnaire is a tool that is applicable for evaluating respondents' agreeance with statements and was as such an ideal method for this phase of the work. Oates (2005) was used to formulate a well-formed Likert scale questionnaire. The questionnaire comprised closed questions in form of statements to which respondents could record their agreeance on a Likert scale from 1 (strongly disagree) to 5 (strongly agree); 3 is the neutral middle ground of neither agreeing nor disagreeing.

In study two, a Likert scale questionnaire was applied to evaluate the end-users understanding of the terminology and sequence of the co-design workshops. The questionnaire comprised four questions that would provide input to iteratively improve on the framework to be rated on a 5-point Likert scale (see Appendix A for the questionnaire):

1. The descriptions of the four ontologies in the extended ludo-narrative variable model were easy to understand
2. The descriptions of the four ontological categories that we used when designing the narrative learning game were easy to understand
3. The descriptions of the characteristics of the four categories were easy to understand
4. The sequence that we used the four ontologies in made sense to me

Semi-structured interviews

Semi-structured interviews are a form of data collection in which the researcher presents a list of themes with accompanying questions to be explored during the conversation with respondents, but in which the researcher is also prepared to follow up on different lines of argumentation as posed in a natural conversational flow, moving back and forth between themes, and exploring other questions or perspectives as deemed relevant. Both the second and the third studies applied semi-structured interviews, which were conducted according to best practices by Oates (2005).

Study 2

In the second study, participants in workshops underwent individual semi-structured interviews following a list of 9 topics formulated with 2 questions each, except for the last topic, which is a catch all question in case respondents felt anything was not covered by the other eight. The topics and questions were are shown in table 7 (and Appendix B):

Table 7: Topics and questions of study 2 interview

The overarching design process	
You and a group of co-designers have initiated design of a learning game based on characteristics of games as narratives	• What is your impression of how this process worked? • Can you suggest any overarching improvements?
The outcome	
The resulting output was a design for a learning game with learning objectives inside a scientific topic	• Would you say that a learning game that was realized from the design has potential for shedding light on the learning objectives? • Can you think of anything that should be added to or removed from the process that would improve the potential?
The ontologies, categories, and characteristics	
The work concerned ontologies which are named World, Object, Agent, and Events, there were described before the design session started	• What are your thoughts about the descriptions of the ontologies, the ontological categories, and the categories characteristics? • Can you think about any ontologies that are missing in the model that you used?
The work sequence	
The ontologies were designed in a sequence which was Agent, World, Object, then Events	• Would you say that a learning game that Did this sequence make sense to you? • Are there other sequences of interest that would empower the design work?
The topic and the learning objectives	
Before staring the design process, you selected a topic and learning objectives and were instructed to generate an overarching context for the learning game	• How did this process work for you? • Could this have been done in any different way to improve the process?
Timeframe	
During the design work you spent 20 minutes on each of the ontologies, except for the Agents ontology, on which you spent 30 minutes	• Do you think the difference in time spent on the ontologies was sensible? • If you disregard the time spent in this session, what timeframe do you believe would be good for co-design work of this nature?
Participants roles and design thematic	
During the design work you spent 20 minutes in the group there were academics, developers, and science centre teachers, and you worked towards a learning game inside science education	• Were there any competencies that you felt the group was missing? • Are there any other areas of study where you think this design method could be applied?
Example material	
Before the co-design session an example related to emergency response was presented	• How did this example work to illustrate the work that was about to be done? • Do you have suggestions for other examples that could be used?
Catch all	
The goal of this workshop is to improve the design process of effective narrative learning games	• Do you have any further comments that you feel does not fit under any of the other themes and questions?

The topics and questions were presented to the respondents in sequence and were also made available on a printed piece of paper placed on the table before them. The interview sessions were audio recorded and transcribed using Nvivo[54].

Study 3

In the third study participants in workshops underwent individual semi-structured interviews (see interview guide in Appendix C) following a list of five topics representing the five main element in the original visual language (Breien & Wasson, 2022) which were:

- Hub
- Agent
- Object
- Task
- Event

The interviews were conducted using shared screen conferencing where an interactive version of the co-design, which had been sent out 24 hours ahead, was available to be discussed and manipulated by both respondents and the researcher. The researcher allowed the respondents to deliberate on aspects of the topics that should be visualized to distinguish physical from virtual. The interview sessions were conducted on a shared screen, audio was recorded and then transcribed and annotated using Adobe Premiere and Microsoft Excel.

3.5.4 Data organization and analysis

Between the phases of DBR, the data from the various methods applied were organized and analysed to lay the foundation for the next phase. After the focus group, the data was organized by the researcher and a refined proposition for the framework was presented as a change log to the evaluators, who were given time to approve it. The subsequent framework version was then fed into the next iteration, in which teachers and developers provided answers to the questionnaire to uncover their understanding

[54] https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home

of the terminology used, and their empowerment to conduct co-designs following the proposed ontological sequence. The responses from the questionnaires were applied to refine the terminology and the sequence used, which was again applied in the next iteration, which involved a round of workshops, including interviews. The transcribed interview data underwent thematic analysis (see next sub-chapter) to refine the framework on a whole. After the framework arrived at its refined state a new set of workshops were conducted to determine how to distinguish between physical and virtual elements. Again, the respondents' data was put through thematic analysis before the results from the analysis underwent heuristic usability evaluation (see sub chapter preceding the thematic analysis) to select a tangible extension for each of the framework's visual language elements.

Thematic analysis (deductive and semantic)

Prior to 2006, thematic analysis was a rarely acknowledged, yet widely used qualitative method for data analysis inside and beyond psychology Braun and Clarke (2006). Arguing that it offers an accessible and flexible approach for qualitative data analysis, Braun and Clarke (2006) proposed guidelines for deliberate and rigorous thematic analysis conduction, and a concrete six step approach, shown in table 8.

Table 8: Six steps of thematic analysis (from Braun & Clarke, 2006)

Thematic analysis step	**Activity**
Familiarization	Transcribing data (if necessary), reading and re-reading the data, noting down initial ideas.
Initial coding	Coding interesting features of the data in a systematic fashion across the entire data set, collating data relevant to each code.
Themes search	Collating codes into potential themes, gathering all data relevant to each potential theme.
Reviewing themes	Checking if the themes work in relation to the coded extracts (Level 1) and the entire data set (Level 2), generating a thematic 'map' of the analysis.
Defining and naming themes	Ongoing analysis to refine the specifics of each theme, and the overall story the analysis tells, generating clear definitions and names for each theme.
Reporting	The final opportunity for analysis. Selection of vivid, compelling extract examples, final analysis of selected extracts, relating back of the analysis to the research question and literature, producing a scholarly report of the analysis.

As shown by Braun and Clarke (2006), thematic analysis can be either deductive or inductive, in the former case where a researcher is aware of and expects certain themes to occur in the texts or data, the latter in which the data itself is analysed from the bottom up, and where the themes emerge less predefined, dependant on what the data itself offers to the researcher. Furthermore, thematic analysis can be semantic or latent, semantic implying that the researcher has a direct interest in what the text expresses, the respondent says in a direct manner, latent meaning that the researcher is interested in moving beyond the words, to uncover aspects related underlying ideas, assumptions, conceptualizations, ideologies and so on, that can be theorized as shaping the semantic content. Both studies two and three presented in this PhD dissertation follow a deductive and sematic process of thematic analysis, in that the research has a degree of expectation about the themes that will result from the analysis. For example, it will be about the ontologies, the categories, and the characteristics of the framework, the sequence of work, the material presented, and so on, and further the researcher was interested in the exact semantics expressed by respondents on how to alter or modify the framework to make it more usable for the purpose of creating narrative learning games. In the first study, the respondents' observations where thematized inside Nvivo to analyse them and propose the next version of the framework. In the second study, the respondents' observations were thematized in a spreadsheet after analysing the audio and the video from the interviews.

Heuristic usability inspection

Heuristic usability inspection was first presented by Nielsen and Mach (1994) as a comprehensive and consistent way to usable design of interfaces across multiple domains. Usability heuristics are, as shown by e.g., Jimenez, Lozada and Rosas (2016), and Quiñones and Rusu (2017), extensively applied, and does not only consider separate elements of interfaces, but also overarching system consistency, resulting in interfaces that can be effectively used by target audiences. Table 9 shows the original usability heuristics as contributed by Nielsen and Mach:

Table 9: Usability heuristics (from Nielsen & Mach, 1994)

Heuristic	Description
Visibility of system status	The design should always keep users informed about what is going on, through appropriate feedback within a reasonable amount of time
Match between system and the real world	The design should speak the users' language. Use words, phrases, and concepts familiar to the user, rather than internal jargon. Follow real-world conventions, making information appear in a natural and logical order
User control and freedom	Users often perform actions by mistake. They need a clearly marked "emergency exit" to leave the unwanted action without having to go through an extended process
Consistency and standards	Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform and industry conventions
Error prevention	Good error messages are important, but the best designs carefully prevent problems from occurring in the first place. Either eliminate error-prone conditions, or check for them and present users with a confirmation option before they commit to the action
Recognition rather than recall	Minimize the user's memory load by making elements, actions, and options visible. The user should not have to remember information from one part of the interface to another. Information required to use the design (e.g., field labels or menu items) should be visible or easily retrievable when needed
Flexibility and efficiency of use	Shortcuts — hidden from novice users — may speed up the interaction for the expert user such that the design can cater to both inexperienced and experienced users. Allow users to tailor frequent actions
Aesthetic and minimalist design	Interfaces should not contain information that is irrelevant or rarely needed. Every extra unit of information in an interface competes with the relevant units of information and diminishes their relative visibility
Help users recognize, diagnose, and recover from errors	Error messages should be expressed in plain language (no error codes), precisely indicate the problem, and constructively suggest a solution
Help and documentation	It's best if the system doesn't need any additional explanation. However, it may be necessary to provide documentation to help users understand how to complete their tasks

In the research presented in this PhD dissertation, heuristic usability inspection was applied to the suggested interface changes for the framework's visual language that enables the distinction of physical and virtual elements. After the respondents' interview data had been transcribed and sorted into themes, all the suggestions under each theme were listed and compared to one another as well as to the full set of other suggestions for all other themes, to arrive at an extension where the distinction became consistent and usable for educators and developers.

3.6 Research ethics

Studies two and three presented in this PhD dissertation use mixed methods with human respondents and comply with the *System for Risk and compliance — Processing of personal data in research and student projects* at the University of Bergen (RETTE[55]). The focus group was documented and transcribed without referencing any individual, but rather constructs as recommended by the group. The Likert scale questionnaires completed on paper and did not collect any personal data making the respondents indistinguishable. The audio and video recordings from the semi-structured interviews in studies two and three are kept on an external hard drive. The respondents identified themselves by name, however, these were immediately substituted with respondent ID numbers in the transcriptions, and the section of the recording where the respondents state their name has been deleted, in accordance with RETTE. The video recordings were all made with the respondent camera turned off. All respondents participating in studies two and three signed consent forms.

The research presented in this dissertation was conducted under the RCN Industrial PhD program, in which the research is expected to involve roles working for the industrial partner. Participating respondents from relevant departments (exhibit design and development, and museum teaching and pedagogics) at the science centre were invited to volunteer for participation, rather than be told to do so as part of their work routine. This was done to ensure that no one would feel obliged to sign a consent form while they did not agree with some aspect of a process within the workshop itself, or during the interviews (i.e., they were not put in a position where they had to participate because a superior authority had told them participate as part of their paid position).

The participants in the focus groups in study 2 were peers, something which according to Oats (2006) allows them to openly contribute ideas and observations from a secure position. In the interview groups in study 2 and 3, however, there were hierarchical dependencies among participants, thus focus groups were discarded as possible method

[55] https://rette.app.uib.no/

for evaluation, since, as described by Oates (2006) work relation dependencies may inhibit respondents to share their opinions and create incentives to agree with someone's observations or suggestions based on who they are, not necessarily what they are saying. To further instil security in the respondents during the interviews, it was made clear that none of the individual responses in audio or transcribed form were to be shared or presented.

As is the norm for the Industrial PhD program, the candidate is employed formally by the industrial partner, in a shared workplace arrangement with formal supervision from a university. Since a main goal of the Industrial PhD program is to contribute research-based knowledge into the industrial partner's areas of expertise, whether being a process, a tool, or other form of special purpose knowledge or understanding, it is normal that much of the research, such as ethnographic oriented studies and methods, include participants working for the industrial partner in a relevant capacity. In the research presented herein, the science centre educators are representative of a future user of a co-design framework for mixed reality narrative game-based learning trails, and at the same time colleagues of the candidate conducting the research. The candidate conducting the research presented in this dissertation, however, was employed by the science centre with the sole purpose to conduct the research. Throughout the conduction of the PhD research the candidate did not work on any projects or activities with any of the respondents. The Industrial PhD funding was kept on a separate earmarked account — in accordance with the legislations from the Norwegian Research Council — and was as such not affecting any of the respondents or their departments in any hierarchical (vertical or horizontal) manner.

In their chapter on ethics in design science, Johannesson and Perjons (2014) discuss the public interest and quality of the resulting artefacts that are designed. A positive consequence of the research presented herein is a co-design framework, and future artefacts created by using the framework (in the form of mixed reality narrative game-based learning trails at science centres that optimize the potential for increased engagement, motivation, and learning) can be used for learning by school pupils visiting the science centre as part of formal school visits. When technology is introduced in learning situations, one may encounter democratic concerns related to availability. In the case herein this is partially mitigated since visits to science centres as part of formal learning are a cost-free right for Norwegian school children living in municipalities where science centres are established. Whereas pupils in other districts certainly also get funding to visit out-of-school learning venues such as museums and other experience centres (e.g., open farms or aquariums) it must be acknowledged that the beneficiaries of the research presented here in the immediate future will be in school districts where science centres are located. Public interest for the framework and the artefacts it can produce may be considered high, and access can be increased through policies to increase access to science centres, something which the Bergen Science Centre is actively pursuing through their Science Centre on Wheels mobile initiative to bring content to pupils in districts adjacent to Bergen. With regards to quality, Johannesson and Perjons are concerned with risk potential in safety critical situations, something that is not relevant here. The risk potential of designed systems not working is that educators and developers are inefficient in a session of co-design, or that a school class must use a paper-based substitute learning trail or activity, something that always exists. It is, however, the concern that artefacts created with the co-design framework can promote misinformation, should the learning content and descriptions not be quality assured well enough. The framework accounts for this by including a methodological preparation phase, in which the educators lean on their formalized resources concerning national learning plans, outcome descriptions from defined curricular materials for the educational level of the learner demographic, and the pace and timing of the practical visit. While the articles describing the framework are published and anyone can do what they want with it, they are greatly encouraged to work rigorously in the preparation phase, so they do not contribute to the increasing amount of misinformation and false facts in modern society.

All empirics, methods, results from the three studies have been published as open access, alongside detailed descriptions on how to facilitate and use the framework, and encouragements to use it. These contributions stand to not gain anyone, beyond hopefully a portfolio of future narrative learning games, inside and outside of science centres, that can engage and motivate coming generations in their exploration of STEAM subjects.

4. Results, findings, and contributions

In this chapter, the findings and contributions from the research described in this PhD dissertation are presented. To reach the main research objective of the research, three research questions were posed, each of which were explored in separate studies building on one another. These research questions are also reiterated and answered in this chapter.

4.1 Characteristics of narrative game-based learning systems with positive effects on engagement, motivation, and learning

To gain insight in empirically reported effects on engagement, motivation, and learning from narrative game-based learning systems a systematic literature evidence synthesis (Kitchenham & Charters, 2007) limited to evidence synthesis (Catalá-López, et al., 2017) was used to find peer reviewed evaluations of these factors. The initial database searches found 61 studies between 2009 and 2019, which were reduced to 40 after duplicate and false positive removal, and to 14 after the three rounds of inclusion criteria. In these 14 studies, 15 narrative learning games are described as one study involved two separate learning games. Subsequently, the 15 learning games were categorized using an extension the Ludo Narrative Variable Model (LNVM) (Aarseth, 2012), which is a narratological model that can be used to categorize all games as narratives, including games that are not narrative by nature. As explained in Article 1 (Breien & Wasson, 2021), two extensions were made to the LNVM to introduce terminological granularity and to distinguish between two different event structures in narrative games. Thus, the first contribution of this research is the extended Ludo Narrative Variable Model (eLNVM), which was subsequently used to categorize the 15 narrative learning games. The next sub section presents the eLNVM, before showing the categories and accompanying characteristics of the narrative learning games that exhibit positive effects to self-reported evaluations.

4.1.1 The extended Ludo Narrative Variable Model

The eLNVM, see table 10, is an ontological model with polar categories on the axis between high author agency, for which there is high freedom to narrate a story, but low freedom of choice for the game player to interactively alter the narrative, and high game agency, for which it is opposite.

Table 10: The extended Ludo Narrative Variable Model (eLNVM) (from Breien & Wasson, 2021)

Ontology **Polarity**	**World**	**Objects**	**Agents**	**Events**
Narrative pole	Inaccessible	Non-interactable	Deep, rich, round	Fully plotted
High author agency	Single room	Static, usable	Grounded, consistent	N/A
	Linear corridor	Modifiable	Sensible	Linear fixed kernels, dynamic satellites
	Multicursal labyrinth	Destructible	Flat	Interchangeable fixed kernels, dynamic or fixed satellites
High game agency	Hub shaped quest landscape	Creatable	Stereotypical	Dynamic kernels
Ludic (game) pole	Open landscape	Inventible	Bots, no individual identity	No kernels (pure game)

Games are categorized on the eLNVM by analysing their game mechanical and narratological principles through reading about them, watching descriptive videos, or playing the game, and pairing them to the right category consulting the categories' characteristics.

The eLNVM inherits the characteristics' descriptions from the original LNVM (Aarseth, 2012), and adds characteristics to extended categories. There are two extensions that differentiate the eLNVM from the LNVM. The first is based on the limited distinction of events in the LNVM. In the LNVM, events are defined as consisting of required kernel events, that must happen to define a particular story (e.g., Little Red Riding Hood heads towards grandmom's house), and satellite events, supplements that fill out the discourse (e.g., in the Grimm Brothers version[56] of Little Red Riding Hood, her mother instructs her to stay on the path, something that is not mentioned in Perrault's version[57] of the tale), but that is not required for making sense

[56] https://www.grimmstories.com/en/grimm_fairy-tales/little_red_cap
[57] https://sites.pitt.edu/~dash/perrault02.html

of the story. In the original model, events are distinguished in categories describing games that 1) applies fixed kernels and satellites, that is, all of them are experienced in the same sequence by everyone; a fully plotted story, 2) applies fixed kernels, but allows for dynamicity in content and experience of satellites, the supplementary discourse may be different between play sessions; a playable story, 3) applies kernels that are replacements for one another, or that is procedurally generated so that different play sessions may tell different stories; dynamic kernels, and 4) applies no kernels, and is as such not a narrative game; pure game. The LNVM, however, fails to distinguish between games that use fixed kernels and dynamic satellites in which the satellites are experienced in linear sequence, and games that use fixed kernels and dynamic satellites in which the satellites, while predefined, can be experienced in selective or otherwise non-linear sequences. The latter may be defined as encompassed by the term dynamic satellites, but if so, the challenge arises in distinguishing between games with predefined kernels experienceable in various sequences, and games that procedurally, or based on other player action, alters the content of the kernels themselves. The playable story was therefore split into two categories: 1) Linear fixed kernels, dynamic satellites, and 2) Interchangeable fixed kernels, dynamic or fixed satellites. Note the detail that the latter category also accounts for satellites that could be fixed inside kernels, while the former does not, since allowing for fixed satellites under that category would make it a fully plotted events game. The other is simply to include naming conventions to objects and agents categories, to simplify discourse.

A discussion of what differentiates the eLNVM from other narratological models that can be used to categorize games, such as act structure models (Aristotle, c. 335BC/1996; Freitag, 1886), monomythical models (Campbell, 1949), and ludology (e.g., Juul, 2011) is provided by Breien and Gkini (2021).

4.1.2 Characteristics of narrative game-based learning systems that exhibit positive effects on engagement, motivation, and learning

The 15 narrative game-based learning systems where categorized using the eLNVM and sorted based on their self-reported effects, before the categories showing the highest count and percentage of positive effect reports were isolated. This allowed identifying categories associated with positive effects. The identified categories were described by what characterized them before the characteristics were proposed as a design template for future systems that could be expected to incur similar positive effects. The characteristics of the positive effects categories are described in table 11.

Table 11: Characteristics of categories associated with positive effects (from Breien & Wasson, 2021)

Ontology	Category	Characteristics
World	Hubshaped quest landscape	Confined areas of the full world (hubs) that are explored at will, where reaching objectives in sequences (quests) open new hubs in the landscape and close others, depending on player choices
Objects	Modifiable	Objects in the world that may be altered, combined, or configured to overcome challenges and reach objectives
Agents	Grounded and consistent	Characters in the game narrative with sensible and well described backgrounds, psychologies, and goals
Events	Linear fixed kernels, dynamic or fixed satellites or Dynamic Kernels	Storyline events of high importance that are either pre-written and interchangeable among each other, allowing for traversing a story in different ways, or that are dynamically written by the system, allowing for development of new stories based on player choices

This work enables an answer to the first research question:

> RQ1: *What characterizes narrative digital game-based learning systems that positively affect engagement, motivation, and learning?*

The eLNVM (Article 1, Breien & Wasson, 2021) recommends designing future narrative game-based learning systems around Hubshaped quest landscape Worlds, Modifiable (or higher game agency) Objects, Grounded and consistent (or higher author agency) Agents, and Linear fixed kernels, dynamic or fixed satellites, or Dynamic kernels Events.

4.2 A co-design framework for narrative game-based learning

The characteristics uncovered to incur the positive effects reported in Article 1 (Breien & Wasson, 2021) were applied in a four iteration DBR process of a co-design framework for narrative game-based learning. Twenty evaluators with backgrounds from technology enhanced learning research, high-school teaching, university college pedagogics, science centre teaching, and serious game development partook. This subchapter, summarises the research from the second study (Article 2, Breien & Wasson, 2022) and answers the second research question:

> RQ2: *How can a co-design framework empower educators and developers in the creation of narrative game-based learning that is based on characteristics that positively affect engagement, motivation, and learning?*

4.2.1 Iteration 1: The explanatory focus group (Design proposal)

In the first iteration the researcher first consulted the characteristics and proposed tentative design principles in form of a method accompanied by a visual language, a group of researchers in the field of technology enhanced learning completed a co-design session. After completing the session, they partook in an explanatory focus group aimed at improving the design principles and making them usable by educators and developers. The results from the session were debriefed via email. The focus group produced seven concrete changes to the design principle, and confirmed that provided these changes were made, they believed it would be usable for the stakeholders.

4.2.2 Iteration 2: Questionnaire about terminology and sequence (Global design)

The second iteration included the researchers constructing specified design principles making alterations to the method and the visual language based on the focus group input. The specified design principles were evaluated for understandability of the terminology and sequence of work conduction during concrete co-design sessions that was evaluated by high-school educators and game developers using a four question 5-point Likert scale questionnaire. The respondents exhibited high understanding of the terminology, albeit less so for the categories' descriptions (avg. 3.86) than those of the ontologies (avg. 4.43) and the characteristics (avg. 4.14). As consequence, the workshop instructions were altered to increased focus on using terminology from the ontologies and characteristics in place of terminology referring to the categories (e.g., referring to 'a place in the world', rather than 'a hub', or 'prewritten events' instead of 'fixed kernels'). The agreement to the sequence of work scored high among the evaluators (avg. 4.43), and no change was made to that part of the method.

4.2.3 Iteration 3: Participants interviews (Partly detailed product)

The third iteration evaluated the experiences from using the framework, in which participants with background from science centre teaching and development, university college pedagogics, and game developers made suggestions for improving it. After completing workshops, participants underwent semi-structured interviews which were transcribed as running number references, sorted into themes, and analysed.

All in all, there were 218 references sorted into 9 themes. Most of the comments were related to the ontologies and their characteristics (69) and suggested improvements to the method (66). The themed suggestions were analysed and resulted in a full restructure of the design principle for the framework.

4.2.4 Iteration 4: Full framework test, and prototyping (Completed product)

After the third iteration, eLuna had become a framework as described in detail in Article 2 (Breien & Wasson, 2022). To properly test whether the eLuna Framework was usable for participants to co-design narrative game-based learning systems based on the characteristics associated with positive effects, a fourth iteration was conducted in which one educator and two developers used the full framework to create the Idun's Apples prototype, which was subsequently categorized on the eLNVM, confirming its categorization to conform with those targeted by the framework. Idun's Apples is a game about sustainability, in which players take the role of Idun, a young lady who initiates the founding of a farmers' market in her local neighbourhood.

4.2.5 The eLuna Framework for narrative game-based learning

The research results from study two, the eLuna Framework, is the second contribution of this research. The eLuna Framework is a co-design framework that allows educators and developers to co-design, supported by a visual language, narrative game-based learning that conforms to characteristics that has been empirically shown to positively affect engagement, motivation, and learning. Figure 9 shows the eLuna Framework (Breien & Wasson, 2022).

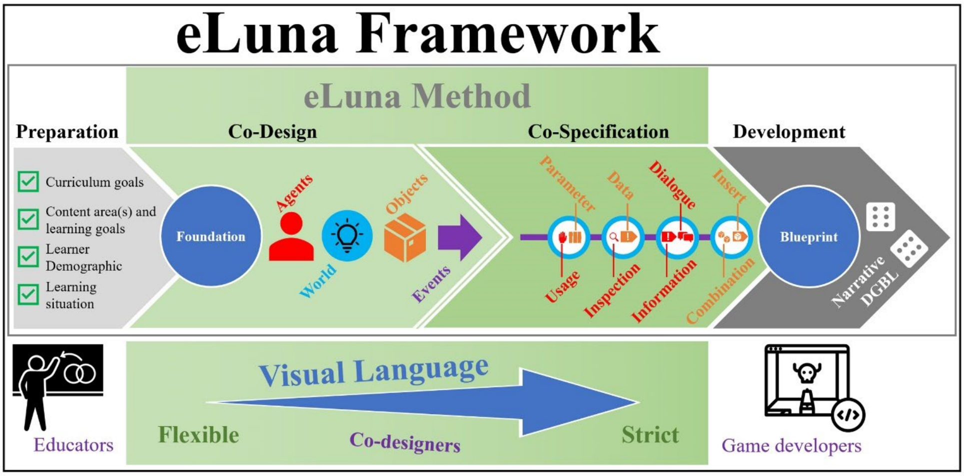

Figure 9: The eLuna Framework (from Breien & Wasson, 2022)

As an answer to RQ2, the eLuna Framework comprises four phases, of which the middle two constitute the eLuna Method. In the preparation phase, educators alone identify curricular goals, content area(s) and learning goals, learner demographics, and learning situation. This becomes the foundation for the two-phase eLuna method of co-design and co-specification. In the co-design, educators and developers co-design the narrative learning game using a flexible annotation form of a visual language to map out the world, objects, agents, and events of the system. In the co-specification, they apply the visual language in a stricter and assessed manner, to co-specify a blueprint schematic of the narrative learning game that can be realized by developers. In the fourth and final phase, development, the narrative game is developed.

Auxiliary results, derived by applying the eLuna Framework, are seven narrative game-based learning system co-designs, one of which was developed into a prototype. Two of the seven co-designs concerned education targeted at a higher education audience, and five targeted high-school level education, three of them visualized used in at-school education, and the remaining two as learning programs at a science centre. The seven co-designs are described in Article 2 (Breien & Wasson, 2022).

4.3 The eLuna visual language mixed reality extension

To extend the capabilities of the eLuna Framework to distinguish physical from virtual elements and thus becoming usable for co-design in mixed reality learning trail environments, the visualization components were revisited in a new co-design experiment in which two groups of three science centre teachers and developers[58] co-designed two narrative game-based learning trails for use with a selected set of exhibits at a science centre. The co-designs were subsequently evaluated by the participants during semi-structured interviews challenging them to observe visual elements in the framework where it was important to distinguish physical from virtual elements, and to propose solutions as to how this visualization could be done. This third and final study of the PhD research, reported in Article 3 (Breien, et al., 2022) answers the third research question:

> RQ3: *How can a co-design framework for narrative game-based learning distinguish the physical from the virtual in mixed reality learning trails?*

In this third study, the partly detailed product (from iteration 3) was revisited, keeping the terminology, sequence, and phases of the eLuna Framework, but investigating how to distinguish between physical and virtual hubs, objects, tasks, agents, and events. The research applied thematic analysis based on respondents semi-structured interviews. Interviewees made a total of 36 identifications of required changes to support distinction, which were reduced to eight themes grouping identifications that were the same. To the eight themes, 47 extension suggestions were made. The 47 extension suggestions underwent heuristic usability inspection and resulted in one extension being chosen for each theme, resulting in the eLuna Framework Mixed Reality Visual Language extension, a pluggable component to the eLuna Framework that can be used in mixed reality learning trail development. Thus, eLuna Mixed Reality Visual

[58] Two serious game developers that were intended to participate in the co-design sessions, were constricted from doing so due to COVID-19 cohort, group size, and distance restrictions, them being external to the science centre organization, this was not possible. At the time (fall 2021) it was uncertain how long mandates would remain in Norway and how strict these would be. It was considered too high a risk to the PhD progress to postpone the sessions, something that in hindsight turned out to be a wise decision, given that the restrictions increased a while after the sessions to the extent of which no sessions could have been completed at all.

Language extension, the third contribution of this research (presented in Article 3; Breien, et al., 2022), is the answer to RQ3.

Auxiliary results from study three are two co-designs for multidisciplinary eLuna trails intended to be used with the Bergen Science Centre Loop exhibition, which has learning goals related to the topics of biodiversity, and democracy and citizenship.

5. Discussion

The research presented in this PhD dissertation contributes the eLuna Framework, a co-design method accompanied by a visual language that empowers educators and developers to design and specify mixed reality narrative game-based learning trails based on characteristics that has been empirically shown to induce positive effects on engagement, motivation, and learning.

The contribution can be divided into three parts:

1. a theoretical contribution, the eLNVM narratological model for categorizing games as narratives,
2. a methodological contribution, the eLuna method co-design and co-specification phases, supported by the preparation and development phases, that are useable for educators and developers to co-design game-based learning, and
3. a practical contribution,
    a. the eLuna visual language, which allows participants to describe the learning games in detail, without requiring technical knowledge, and
    b. an extension to the eLuna visual language that supports distinction of physical and virtual elements, allowing for the use of eLuna to develop mixed reality game-based learning as well as fully physical game-based learning.

The goal of the PhD research presented in this dissertation was to contribute a co-design framework for mixed reality narrative game-based learning trails that enforces positive effects on engagement, motivation, and learning. This has been realized in the eLuna Framework with the mixed reality extension. The eLuna Framework builds on and extends research by Kahr-Højland (2011) and Hauan (2017). Kahr-Højland (2011) define learning trails as effective to focus learning, by mitigating several distractive factors in science centre learning environments and shows that learning trails can be effectively centred around the museum exhibits, the students, and mobile devices on which the students carry a virtual story that ties the exhibits together in a narrative whole. Hauan (2017) showed how games, narratives, and the learners are the key factors to promote flow and engagement in learning trails (termed embedded learning environments).

Kahr-Højland and Hauan showed that learning trails focused on games and stories that use the exhibits as active elements of the students' learning environment promote flow and engagement and help focuses the student's attention on exhibit completion. Neither of them provided descriptions on how the narrative games should be designed and specified, something which a large research community sees as a requirement to capitalize on the entertaining properties of games, while emphasizing the learning goals and objectives. Thus several calls for proper co-design frameworks for all game-based learning has been made (e.g., Silva, 2020; Marchiori et al., 2011; Arnab et al., 2015; Lameras et al., 2017; Carvalho et al., 2015).

A prerequisite for the development of the eLuna Framework has been an understanding of what characteristics of narrative learning games positively affect engagement, motivation, and learning. To this effect, the LNVM (Aarseth, 2012) was extended and subsequently used to categorize learning games, before sorting them based on their self-reported effects, and inspecting what characteristics were associated with which effects. The eLNVM contributes a model for narrative games and increases the expressive power in both design and analysis of narrative games from what has been offered by traditional narrative theory (Aristotle, c. 335BC/1996; Freitag, 1886; Campbell, 1949). The research presented in this dissertation takes a position in the ludologist vs. narratologist debate (e.g., Pearce, 2005) — a debate claimed to have never happened (Frasca, 2003) — by defining a game as a dominant narrative media that requires their own models to inspect, analyse, and design in accordance with a narrative theory for games (Aarseth, 2012). The eLNVM answers calls to define what narratives are in games (e.g., Armstrong and Landers, 2017), and has been placed in context of its descriptive power both in terms of traditional media, and non-games that are still ludological systems (Breien and Gkini, 2021). As such, even if the eLNVM assumes that all games can be described as narratives — even in the cases where they are not — it is in narratological terms not in conflict with ludology. Albeit ludologists may claim that many eLNVM games are not narratives, even if the characterization of the games on the eLNVM will claim that they are. The reasoning for this is speculated upon by Simons (2007), but which is arguably not so relevant here, since the game is still the game, and the important issue is whether, how and why it reaches its intended effects. Procedural authorship (Murray, 1997), procedural rhetoric (Bogost, 2007) and emergent narrative games (Aarseth, 2004; 2012) can also be categorized using the eLNVM, albeit as a pure game with no story. Game systems that generate kernels are covered as another category on the eLNVM, but even that assumes that there is a logical structure in place that is intended to present a narrative with kernels, something which is not the case when one starts playing a game of chess, or when someone strikes a troll-in-a-box in a carnival attraction, even if one might spin a story about it in hindsight. The eLNVM can also be used to categorize non-game narratives, such as books or movies, but those would always consist of the model's non-interactive categories, which only leaves the agents ontology flexible, something which leads to speculation as to whether it is not then better to use models to describe characters in literature or other media rather than the eLNVM.

Research has shown that engagement in game-based learning, and thereunder mixed reality narrative game-based learning trails, does not necessarily imply good learning, 1) since narrative games used in learning trails can impose excessive cognitive loads on learners and thus deteriorate the learning (Novak, 2015; Zhonggen, 2018; Ullah, et. al., 2022), 2) lacing empowerment of educators or game developers in design processes may lead to fun experiences that do not emphasise learning (e.g., Marchiori et al., 2011; Silva, 2020), or, 3) drill and practice exercises that fails to capitalize on the entertaining elements in games (e.g., Van Eck, 2006; Qian and Clark (2016); Carvalho et al., 2015). Thus, several calls have been made in research on the science of game-based learning in general (e.g., Sawyer, 2005; Van Eck, 2006; Van Eck, 2015; Rushby, 2012; Connolly at. al., 2012; Wouters et. al., 2013; Iten and Petko, 2014) and in narrative learning games in particular (Armstrong and Landers, 2017; Novak, 2015; Iten and Petko, 2014) to further explore how and under what conditions game elements, such as narratives, affects learning. The eLuna Framework addresses this call with particular focus on the central game element of narratives and provides a co-design framework that enforces narrative game characteristics that positively affect engagement, motivation, and learning. The eLuna Framework is particularly targeted at leveraging the elements that are most important in science centre learning trails and bases itself on narrative game characteristics that have been shown to positively affect engagement, motivation, and learning.

As shown in the background Chapter 2, the LNVM (Aarseth, 2012) can be used to categorize serious games and COTS games. Serious games and COTS games can also be categorized using the eLNVM, since it only adds a further distinction of events categories as well as naming conventions for objects and agents to the original, retaining all its properties as an ontological narratological model. The eLuna Framework is based on a set of characteristics of categories on the eLNVM that has been empirically shown to positively affect engagement, motivation, and learning. Many entertainment games (such as Star Wars: Knights of the Old Republic[59] and Monkey Island[60], to reference some very well-known classics) and learning games (such as Crystal Island[61] and CircularIO[62]) adhere to the categories emphasised in the eLuna Framework, and the eLuna visual language can be used to describe such games in detail. The eLuna Framework is usable to co-design serious games. While the eLuna Framework technically can be used to co-design COTS games, even ones not intended to be used for learning, it is not recommended since eLuna takes learning into account. Learning is not necessarily the main focus, or a focus at all, in development of commercial entertainment games, and while such a game developed with eLuna will be functional, and as the examples above show, potentially very successful, there may be other considerations in the entertainment industry that would weight design decisions towards other categories on the eLNVM than the ones targeted by eLuna. These are categories that may engage and motivate just as much as eLuna games, and lead to reaching market objectives. Moreover, the eLuna Framework implies co-design involving educators. Whereas entertainment game design can profit from involving subject matter experts from outside of game development (the game SPORE[63]

[59] https://en.wikipedia.org/wiki/Star_Wars:_Knights_of_the_Old_Republic
[60] https://en.wikipedia.org/wiki/Monkey_Island
[61] https://projects.intellimedia.ncsu.edu/crystalisland/about/
[62] https://www.hvl.no/studier/studieprogram/Digital-kompetanse-for-renovasjonsbransjen/
[63] https://en.wikipedia.org/wiki/Spore_(2008_video_game)

extensively involved biologists in game design, and the Hitman[64] series employed full time architects to help design the environments), one would be hard pressed to argue that educators are particularly important participants, and no research has been done to evaluate eLuna usefulness if transferred to support other external roles in co-design of games. The eLNVM and the eLuna Framework does not function to categorize or co-design gamification, since gamification does not always include elements relating to all ontologies on the eLNVM; if they did, one may argue that what is categorized or designed is not gamification, but a game. Table 12 shows what categories in game-based learning that can be categorized using the eLNVM, as well as how they may be co-designed using the eLuna Framework.

Table 12: Game-based learning categorization on the eLNVM and co-design using eLuna

Game-based learning category	Can be categorized using the eLNVM	Can be co-designed using the eLuna Framework
Serious game	Yes	Yes
COTS game	Yes	Yes, however, other categories may be applicable to engage and motivate play, and other parameters may be relevant that conform to other categories
Gamification	No	No

While the calls for more research as shown above is extensive, much research has still been conducted on what aspects of games intended for learning and otherwise that engage students/players and motivate learning. As shown in the background chapter of this dissertation, literature reviews on learning game effects on engagement and motivation since the early 2000s provide several detailed observations and recommendations of game-based elements that positively affect the parameters. As

[64] https://en.wikipedia.org/wiki/Hitman_(franchise)

eLuna is a structural system for a game, and does not dictate gameplay mechanisms, modalities used, sensory fidelity, or output platform nor presentation, much of this research could be leveraged to further augment the effects that come from eLuna games. The eLNVM and eLuna extends the work of Connolly at. al. (2012) on game genres, in which the eLNVM could be used to identify effects from game genres, that can be linked to categories on the model, and eLuna itself and the learning games that comes from using it could be targeted at genres that they represent, building on positive effects associated with the genre. Wouters et. al. (2013) show that learners learn more from games as supplementary material to, or when supplemented by, other instructional methods. This suggest that the relationship to a larger learning environment should be taken into account in the phases of eLuna co-design, something which is accommodated for in the preparation phase where the learning situation is described and in the visual language, that allows for connection to external learning resources and assessments when events occur. Whereas Bellotti et. al. (2013) finds learning games to be cost effective in acquisition of knowledge and skills, games are, as pointed out by Clark (2007) expensive to produce. After developing the Idun's Apples prototype in the second study presented in this dissertation (Breien & Wasson, 2021), both participating game developers commented that the coding work was substantially diminished compared to previous projects on which they had worked. Whereas the focus of the study was not on coding efficiency, and the time spent on the activity was not tracked rigorously enough to compare it to historic data, the comments may indicate that eLuna games, possibly due to their visual language blueprint structure, effectivise programming activities during the development phase. The eLNVM and the eLuna Framework addresses two prerequisites for assessment of effects in games posed by Bellotti, et. al., (2013): 1) better characterization of players' activities, tasks, and profiles using the eLNVM to categorize them as was done in Breien and Wasson (2021), and 2) better integration of assessment structures in the games themselves, provided by the trigger for learning tasks, and the storing of learning analytics data as offered by eLuna events. Bellotti et. al. (2013) further points to practical aspects of learning games with positive effects which could be accommodated for in eLuna games, such as use of visual stimulus for favourable knowledge acquisition and retention. This is resonated by Laamarti et. al. (2014) showing how repeated visual feedback, music, and haptic feedback can be a success factor in serious games. While the findings by Laamarti et. al. (2014) related to serious games used for training, which the authors classify as another application area from learning, they may still incur similar positive effects in serious games for learning and may be leveraged in eLuna games. eLuna games can employ all forms of visual styles (including lower fidelity ones, which by Landers, Armstrong, and Collmus (2017) are shown to sometimes be advantageous), provide any form of music and audio signalling (for example on completing tasks and triggering events), and accommodate any form of interaction, physical or virtual, including haptic and force-feedback devices. Landers, Armstrong, and Collmus (2017) shows improved presence through realistic and relevant representation, which may be confirmed by the findings in Breien and Wasson (2021), that showed high author agency agents as a positive effects category in learning games.

In entertainment game research, one finds thorough research that has led to GameFlow (Sweetser and Wyeth, 2005), models for player types, such as the BrainHex model (Nacke, et. al., 2014), and award systems (Cruz et. al., 2017). While viewing GameFlow as something that engages students in learning content should be treated with caution since engagement in entertainment may not enforce learning content, it still provides an excellent staring point to show what engages players in games. GameFlow can be combined with eLuna to assure that proper focus is placed on the learning objective throughout the game. Player types may be harder to accommodate in a learning game than in an entertainment game — since the latter can target a player type demographic in their business development and make a profit serving that audience with a good product — as the learning game must target a demographic of learners that most likely comprises a wide range of player types. A science centre learning trail, for example, typically targets national or local learning curriculum and learning outcome descriptions for a particular age range of students, such as upper elementary or junior high school. This is a broad range demographic stratum of all boys and girls between the ages of 13 and 16 participating formally in school programs, something which leaves little option for targeting player types, since it is probable that learning trail users in such instances would be spread across all player types. Research on which game elements that makes particular player types enjoy games structures could still be capitalized on in eLuna designs. Iten and Petko (2014) showed that it is not primarily anticipation of having fun, but to learn effectively that influences the intent to use serious games, and it is therefore possible that learners may have beneficial gain from learning games, even if a particular game does not exactly match the player type of a particular learner. Some learning games are targeted at narrow demographics, and others will be supplementary to other learning, and thereby successful even if they only engage a portion of the learner mass, which may sometimes be overrepresented by a particular player type, and could then be targeted. Whereas eLuna addresses characteristics that are associated with positive effects, these characteristics are structural in nature, and do not say anything about 1) the pacing of the experience when a task is completed by pairing objects and/or agents, 2) what mental or motoric challenge is presented to the player when conducting the task, 3) what audio-visual elements are used as signalling in the environment, 4) what sort of media is applied to present the story's kernels, or 5) what interaction devices are used to interact with the game. As a simple example, consider an eLuna task in which a key is combined with a lock (modifiable object) and a door is opened by an agent, revealing a new task in a quest, and perhaps a new hub that may introduce new agents and objects, as well as mediate narrative content. The placing of the key in the lock could be performed with a game controller in a console style reaction game, where the agent must navigate obstacles to place the key in the lock at just the right time, resembling games such as Tomb Raider[65] and catering to daredevil player types. Another way would be as in the game Assemble With Care[66], in which the intricacies of the lock must be explored before task completion, catering to mastermind player types. The eLuna Framework is tied to structures of a narrative game and does not hinder eLuna developed games to target the full range of player types.

Research has shown that award systems, while being extrinsic reinforcers, intrinsically motivate and engage play of games (Cruz et. al., 2017; Wang and Sun, 2011). Often associated with gamification, reward systems are also prolific in games, from the

[65] https://en.wikipedia.org/wiki/Tomb_Raider
[66] https://en.wikipedia.org/wiki/Assemble_with_Care

straightforward accumulation of some currency such as coins in Super Mario[67], to achievement systems[68] that have become industry standard in game publishing — something that has become mandatory for games distributed on the Sony PlayStation and Microsoft Xbox platforms — across games. Since award systems are reported to enforce intrinsic motivation, which again is central in Malone's instruction theory Malone (1981), award systems may have positive effects on learning in games. A game developed using eLuna can include reward systems of any form, something which may be advisable for eLuna games as well as other learning games in the future.

5.1 The eLuna Framework in practical application

At the time of writing, practical work on the eLuna Framework is ongoing, with two science centre teachers and two developers, all with eLuna experience, co-designing and co-specifying a narrative game-based learning trail based on the Loop exhibition at VilVite to create a blueprint and a prototype mimicking the Idun's Apples process from study 2 using the mixed reality visual language. The Bergen Science Centre VilVite is also integrating the eLuna Framework in the development plans for their next main exhibition project. Alongside the nine co-designs presented scientifically in studies 2 and 3, the eLuna Framework has also been used in several research and development projects in learning sectors. It is the basis for learning games used in the Wester Norwegian University of Applied Sciences[69] and the University of Bergen Centre for the Science and Technology (SLATE)[70] after education program in digital competencies of the Norwegian public renovation sector[71], a workshop has been held with the Norwegian Labour and Welfare Administration (NAV)[72] to investigate whether narrative learning games could motivate job application processes. Furthermore, the eLuna Framework is currently being used as foundation to co-design a narrative game about cyber security targeted at increasing awareness internally and/or

[67] https://en.wikipedia.org/wiki/Super_Mario
[68] https://en.wikipedia.org/wiki/Achievement_(video_games)
[69] https://www.hvl.no/en/
[70] https://slate.uib.no/
[71] https://www.hvl.no/digitalgjenvinning/ (retrieved 15.12.2022)
[72] https://www.nav.no/en/home

externally at the Norwegian Petroleum Directorate (NPD)[73], through the Norwegian Computing Centre's[74] ASCERT project[75]. eLuna is also used in the co-design of a learning game targeted at high-school climate model literacy, by the Bjerknes Centre for Climate Research[76].

5.2 Validity and limitations

Validity in qualitative research, as described by e.g., Whittemore, et. al. (2001) refers to how the results from the data analysis based on respondent participation represent findings among similar individuals that did not participate. Concerns about validity does not only include whether respondents are representative of a group of relevance for the research, but also limitations based on group selection and backgrounds, since, for example, selecting respondents from the same place of work may influence the results based on cultural factors in the workplace, and thus not necessarily be directly transferred to similar individuals in other workplaces.

In the first study, the empirical data was collected through a systematic literature review (Kitchenham & Charters, 2007) limited to rapid evidence synthesis (Charters, Catalá-López, et al., 2017) using a very strict search string and inclusion criteria resulting in a tightly clustered validity result consisting of empirical articles that both described narrative game-based learning systems in sufficient detail, and self-reported empirical results from the systems effects on learner engagement, motivation, and learning. The strictness of the initial search enabled making such an extensive study inside the time of a PhD timeframe, with limited PhD resources. However, it is also a limitation since it can be expected that there are studies that would have otherwise met the inclusion criteria if they had been obtained in the first search. A recommendation for further work is to broaden the search string parameters, obtain a larger dataset, and repeat the process, which is well described and repeatable from the first study. This may inform on eLNVM category effects for which there is little data in the current study,

[73] https://www.npd.no/en/
[74] https://nr.no/
[75] https://nr.no/prosjekter/ai-drevet-ovelsesplanlegging-for-cybersikkerhetstrening/
[76] https://bjerknes.uib.no/en

granularize the findings for other categories and generate new insight on details of effects, provide information about other categorical combinations that report positive effect, and finally uncover contradictions in the current finding by, for example, observing systems that follow the categories obtained herein, but that do not report the same effects.

The second and third studies used mixed methods consisting of a focus group, a questionnaire, and two interviews. The respondents were high school teachers, learning game developers, and science centre teachers. While the validity in the respondent groups is high, as

1. the teachers work full time teaching to the main learner demographic, following the same learning plans and goal descriptions as the science centre,
2. the learning game developers have extensive experience both with developing learning games for the main learner demographic, and concretely for use in science centre's exhibits, exhibitions, and learning trails and programs, and
3. the science centre teachers work directly to specify and implement learning trails and programs inside the formal teaching to the main learner demographic,

all respondent groups come from limited samples. The science centre teachers all work at the Bergen Science Centre, the teachers were all recruited from the same local school, and the learning game developers all worked at the same company. There may be cultural traditions, technological dependencies, and/or internal process related matters in individual organizations that may not be the same when replicated on the outside.

For the high-school teachers, the results showed very high understanding of the terminology used in the co-design workshops. One explanation for these results is that the terminology used is well described and presented, and that it is easy to understand for high-school teachers. Another explanation may be an unknown cultural dependency at their workplace, that for some other reason than them being high-school teachers make then more susceptible to understand such scientifically theoretical terms that is applied when using the eLuna Framework. One can to a certain extent say the same for the game developers, who also exhibited high understanding of the same terms, even higher than the high-school teachers. This was more expected, though, since the terminology itself stems from sources such as the LNVM, and ergodic narratology, which describe game structures that at a higher level than normal should be familiar to someone that works professionally in game development. It would be advisable to present the co-design workshop to many more teachers, and to a certain extent learning game developers as well, to broaden the knowledge base about how well participants understand the eLuna terminology, and alter the use, description, and presentation of it according to findings. While the results from the second study indicates that participants will understand the terminology, it is important to be aware of that they actually may not, and thus rigorously assess participants terminological understanding as preparation ahead of workshops, for misunderstandings and misconceptions to be addressed, so as not to negatively affect or influence the results from the framework phases.

The learning game development community in Bergen is small, and when it comes to finding a company in the region that works only with learning games, and that has worked to deliver learning games to science centres, the number is reduced to one. All learning game developers in study two and three work for this company. Whereas they are the most valid representatives for the development role that is required by the eLuna Framework available locally, similar cultural dependencies as discussed above may not only have affected their level of terminological understanding, but also other parts of the research, during the interviews, when, for example, discussing the shape or colour of a particular element in the visual language, the sequence of work during the co-design workshops, or a clarification regarding some part of the presentation material used. Cultural aspects of the workplace may also come into play during workshops, which may have affected them in one way or another. Additionally, coming from the same employer, the learning game developers can be expected to have technological and process dependencies that they bring with them from the routines and structures that they are familiar with, and tools, frameworks, and methods that are prominent in their daily work. The company in question is an SMB, and uses one of the two most used integrated development environments in the game development business, and employs typical lean business and agile development processes that are prolific within technology and game development in the segment, so the differences are not likely great; still, there are variants, and always the chance that the particular company that participated here in some relevant aspect or domain is an outlier, that somehow affects the results and thus the eLuna Framework on a whole. The eLuna Framework phases and visual language should as such be evaluated by other professional learning game developers, of which there are some in Norway, and several more in Scandinavia, without geography having to be a constraint. All the required framework and visual language descriptions, workshop conduction protocols, and the methodological descriptions for evaluations are available in the extended abstract and the published articles to replicate the studies.

Similarly, the participating science centre teachers all work at the same science centre. As opposed to the development company, which is a for-profit corporation, the Bergen Science Centre is a non-profit corporation with a mandate to contribute to learning and understanding during school visits, and where all the income is invested back into providing and improving the service. The sharing and collaboration culture among science centres is strong, their regional association networks are active, and they meet, discuss, and contribute to one another practically and methodologically from national to international arenas that would otherwise be contradictory to business strategies in effect in commercial companies. One should, however, not underestimate that the practical application and follow up of processes, and use of software or tools may vary between centres. The cultural dependencies may be even stronger between individual science centres than among learning game developers. Learning game developers are specialized game developers, but otherwise apply much of the same skills and competencies as entertainment game developers. Game development overall employs more people in Norway than science centres do, and moreover, they are more distributed across the country; most will have peers within reasonable distance to create a culture and a community of practice. Furthermore, science centres focus on different exhibition subject matters and specialize over time. This leads to a larger divergence especially among content expertise and production employee roles, where one science centre is strong on wind turbines and gravitation, (often employing masters or PhDs in related areas), another is best on mammal digestive systems and soil bacteria, (and have similar employees from such backgrounds). Finally, science centres vary their use of elements and technologies in the exhibits themselves. Some will be very analogue and physical, gravitating towards physical logics puzzles, visual illusions, and analogue experiments, while others will be high technological in their exhibit design basis, showcasing sensors, data transfer and accumulation, visualization techniques and tangible interfaces, wearable and augmented devices, and so on, as an element in its own right, alongside the content of the exhibits and the subject matters of the exhibitions. While the eLuna Framework is constructed to support both physical and virtual elements, and to support learning goals of any subject matter through narrative gameplay, further study may reveal strengths and shortcomings with the framework under certain circumstances or combinations of them which has not been revealed. This is in addition to the argumentation already presented with regards to the learning game developers. As for with the game developers, all material and assets required for replication is presented in the extended abstract and the articles, and ready for replication as a new design-based research iteration.

6. Conclusion

The research presented in this dissertation is founded in information science with application in museum sciences and game studies. Finding a lack of a common narratological model to properly categorize games as narratives, the research contributes the extended Ludo Narrative Variable Model (eLNVM), that can be used to categorize all games as narratives. It also contributes the eLuna co-design Framework for narrative game-based learning and the eLuna Mixed Reality Visual Language extension for educator and developer co-design of narrative game-based science centre learning trails. Such learning trails focus on narratives and games in embedded learning environments comprised of physical world (exhibit) and virtual (digital companions) elements. The eLuna framework has practical application for educators, game-developers, and museum and science centre staff, and may also be used for designing fully virtual or fully physical settings, such as in the co-design of digital game-based learning and physical exercises conducted for example in military training. The eLuna Framework is based on characteristics of narrative learning games that enforce positive effects on engagement, motivation, and learning. The characteristics of the eLuna Framework were identified through a literature review and the framework itself was developed through two iterative design-based research studies using mixed methods inside an information science research framework. As part of the research, nine co-designs were completed.

The main objective of the research presented in this dissertation was *to develop a co-design framework for mixed reality narrative game-based learning trails that enforce positive effects on engagement, motivation, and learning*. This work was divided into three studies, each published in an article (see Part II).

The objective of the first study was to explore *what characterizes narrative digital game-based learning systems that positively affect engagement, motivation, and learning*. Since initial research revealed that there was no common model for categorization of games as narratives in the research field on game-based learning, and that individual studies for this reason applied different models, or none, the Ludo

Narrative Variable Model (LNVM) was extended to the eLNVM, and 15 narrative learning games were categorized on it. Organizing the studies based on their self-reported effects and their categories revealed that learning games categorizing as *hub shaped quest landscape worlds*, in which *interchangeable fixed kernel events* are triggered by *grounded and consistent agents* using *modifiable objects*, induce positive effects on engagement, motivation, and learning.

The second study, comprised design-based research using the Information Science Research Framework (ISRF) and mixed methods, was designed to uncover *how a co-design framework can empower educators and developers in the creation of narrative game-based learning that is based on characteristics that positively affect engagement, motivation, and learning*. The eLuna Framework that comprises a four-phase method and a visual language to prepare, co-design, co-specify, and develop digital game-based learning, was iteratively co-designed, and evaluated by educators and game developers. The framework is based on the characteristics of the eLNVM ontological categories that were shown to induce positive effects on engagement, motivation, and learning. Seven co-designs were produced, one of which was developed into a prototype. The research presented in Article 2 shows that the eLuna Framework is usable by and empowers educators and game developers to co-design game-based learning. Furthermore, inspection of the prototype confirms that learning games developed using the eLuna Framework conforms to the characteristics of the intended categories that induce positive effects.

Since the overall objective of the research presented in this dissertation was to contribute a co-design framework for mixed reality narrative game-based learning trails, a third study to complete the research was conducted to find out *how a co-design framework for narrative game-based learning can distinguish the physical from the virtual in mixed reality learning trails*. An iteration of the final phase of design-based research was conducted in which educators and game developers co-designed two narrative game-based learning trails comprising physical and virtual elements using the eLuna Framework, where, during co-design, no distinction between physical and virtual was made. Consulting their own eLuna visual language designs using an online mock-up tool, participating educators and game developers proposed extensions to the visual language icons and shapes, to accommodate for effective distinction between physical and virtual elements. Using deductive and semantic thematic analysis, and heuristic usability inspection, a full extension to the eLuna visual language is contributed, based on shape forms and positive/negative outlines as effective to distinguish physical from virtual in mixed reality narrative game-based learning trails co-design.

Based on characteristics that are shown to induce positive effects on engagement, motivation, and learning, providing a method and a visual language that is usable by, and empowers educators and game developers to prepare, co-design, co-specify, and develop mixed reality narrative game-based learning trails, the eLuna Framework fulfils the main objective of the research presented in this dissertation.

6.1 Limitations and further study

While the eLNVM was able to identify characteristics that positively affect engagement, motivation, and learning, and the eLuna Framework reaches the objectives of the research presented in this dissertation, there are still several limitations to the scope and focus of the studies, and the results that has been shown has, as hoped for in research, spurred many new questions. These limitations and suggestions for further study is presented here.

The extended Ludo Narrative Variable Model (eLNVM) (Breien & Wasson, 2021) provides terminological granularity to the objects and agents ontologies and differentiates between presenting prewritten events (fixed kernels) in a predefined (linear) or user initiated (interchangeable) manner. Whereas these extensions were made to increase the detail of games that could be categorized inside narrative game-based learning, the contribution is also applicable for all game studies, also focused on commercial, entertainment, cultural, and other phenomenon. A call is made to the broad games research community to explore if the eLNVM can properly categorize all games as narratives, or if further refinement to the model is required. Breien and Gkini

(2021) show how the eLNVM can be used to determine narratological models for all narrative games since it can categorize games that are not narratives, alongside games that are both linear and non-linear in their storytelling mechanisms. The research presented here categorizes a total of 16 games using the eLNVM (15 studies in Article 1, and the Idun's Apples prototype in Article 2), thus far reinforcing Aarseth's (2012) notion that the LNVM can be used to categorize all games as narratives, however, adding the seven that were categorized by Aarseth gives 23 games categorized, which is a low number, more games, both for learning and entertainment, should be categorized to verify and possibly further extend the eLNVM.

The eLNVM was used to categorize narrative learning games and organize them by their self-reported effects on engagement, motivation, and learning. The characteristics of the categories that exhibited positive effects were used as basis for the development of the eLuna co-design Framework. While the eLuna Framework is targeted at learning games, commercial games can also be created using the eLuna Framework in cases where the resulting characteristics of eLuna coincide with characteristics targeted by the games. The eLuna Framework targets the effects on engagement, motivation, and learning. Commercial games may often place emphasis other factors for which other categories in the eLNVM may be applied. Further categorization of games using the eLNVM may provide insight in other effects in games, and in the future one may envision further extensions to the eLuna Framework, where some categories are replaced to meet other effect objectives. These categorical extensions would be reflected in the eLuna Framework Visual Language, where new icon sets would be created to represent alternative characteristics.

During the literature review, 14 out of 18 papers passed inclusion round four meaning that they included a system description (Breien & Wasson, 2021). Almost one fourth of the non-included studies were excluded due to insufficient description of the game and story, thus it would not be possible to properly categorize the game using the eLNVM. During the inclusion round, other referenced sources were also examined, such as seeking out university website blog posts or project pages, looking for videos of the learning games in use, descriptions posted by formal participants in the studies, or downloadable / web-playable versions of the games. Four of the narrative learning games described in research were simply not available in any observable format, in written text, by video, playable, or anything else. For the eLNVM and other models to categorize games to be useful, detailed system descriptions are required. Thus, another result from the literature review is a call to the community to make available descriptive material of all learning games studied. While there is often not space allowance for this inside journal articles or conference papers, there is often an option to permanently store supplementary material referenced from the research, and universities often have repositories for scientific work where it can be presented; one could also argue that a game description should be eligible for a conference paper or poster on its own.

The literature review applied a very strict search string, only allowing for studies that had the word “narrative” or “story” in the title, and that mentioned both game alongside learning, training or education, and motivation or engagement in the abstract or keywords (see search string in section 3.3.1, table 3). These restrictions were applied to find the foundational studies of narrative DGBL that evaluate and self-report effects on engagement, motivation, and learning over 10 years. While the result set in the literature review provided enough data to contribute the characteristics of the eLuna Framework, the dataset is limited to 15 studies, meaning that there are low numbers of learning games applying several of the categories, even missing data for some categories. The characteristics applied to the eLuna Framework were isolated and separated as positively affecting the relevant parameters, and this set of characteristics enables the development of narrative learning games that optimize the potential for incurring similar positive effects. More data, however, would have possibly identify similar effects incurred from other categories, which could lead to further extensions to the eLuna Framework. More data would also possibly allow for further distinction of effects from interchangeable fixed kernel and dynamic kernels events categories, and the effect from higher game agency objects and higher author agency agents. To further elaborate on the eLuna Framework, a broader search should be applied, more narrative learning games should be categorized using the eLNVM, and the findings should be compared to those of the original study.

The literature review rapid evidence synthesis in Article 1 presented an analysis of the ontological categories in isolation; no emphasis was placed on cross referencing studies categories among the ontologies. Effects may be visible in the literature review dataset towards fortunate combinations of categories that also allow for others than the ones targeted by the eLuna Framework to incur positive effects. It is probable, however, that more data would be required, given that 15 narrative learning games leaves little data to cluster for overlapping categorization.

Through the inclusion of the mixed reality visual language extension, the eLuna Framework can be used to co-design narrative game-based learning in fully virtual, fully physical, or mixed reality environments such as science centre learning trails. Whereas study two (reported in Article 2) included a design-based research phase to validate a resulting game prototype's compliance to the characteristics, no such prototype was created in study three (reported in Article 3) to validate the extended visual language. A reasoning for this is that the eLuna Framework, including its original visual language had already been validated, and the mixed-reality extension made no alterations to the visual language's expressive power; it only made identifications of physical and virtual elements to distinguish between them, thereby already conforming to the previous validation. Still, a mixed reality narrative game-based learning trail prototype should be developed, and rigorous validation of it should be carried out.

The eLuna Framework targets characteristics empirically associated with incurring positive effects on engagement, motivation, and learning, and should as such optimize the potential for learning games created with it to incur similar positive effects. However, before one can say that eLuna narrative learning games, used in learning trails or elsewhere, incur such effects, interventions and evaluations must be carried out. The research in studies two and three resulted in nine co-designs, some of which may be revisited and refined to serve as evaluation candidates. If the eLuna Framework turns out to result in games with a high probability of positively affecting engagement, motivation, and learning, a future direction for further research would be to develop a tool for making eLuna co-designs and co-specifications. An eLuna tool could allow participants creation and connection of visual language elements, first flexibly, then more strictly adhering to the eLuna Method phases. An eLuna tool could output digital blueprints that could automatically generate much of the required technical code for digital games and companions, also setting up expected data transfer protocols where they would logically be required in mixed reality environments. Such a tool would allow more time to be spent on content and learning objectives.

The conduction of the DBR phases in the research was focused on developing the eLuna Framework, and spawned nine co-designs, seven for narrative DGBL, and two as mixed reality learning trails. The transcription and subsequent thematizing was carried out with the goal to provide insights into usability and usefulness for stakeholders to apply the framework, not to further refine the co-designs to becoming full-fledged game-based learning systems. The research, however, leaves 16 hours of anonymized data and descriptions of the nine narrative learning games documented at various degrees of strictness using the eLuna Visual Language. Since the participants in the DBR phases all responded with one of the co-designs in mind — the one that they had just participated to create — the data holds large amounts of ideas and reflections on the nine candidates and how to further them to becoming real learning games. In further research, it could be a good idea to re-visit the co-design and the data, re-thematize the transcriptions with focus on the comments on games, then develop the best described ones and evaluate their effects with the intended learner demographic.

The eLuna Framework is based on ontological categories' characteristics and informs the use of these to promote positive effects on engagement, motivation, and learning. The eLuna Framework, however, does not dictate the pacing of the game, the utilization of motoric and/or mental challenges in task completion, sensory stimulus, such as audio and video effects and perspectives, but also elements like haptics, movement, even taste and smell, interaction devices and presentation platforms, genre of the narrative story, whether it being drama, romance, action, horror, or other, and so on. The Background (Chapter 2) provides an overview of studies of elements in games that can promote engagement, motivation, and learning, a selection of which has been revisited in the discussion (Chapter 5). Since eLuna games are versatile in use and application of game design elements, interaction, and presentation, further study should be conducted to see how the findings from other studies can reinforce eLuna further, potentially strengthening the positive effects that using the framework already promote.

Finally, having been shown to be a usable method that empowers educators and game developers to co-design mixed reality game-based learning trails that enforce positive effects on engagement, motivation, and learning, the author wishes to encourage anyone in industry or science with the interest to develop more learning games using the eLuna Framework. These learning games can be of fully physical, fully virtual, or mixed reality types.

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Appendices

A. Questionnaire used in study 2

How much do you agree with these statements:

	(5) Strongly agree	(4) Agree	(3) Neutral	(2) Disagree	(1) Strongly disagree
1. The descriptions of the four ontologies in the extended ludo-narrative variable model were easy to understand	○	○	○	○	○
2. The descriptions of the four ontological categories that we used when designing the narrative learning game were easy to understand	○	○	○	○	○
3. The descriptions of the characteristics of the four categories were easy to understand	○	○	○	○	○
4. The sequence used in the four ontologies in made sense to me	○	○	○	○	○

B. Interview guide used in study 2

The overarching design process	
You and a group of co-designers have initiated design of a learning game based on characteristics of games as narratives	• What is your impression of how this process worked? • Can you suggest any overarching improvements?
The outcome	
The resulting output was a design for a learning game with learning objectives inside a scientific topic	• Would you say that a learning game that was realized from the design has potential for shedding light on the learning objectives? • Can you think of anything that should be added to or removed from the process that would improve the potential?
The ontologies, categories, and characteristics	
The work concerned ontologies which are named World, Object, Agent, and Events, there were described before the design session started	• What are your thoughts about the descriptions of the ontologies, the ontological categories, and the categories characteristics? • Can you think about any ontologies that are missing in the model that you used?
The work sequence	
The ontologies were designed in a sequence which was Agent, World, Object, then Events	• Would you say that a learning game that Did this sequence make sense to you? • Are there other sequences of interest that would empower the design work?
The topic and the learning objectives	
Before staring the design process, you selected a topic and learning objectives and were instructed to generate an overarching context for the learning game	• How did this process work for you? • Could this have been done in any different way to improve the process?
Timeframe	
During the design work you spent 20 minutes on each of the ontologies, except for the Agents ontology, on which you spent 30 minutes	• Do you think the difference in time spent on the ontologies was sensible? • If you disregard the time spent in this session, what timeframe do you believe would be good for co-design work of this nature?
Participants roles and design thematic	
During the design work you spent 20 minutes in the group there were academics, developers, and science centre teachers, and you worked towards a learning game inside science education	• Were there any competencies that you felt the group was missing? • Are there any other areas of study where you think this design method could be applied?
Example material	
Before the co-design session an example related to emergency response was presented	• How did this example work to illustrate the work that was about to be done? • Do you have suggestions for other examples that could be used?
Catch all	
The goal of this workshop is to improve the design process of effective narrative learning games	• Do you have any further comments that you feel does not fit under any of the other themes and questions?

C. Interview guide used in study 3

Consulting the eLuna Visual Language codesign schematics constructed by the researchers based on the workshop: Please identify the real and the virtual elements and describe to the best of your ability how these could be visually distinguished from one another by suggesting extensions to the original visual language.
Please reference the ontologies: **World** **Objects** **Agents** **Events**

Part 2 – The articles

Article 1

Breien, F. S. & Wasson, B. (2021). Narrative Categorization in Digital Game-Based Learning: Engagement, Motivation & Learning. *British Journal of Educational Technology*, 52(0), 91-111. DOI:10.1111/bjet.13004

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Narrative categorization in digital game-based learning: Engagement, motivation & learning

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Abstract

Previous research shows that digital game-based learning (DGBL) can have positive effects on engagement, motivation and learning, and that using narratives may reinforce these effects. A systematic review identified 15 DGBL systems that report effects from their use of narratives. A gap in the field, however, is the lack of a common model to categorize and isolate narratives in DGBL to enable an analysis and comparison of how, and under what conditions, narratives have effects on learning in DGBL systems. The ludo narrative variable model (LNVM) that has been used to isolate and categorize narratives in research on commercial video games is a candidate to fill this gap. This research has investigated the potential of this model for DGBL and resulted in an extended LNVM (eLNVM) that can be used to isolate and categorize narratives in DGBL. The 15 DGBL systems were categorized on the eLNVM and the results show that there are characteristics of DGBL systems with positive self-reported effects that separate them from other DGBL systems. Furthermore, it was possible to identify characteristics of the narrative modeling that are associated with positive effects on engagement, motivation and learning. The paper concludes with a description of how the eLNVM will be used in future research.

Introduction

Digital Game-Based Learning (DGBL), first termed by Prensky (2001), refers to any form of use or integration of digital games into learning environments. DGBL spans from serious games developed with learning or instructional objectives, to student game design activities to explore a subject matter, and the use of commercial off-the-shelf (COTS) digital games to address both content-based and high-order learning outcomes (Van Eck, 2006). In their review of gamified learning, Subhash and Cudney (2018) define the digital domain of Game-Based Learning (GBL) to separate between non-game systems such as Learning-Management Systems (LMS) that use some game elements and mechanics, called gamification (Deterding, Dixon, Khaled, & Nacke, 2011), and games designed for, or used in, educational settings. The latter range from role-play

Practitioner Notes

What is already known about this topic

- Digital Game Based Learning (DGBL) refers to any form of use, or integration, of digital games in learning environments.
- Narratives are one of three core game structures, alongside rules and space.
- There is consensus in the DGBL field that by employing narratives, DGBL has the potential to positively affect engagement, motivation and learning.
- There is a gap in the field, which is the lack of a common model to categorize and isolate narratives in DGBL in order to enable an analysis and comparison of how, and under what conditions, narratives have effects on learning.
- There is a further gap in the field, which is knowledge of what characterizes a DGBL system that shows positive effects from narratives on engagement, motivation and learning.

What this paper adds

- eLNVM, a usable model that enables the isolation and categorization of narratives in DGBL and the evaluation of past and future DGBL effects.
- An ontological characterization of narrative DGBL that enforce positive effects on engagement, motivation and learning.

Implications for practice and/or policy

- eLNVM provides a tool to use for isolation and categorization of effects from narratives in DGBL for use by practitioners and researchers.
- This study shows trends towards what characterizes effective use of narratives to promote learning contributing to best practice guidance for DGBL game designers.

games (RPGs), serious games, gamified applications, mobile-based learning games and 3D simulation games for learning. DGBL can also include COTS games used in educational settings, and probably also a wider set of video game genres added to RPGs and 3D simulation games, which are listed as main game genres alongside strategy, and action in Apperly's (2006) critical approach to game genres. A simple and summative definition of DGBL is that it "incorporates educational content or learning principles into video games" (Coffey, 2009, p. 1). This study adopts the definition provided by Coffey and refers henceforth to any digital game used for education, instruction or training as a *DGBL system*.

One key aspect of DGBL is the narrative or story, which Ermi and Mäyrä (2005) show to be one of three core game structures, alongside rules and space. Serious games (DGBL systems) "harness the power of digital games for training or education" (Fu-Hsing, Kuang-Chao, & Hsien-Sheng, 2012, p. 240). Serious games are growing in popularity (Hersh & Leporini, 2018), and support leaners in learning effectively and to enjoy learning (eg, Coffey, 2009; Ferguson *et al.*, 2019; Fu-Hsing *et al.*, 2012; Rushby, 2012). Rushby (2012), however, concludes that while "there is evidence serious games do help people learn, there is very little evidence as to how they do that" (Rushby, 2012, p. 179) and calls for further study related to (1) which characteristics make good serious games, and (2) how good serious games can be made even more effective.

Several literature reviews (eg, Clark *et al.*, 2016; Connolly *et al.*, 2012; Novak, 2015) have explored narrative effects on engagement, motivation, and learning in DGBL. There is a consensus among these reviews that DGBL can have positive effects on, and offer novel venues for, learning in some circumstances, by motivating and engaging learners using narratives. Since narratives are a key aspect of DGBL, we explored how narratives are used to enhance engagement, motivation and learning in DGBL systems.

It is important to understand how each game design feature affects the specific learning outcomes and/or benefits when examining their relationship to learning (Novak, 2015). Lester *et al*. (2014) call for further study to isolate specific game design features to understand which features are relevant to student engagement. While investigating narrative effects on learning, Armstrong and Landers (2017) found a scarcity of current studies on narrative DGBL systems that isolate narratives from other game elements. According to them this makes unclear the conditions under which narratives themselves impact learning, and whether effects attributed to narratives come from them at all. Consequently, they call for further study of how, and under what conditions, narratives have effects on learning in order to conduct meaningful future research. This leads to the current study of how narratives are categorized in DGBL, and what characteristics, if any, define DGBL systems with positive effects on engagement, motivation and learning. We concur with the findings of Armstrong and Landers; not only is there a shortage of studies that isolate narratives from game play effects on learning, the papers reviewed in this study also reveal that there are many ways that researchers categorize narratives in DGBL. While this leads to various means and opportunities to analyze individual DGBL systems, it makes comparison challenging.

The study reported in this paper contributes to current research by presenting a model for the isolation and categorization of narrative effects from other game mechanics by drawing on, and extending, Aarseth's (1997, 2005, 2012) work on narrative game theory. Through a systematic literature review (Catalá-López, Stevens, Garritty & Hutton, 2017; Kitchenham, 2007; Kitchenham & Brereton, 2013) of narrative DGBL systems from the last 10 years, and by categorizing the evaluated systems on an extension of Aarseth's LNVM, our research explores whether the proposed extended LNVM (eLNVM) is a suitable tool to isolate and categorize narratives in DGBL. Furthermore, to investigate whether effects can be characterized using eLNVM, the DGBL systems' categorizations are clustered by their reported effects on engagement, motivation and learning.

Our results show there are distinct and isolated characteristics of narratives that are integrated in DGBL systems that are also evaluated to successfully reinforce engagement, motivation, and learning. eLNVM is useful to perform categorization of narrative characteristics, which can further be used to provide development guidelines that can be used by educators and game developers, separately or in multidisciplinary teams. The use of these design guidelines has the potential to optimize the use of resources that go into designing narratives in effective DGBL. Furthermore, the results show that eLNVM is an effective tool to isolate narratives and narrative effects on learning in single DGBL systems, as well as when comparing them to one another.

Background for the study

DGBL, learning theories and reach

According to Coffey (2009), DGBL draws upon a constructivist theory of learning. In their review of GBL and 21st century skills, Qian and Clark (2016) analyzed 22 studies and found that of the 28 explicit references to 10 established learning theories, 13 of the references were to constructivism, with the second most referenced learning theory being constructionism, with only four references. Qian and Clark (2016) show that DGBL often fail to use learning theoretical foundations, however, they go on to show that DGBL tends to yield positive outcomes when learning theories are incorporated, and that particularly a sociocultural theory of learning (Vygotsky, 1978) and flow theory (Csikszentmihalyi & Csikzentmihaly, 1990) are well-suited to game design and learning outcomes (Qian & Clark, 2016).

As described in “Innovating pedagogy 2019” (Ferguson *et al*., 2019), research shows that digital games have been used by all age groups, and that they can help learners develop skills such as collaboration, problem solving and creativity. Confirming the broad reach of DGBL across age and subject matters, Clark, Tanner-Smith and Killingsworth’s (2016) review of digital games, design and learning generate a dataset of 69 studies of DGBL used in K-16 education, published between 2000 and 2012. Through a meta-review they further identify 65 DGBL used in adult workflow training between 1976 and 2009, and 71 DGBL used by all age groups between 1986 and 2012.

In their granular review of 29 studies of implemented DGBL, Qian and Clark (2016) identified 28 game design elements. The most implemented game design elements were *collaboration* (eight times) and *role playing* (seven times), with *narrative* (six times) being the third most utilized. The strength of narratives as a game element is evidenced in commercial video gaming through successes of narrative based titles such as Grand Theft Auto and Red Dead Redemption, which have sold 290 and 24 million units to date respectively (Take Two Interactive annual report, 2019) and have excellent review scores in past and present instalments (https://www.metacritic.com/game/playstation-4/grand-theft-auto-v; https://www.metacritic.com/game/playstation-4/red-dead-redemption-2).

This study is motivated by the above-mentioned research which shows that DGBL can employ effective learning theories, and moreover, is able to provide a meaningful platform for learning for wide demographics. The research seeks to provide a means for isolating categories in DGBL, and to explore which characteristics enable a better understanding of the conditions under which positive learning effects occur.

Effect of narratives on engagement, motivation and learning

Engagement, motivation and learning in DGBL systems has been explored for nearly 40 years. Thomas W. Malone’s seminal paper “Toward a Theory of Intrinsically Motivating Instruction” (Malone, 1981) is considered by many (eg, Dempsey, Lucassen, Gilley, & Rasmussen, 1993; Fulya Eyupoglu & Nietfeld, 2019; Habgood, Ainsworth & Benford, 2005) to be the initial research in this area. Specific research on narratives in DGBL was thoroughly examined and defined by Marc Prensky through his pioneer work in the field (eg, Prensky & Thiagarajan, 2007).

Narratives used to facilitate learning in other forms of instructional contexts (eg, through books, movies, audio, etc.) have been shown to be superior to expository texts with regards to fostering comprehension, retention and recall (Armstrong & Landers, 2017). While advantages of pairing narratives with DGBL have been suggested (eg, Dettori & Paiva, 2009), evaluations of narrative DGBL have yielded mixed results. Clark *et al*. (2016) find insignificant results that show DGBL may be more effective without, than with narratives. Novak (2015) does not find positive motivational effects from narratives but argues that narratives may still provide contextual anchoring and facilitate better knowledge construction and information organization (Novak, 2015). Other studies, such as empirical tests on the Crystal Island narrative DGBL (Lester *et al*., 2014; Rowe, Lucy, Bradford, & James, 2010; Rowe, Shores, Mott, & Lester, 2011; Lee, Mott, & Lester, 2010; Xu & Woodruff, 2017), have shown positive effects from narratives on engagement and motivation, as well as on learning objectives and processes such as cognitive modeling and memory.

With regards to learning outcomes, warnings are raised as to: (1) if narrative conditions in DGBL impose an excessive cognitive load on learners, which negatively affects their learning outcomes

(Novak, 2015); (2) that cognitive capacity is consumed by following a game narrative, rendering the learner with insufficient capacity to think deeply about the academic material in DGBL (Pilegard & Mayer, 2016); (3) that switching between story text and processing of other information may cause cognitive overload with detrimental effects on learning (Ross, Pye, & Randell, 2016); and (4) that young children may be particularly prone to such overload, due to their immature cognitive and attention skills (Courage *et al*., 2015).

The above research shows that while narratives in DGBL are not well understood, they enforce positive effects on learning in other domains. Narratives are important game elements and have the potential to positively affect learning in DGBL. Thus, this study focuses on narratives in DGBL and their effect on engagement, motivation and learning.

The Ludo Narrative variable model

In his book "Cybertext: Perspectives on Ergodic Literature" Aarseth defines Ergodic Literature as any piece of literature where nontrivial effort is required to allow the reader to traverse a text (or story), beyond trivialities such as eye movement and the periodic, or arbitrary, turning of pages (Aarseth, 1997). The separation between triviality and nontriviality intrinsically defines all narrative games as Ergodic literary works, in that a story that is traversed only using trivial motoric abilities may not be considered a game of any form, while the interactivity of any game can be defined as nontrivial and needed to drive a game narrative forward. In a further study, Aarseth introduces a narrative theory of games and the LNVM (Aarseth, 2012), which is based on his related work on game quest structure and storytelling (Aarseth, 2005).

Recognizing computer games as a dominant cultural form that influence others such as cinema, TV, literature, theater, painting and music, Aarseth (2012) poses the question of whether narrative theory should be modified or expanded to incorporate games. In seeing critical self-reflection remaining a hallmark of scholarship, Aarseth (2012) reminds us that when we examine a phenomenon with critical tools developed for another type of phenomenon, the tools must be critically examined for theoretical concepts to remain meaningful when transported to new fields. To this end Aarseth (2012) proposes the LNVM as a usable model for categorizing and studying narratives in games inside four ontological dimensions that are present in all games as well as narratives.

Table 1 shows the LNVM, which constitutes a categorized graph from the narrative pole to ludic (or game) pole inside each of the ontologies that have been shown to be shared by all games and narratives. The *narrative pole* offers high author agency, at the sacrifice of game agency, and the *game pole* offers high game agency, at the sacrifice of author agency. The *object* and *agents ontologies* are categorized on linear scales. For objects this implies a scale of objects from something that may only be observed to exist under the *non-interactable* category, to something that can be invented in the game, by for example using programing code available inside the game interface under the *inventible* category. For agents this implies a scale of character depth, from characters described in detail with regards to background, motivation, psychology, and so on, under the *deep, rich, round* category, to characters that exist with no purpose other than gameplay, such as hordes of aliens in a shooting game under the *bots, no individual identity* category. Contrastingly, the world and events ontologies are categorized as taxonomies. These are different from each other and imply no scale, but rather implementation methodologies in video games that to a larger and lesser extent offer polar game to author agency. While the world and event ontologies have emerged in commercial video game development since the 1970s, and were both scientifically described by Aarseth (2005, 2012), these ontologies merit further description. Table 2 describes the taxonomies for the world ontology, concerning how a game environment evolves based on

Table 1: The ludo narrative variable model (Aarseth, 2012)

Ontology	*World*	*Objects*	*Agents*	*Events*
Polarity				
Narrative pole	Inaccessible	Non-interactable	Deep, rich, round	Fully plotted
High author agency	Single room	Static, usable	N/A	N/A
	Linear corridor	Modifiable	N/A	Dynamic satellites/ playable story
	Multicursal labyrinth	Destructible	Flat	Dynamic kernels
High game agency	Hub shaped quest landscape	Creatable	N/A	N/A
Ludic (game) pole	Open landscape	Inventible	Bots, no individual identity	No kernels (pure game)

Table 2: Taxonomical description of the world ontology

Taxonomy	*Description*
Inaccessible	Any non-interactive world that may only be traversed in a linear manner after solving challenges
Single room	A singular space that may be explored to solve a challenge
Linear corridor	Where solving challenges open one singular room at the time in a predefined order
Multicursal labyrinth	A labyrinth with several selectable paths leading to the same conclusion
Hubshaped quest landscape	A world of several areas, where new areas open as challenges are solved in others
Open world	A free roaming environment to be explored at will to solve challenges

user action. Table 3 describes the taxonomies of the events ontology. These taxonomies concerns kernels, cardinal functions of a narrative that are both necessary and sufficient for a particular story to exist, also known as nuclei (Barthes & Dulsit, 1975), opposed to satellites, who in narratology are divided into three optional expansions to a story; catalyzes, who are consecutive but not consequential to the story; and, implicit and explicit indices, adding information to narrative events (Kwiat, 2008).

Using LNVM to categorize a game and analyzing the game's effect on "something" before comparing it to other games with the same kinds of effects, characteristics may emerge as to which degree a game uses game- and author agency inside the separate ontologies to successfully reach its goals.

This study recognizes the need to further categorize and characterize narratives in DGBL and to promote efficient strategies for effective design and comparable evaluation of future systems. This research applies the LNVM to explore its potential as a tool to meaningfully isolate and categorize narratives from game elements in DGBL and explores whether there are characteristics that are associated with positive effects on engagement, motivation and learning.

Research questions

Previous research shows that DGBL can have positive effect on learning for broad demographics when properly applying learning theories, and that narratives in DGBL may enforce learning. A

Table 3: Taxonomical description of the events ontology

Taxonomy	*Description*
Fully plotted	Neither kernels nor satellites content or sequence is affected by interaction
Dynamic satellites, playable story	Kernels content and sequence remains fixed, while satellites can be altered or rearranged
Dynamic kernels	Content of kernels may be changed by interaction, leading to potentially different stories
No kernels	A game with no narrative

gap in the current research is the lack of a common model to isolate and categorize narratives and other game elements in DGBL systems. This makes it difficult to identify how, and under what conditions narratives have effect on engagement, motivation, and learning. We address this gap by investigating whether the LNVM can be such a common model. The study is guided by two research questions:

1. How can the LNVM be used to isolate and categorize narrative DGBL systems?
2. What characterizes narrative DGBL systems that positively affect engagement, motivation and learning?

Method

A systematic literature review with a search protocol and inclusion criteria process (Kitchenham, 2007; Kitchenham & Brereton, 2013) limited to the simplifications set forth by Catalá-López *et al*. (2017) in describing rapid reviews for evidence synthesis was carried out. The development and implementation of the search protocol comprised three stages:

1. **The unstructured initial informal search** across 10-fold databases to test different combinations of search words and database results,
2. **The test protocol** to develop search string and criteria, and to select the final databases to use, and
3. **The main protocol**, in which the actual search protocol was conducted using our search query and inclusion criteria.

A search for research papers about narrative DGBL systems published in scientific journals or conference proceedings between January 2009 and August 2018 used the following search string:

Title: (Narrative OR Story) AND Title/Abstract/Keywords: (Game) AND (Learning OR Training OR Education) AND (Motivation OR Engagement)

The results were evaluated through four exclusion rounds to produce a dataset of DGBL systems' that could be coded by their self-reported effects from narratives on engagement, motivation, and learning. Based on their qualitative descriptions, the DGBL systems in the dataset were then categorized on the LNVM. The clusters were compared and analyzed to explore characteristics that isolated and separated clusters of DGBL systems showing different effects from one another.

Table 4: The distribution of papers as found per database per year

Database	*ACM Digital Library (IT)*	*IEEE Xplore (IT)*	*PsycINFO (Psychology)*	*Science Direct (General)*	*Web of Science (General/learning)*	*Total per year*
Year						
2009	0	0	1	1	1	*3*
2010	1	0	1	0	1	*3*
2011	2	1	3	2	2	*10*
2012	1	1	1	2	1	*6*
2013	0	2	1	1	1	*5*
2014	1	0	0	3	3	*7*
2015	1	1	0	0	1	*3*
2016	1	1	0	1	3	*6*
2017	2	1	1	3	4	*11*
2018(7)	3	0	1	2	1	*7*
Total per database	12	7	9	15	18	61

Results

The search query, see Table 5, produced 61 papers, the distribution of which is presented as obtained across five databases, by year, in Table 4. The five databases were selected after showing good coverage during initial unstructured search and test protocols, and for covering a broad range of disciplines, two with IT related content also including games studies (ACM, IEEE), one with focus on psychology (PsycINFO), and another two of general purpose (Science Direct, Web of Science), the later with a strong relation to learning sciences.

Completing the main search protocol and applying the inclusion criteria resulted in a dataset comprising of 14 papers and 15 DGBL system evaluations, as one paper (Barab *et al.*, 2010) evaluated two different DGBL systems. In Table 5, the search protocol and inclusion criteria rounds are described as they were performed: Main search, Duplicate removal, False positive removal, and four Inclusion rounds (abstract, full text, full text, system description).

The evaluations of the 15 DGBL systems were explored for self-reported effects on engagement, motivation, and learning. These were coded positive, negative, neutral, or not applicable (N/A). In cases where an evaluation reflected on several demographics, a positive report was liberally noted if positive effects were found for one or more of the demographics. Table 6 shows the distribution of evaluated effects reports in each paper.

As the categorization of DGBL systems was undertaken, two shortcomings were found in the LNVM, resulting in an extension of the model itself. The first extension is related to the category naming in the agents ontology, the second is related to the characteristics of categories in the events ontology.

While Aarseth provides a linear scale of characteristics in agents depth from his *Deep, rich, round* to *Flat* character categories in the agents ontology that is visible in his categorization of different works across an open scale between them in his original presentation of a narrative model for games (Aarseth, 2012), he does not, however, label the interim categories by name. To label these and thus provide a clearer terminology for future discourse when analyzing narrative games, including narrative DGBL systems, the agents ontology is extended with three categories as shown in Table 7 (extended categories in **bold**):

When plotting the DGBL systems on the events ontology, it became apparent that the *Dynamic satellites/ playable story* category encompasses two types of characteristics that constitute fundamentally different event structures in games. To capture this granularity the *events ontology* is extended as shown in Table 8 (extended categories names in **bold**):

Based on the extensions, Table 9 shows the extended LNVM (eLNVM), which is further used to categorize the DGBL systems.

The 15 DGBL systems were categorized on the eLNVM as shown in Table 10. When described by ontology, most were *linear corridor* worlds (7) offering *static, usable* objects (8) to *grounded, consistent* agents (8) that navigated *interchangeable fixed kernels* events (5).

Analysis

Using the eLNVM ontological categorization for each DGBL system (Table 10) and the DGBL systems' evaluated effects (Table 6) as basis, an analysis was made to explore how clustering is distributed for each of the ontologies. The coded systems were sorted as follows:

1. Fully positive (nine DGBL system evaluations): Learning outcomes are positive, both engagement and motivation are either positive or N/A,

Table 5: Search protocol and paper inclusions criteria

Main search protocol (in databases listed in Table 4)

Search query:

"Title: (Narrative OR Story) AND Title/Abstract/Keywords: (Game) AND (Learning OR Training OR Education) AND (Motivation OR Engagement)"

61 papers

↓

Removal of duplicates

50 papers

↓

Removal of false positives

E.g. positive return of paper by search query by inclusion of search words inside other words with different meaning (like the word "history" giving a positive result on the embedded word "story"), or reference to "narrative evaluation methods"—Verified by two researchers

40 papers

↓

Inclusion round one: Abstract

"The study must be about the design—or evaluation of a fully or partially interactive digital tool, system or process that teaches or trains someone in a subject matter, skill, trait or process"—Verified by two researchers

27 papers

↓

Inclusion round two: Full text

Three conditions (1) The study does not target users with special assistive needs or medical conditions, (2) The study is targeted at school children, students or adults in professional or academic settings, and (3) The study provide results, observations, comments, recommendations, practices or other relevant information about narratively obtained motivation and/or engagement and learning outcomes from the learner or practitioner—Verified by two researchers

19 papers

↓

Inclusion round three: Full text

Classify by (1) Study type, (2) Sample size, (3) Demography, (4) Method, (5) Subject matter, (6) Game type/genre. Papers removed if problematic—Verified by two researchers

18 papers

↓

Inclusion round four: System description

Confirm that the evaluated DGBL systems were qualitatively sufficiently described to meaningfully categorize them on the Ludo-Narrative variable model (by reading the papers, but also by following links to on-line resources, playing games, watching academic videos of game play sessions, and/or by following reference links to previous papers in which the DGBLs were further described)—Performed in detail by one researcher, reported for all eliminations to another researcher

Table 5: *(Continued)*

14 papers (15 systems)
↓
Search results
Empirical studies of narrative DGBL systems with effects on engagement and/or motivation as well as learning outcomes, all possible to categorize by ontology on the Ludo-Narrative variable model. One paper concerned two narrative DGBL that were categorized differently, leaving 15 systems. Three papers where about the same DGBL, used with different purposes for different groups, and were therefore left as separate systems

2. Neutral learning (two DGBL system evaluations): Learning outcomes are neutral, both engagement and motivation is either positive or N/A,
3. No positive effects (three DGBL system evaluations): Neither engagement nor motivation is positive, and
4. Negative learning (one DGBL system evaluation): Learning outcomes are negative.

Only six of the 15 DGBL studies report on both engagement and motivation, but all studies report on either one or the other. Therefore, the distinction between clusters 1 and 3 was intentionally made to separate evaluations that showed positive effects on at least one of engagement or motivation, as well as no neutral or negative effect on the other, from those evaluations that reported no positive effects on learning outcomes, engagement or motivation. Among the nine fully positive evaluations, two failed to report on engagement, while four failed to report on motivation.

The DGBL systems clustered by coded effects and categories, show the characteristics that both separate and isolate DGBL systems with fully positive effects from all others. This is shown and described for each ontology in Figures 1 through 4.

Figure 1 shows that there is a clear characteristic for fully positive DGBL systems to gravitate towards the taxonomical *hubshaped quest landscape* and *open landscape* categories, and moreover, only positive coded evaluations of DGBL systems fall into these two categories. Only two positive coded DGBL systems are categorized under the *linear corridor* category, which is also a gravitational category for neutral learning and no positive effects DGBL systems. The negative learning coded DGBL system falls under the *inaccessible* category. None of the selected systems fall into the *single room* and *multicursal labyrinth* categories.

Figure 2 shows that while eight DGBL systems fall under the *static, usable* category, only two of these are fully positive. The other fully positive DGBL systems gravitate alone to the *modifiable* and *creatable* categories. The events ontology is a linear scale, where a higher degree of game agency also implies all lower degree categories for the same objects, for example, a *creatable* object is necessarily also *modifiable*, since creating any new object may also be viewed as modifying another with larger or smaller changes to different parameters. Furthermore, an object of any type can also be treated as one of higher author agency than itself, eg, any object of higher game agency than *modifiable* may be considered *static* or even *non-interactable*. It cannot be known from this data whether the reason that the two DGBL systems under the *creatable* category have positive effects is because objects are *creatable*, or because they are *modifiable*. It is thus considered safest to characterize fully positive coded DGBL systems as *modifiable* or higher game agency categories in this research. No DGBL systems fall under the *noninteractable, destructible* or *inventible* categories, however, the former two are both implied as part of the DGBL systems that fall under the *creatable* category.

Table 6: Evaluations effect reports per paper in dataset

Study	*Effect on engagement*	*Effect on motivation*	*Effect on learning outcomes*
Barab *et al.* (2010)[d]	Positive	N/A	Positive
Dickey (2011)	Positive	Positive	Positive
Garneli *et al.* (2017)	Neutral	Negative	Neutral
Jemmali *et al.* (2018)[b]	Positive	Positive	Positive
Lester *et al.* (2014)[a]	Positive	Positive	Positive
Marsh *et al.* (2011)	Positive	N/A	Positive
Pilegard and Mayer (2016)	Neutral	Neutral	Positive
Ross *et al.* (2016)[c]	Positive	Neutral	Negative
Rowe *et al.* (2010)[a]	Positive	N/A	Positive
Rowe *et al.* (2011)[a]	Positive	N/A	Positive
Sangalang *et al.* (2013)	N/A	Positive	Neutral
Wang *et al.* (2017)	N/A	Neutral	Neutral
Wouters *et al.* (2011)	N/A	Positive	Neutral
Zhang *et al.* (2018)	Positive	N/A	Positive

[a]Three studies about the same narrative DGBL but are treated separately due to (1) modification and (2) different research questions and focuses.
[b]This study reports on different game versions. Criteria and effects in the table focus on the "Rich Narrative Version."
[c]This study reports on two systems where only one is a DGBL. Criteria and effects in the table focus on "Fantastic Flying Books of Morris Lessmore."
[d]This study reports on two narrative DGBL which for research criteria and effects are equal, but that are categorized differently in the LNVM ontologies.

Table 7: The extended agents ontology

Category	*Description*
Deep, rich, round characters	Aarseth's definition
Grounded, consistent characters	Characters that are described in terms of background, origin, morale, culture, etc., and that act in a seemingly consistent and sensible manner, but that are not fleshed out and described in the detail like the deep main characters found in literary works by e.g. Dostojevskij, Tolstoy, or Hemingway
Sensible characters	Characters with little background detail, but that have a personality that may seem sensible in the ongoing discourse, without providing grounding enough for the observer to evaluate whether the characters behaviour is consistent with the characters pre-events history or not
Flat characters	Aarseth's definition
Stereotypical characters	Characters that have cultural roles and act as such e.g. The Butler, The Bartender, The Detective, The Noble, etc
Bots, no individual identity	Aarseth's definition

Figure 3 shows that all fully positive coded DGBL systems fall into categories from *sensible* through *deep, rich, round*, gravitating to the *grounded, consistent* category and as such are all on the high author agency end of the ontology, which is linear as is the objects ontology. The *grounded,*

Table 8: The extended events ontology

Category	Description
Fully plotted	Aarseth's definition
N/A	N/A
Linear fixed kernels, dynamic satellites	Predetermined kernels that arrive in a fixed sequence from story beginning to end, in which the satellites are dynamic
Interchangeable fixed kernels, dynamic or fixed satellites	Predetermined kernels that arrive at an interchangeable sequence, in which the satellites may be dynamic
Dynamic kernels	Aarseth's definition
No kernels (pure game)	Aarseth's definition

Table 9: The extended ludo narrative variable model (eLNVM)

Ontology	World	Objects	Agents	Events
Polarity				
Narrative pole	Inaccessible	Non-interactable	Deep, rich, round	Fully plotted
High author agency	Single room	Static, usable	Grounded, consistent	N/A
	Linear corridor	Modifiable	Sensible	Linear fixed kernels, dynamic satellites
	Multicursal labyrinth	Destructible	Flat	Interchangeable fixed kernels, dynamic or fixed satellites
High game agency	Hub shaped quest landscape	Creatable	Stereotypical	Dynamic kernels
Ludic (game) pole	Open landscape	Inventible	Bots, no individual identity	No kernels (pure game)

consistent category is also the most populated, comprising eight DGBL systems. Three of these are of either no positive effects or of negative learning clusters. Additionally, one of the three DGBL systems in the *sensible* category shows neutral learning. There are no DGBL systems that use the *bots, no individual identity* category.

Figure 4 shows that fully positive coded DGBL systems categorize as *linear fixed kernels, dynamic satellites,* or *interchangeable fixed kernels,* or *dynamic kernels*. However, while four of the five DGBL systems that categorize as *interchangeable fixed kernels* are fully positive, only two of four DGBL systems that categorize as *linear fixed kernels* are fully positive. All the three DGBL systems that categorize as *dynamic kernels* are fully positive. All three DGBL systems categorized as *fully plotted* show either no positive effects on engagement or motivation, or have negative effect on learning. There are no DGBL systems categorized with *no kernels*, which according to Aarseth (2012) would mean it cannot be a narrative.

Table 10: The ludo narrative ontological categorization per system

Study	*World*	*Objects*	*Actors*	*Events*
Barab *et al*. (2010)—A[a]	Hubshaped quest landscape	Modifiable	Deep, rich, round	Dynamic kernels
Barab *et al*. (2010)—B[a]	Open landscape	Creatable	Deep, rich, round	Dynamic kernels
Dickey (2011)	Open landscape	Static, usable	Grounded, consistent	Interchangeable fixed kernels
Garneli *et al*. (2017)	Linear corridor	Static, usable	Stereotypes	Fully plotted
Jemmali *et al*. (2018)	Linear corridor	Modifiable	Grounded, consistent	Linear fixed kernels
Lester *et al*. (2014)	Hubshaped quest landscape	Static, usable	Sensible	Interchangeable fixed kernels
Marsh *et al*. (2011)	Linear corridor	Modifiable	Grounded, consistent	Linear fixed kernels
Pilegard and Mayer (2016)	Linear corridor	Static, usable	Grounded, consistent	Linear fixed kernels
Ross *et al*. (2016)	Inaccessible	Static, usable	Grounded, consistent	Fully plotted
Rowe *et al*. (2010)	Hubshaped quest landscape	Modifiable	Grounded, consistent	Interchangeable fixed kernels
Rowe *et al*. (2011)	Hubshaped quest landscape	Modifiable	Grounded, consistent	Interchangeable fixed kernels
Sangalang *et al*. (2013)	Linear corridor	Static, usable	Sensible	Interchangeable fixed kernels
Wang *et al*. (2017)	Linear corridor	Static, usable	Grounded, consistent	Fully plotted
Wouters *et al*. (2011)	Linear corridor	Static, usable	Flat	Linear fixed kernels
Zhang *et al*. (2018)	Open landscape	Creatable	Sensible	Dynamic kernels

[a]In Barab *et al*. (2010), two systems are examined. These have different ludo narrative categorization and are thus treated as separate systems in this study.

Discussion

One result of this study is eLNVM, a common model that allows separate and comparative investigation of the effects that DGBL systems have on learning and the conditions under which it occurs. Fifteen DGBL systems comprise a small dataset, a result of the very strict exclusion criteria of this study; however, none of the DGBL in the studies failed to be categorizable. The original LNVM was introduced using only five commercial games (Aarseth, 2012).

It is possible to observe categorization clustering of fully positive DGBL systems that separates them from all other DGBL systems on the eLNVM, revealing characteristics for fully positive DGBL systems in this research. While all four ontologies show clear categorization clustering of fully positive DGBL systems, only three of them—World, Objects and Events—are also isolated under their plot categories. The Agents ontology shows mixed isolation results.

The second result of this study shows that a narrative DGBL with positive effects on engagement, motivation and learning has the following four characteristics in the eLNVM:

1. **A quest-based hub-landscape world**, in which confined areas of the full world (hubs) are explored at will, and where reaching objectives in sequences (quests) open new hubs in the landscape and close others, depending on player choices,

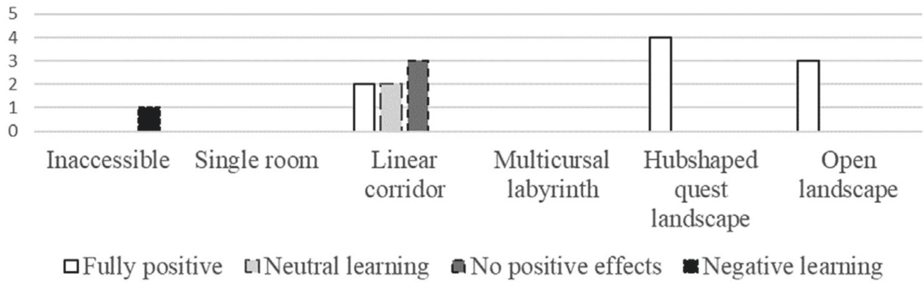

Figure 1: Distribution of DGBL system categorizations on the extended ludo narrative variable clustered by evaluated effects, world ontology

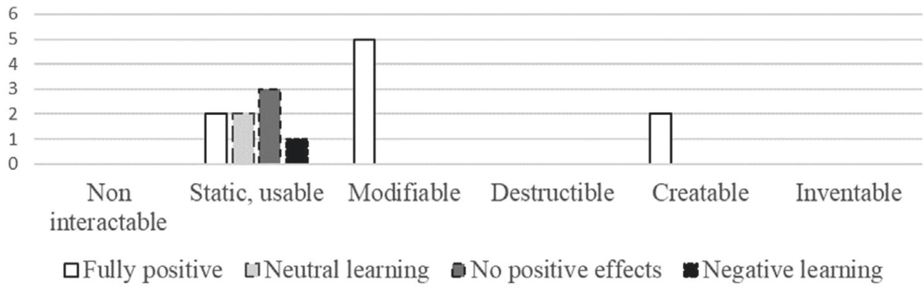

Figure 2: Distribution of DGBL system categorization on the extended ludo narrative variable clustered by evaluated effects, objects ontology

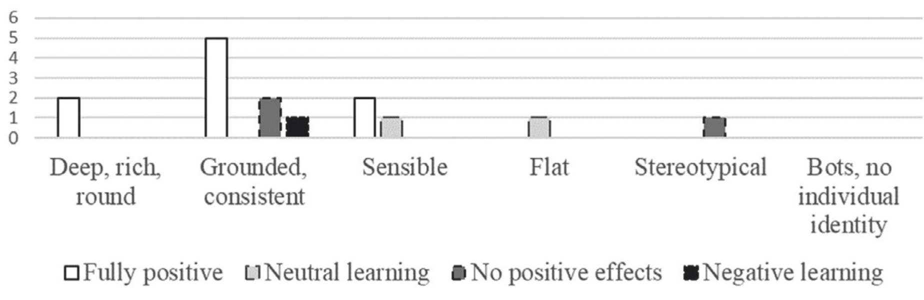

Figure 3: Distribution of DGBL system categorizations on the extended ludo narrative variable clustered by evaluated effects agents ontology

2. **Modifiable objects,** that are objects in the world that may be altered, combined, or configured to overcome challenges and reach objectives,
3. **Grounded and consistent actors,** which implies characters in the game narrative with sensible and well described backgrounds, psychologies and goals, and
4. **Interchangeable fixed or dynamic kernels,** which are storyline events of high importance that are either pre-written and interchangeable among each other, allowing for traversing a

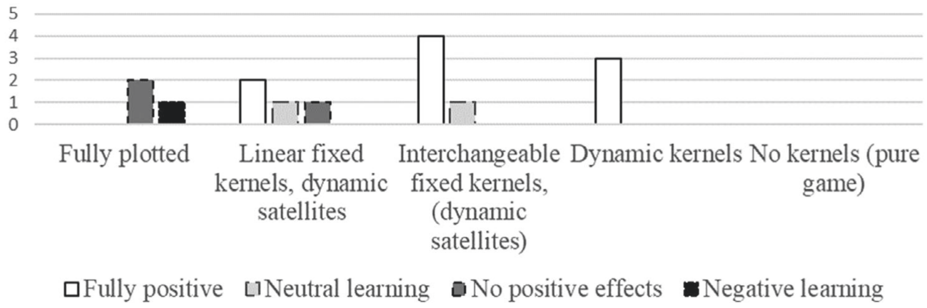

Figure 4: Distribution of DGBL system categorizations on the extended ludo narrative variable clustered by evaluated effects, events ontology

story in different ways or that are dynamically written by the system, allowing for development of new stories based on player choices

Limitations

Reflection on the study has revealed multiple areas that could be improved.

Verification of self-assessment in dataset

This study does not verify the subjective self-assessments of the DGBL systems' effects on engagement, motivation and learning. This is due to the lack of detailed enough information about the 15 DGBL systems as described in the papers and in the online information about the systems. Furthermore, the evaluations are described with differing foci, different methods, in different depths and variation, and the DGBL systems themselves are often not available in playable form, reproducing and verifying the results would be extremely difficult. In future work we will design and evaluate systems of our own making, and while this study does not have the opportunity to verify self-assessments, the goals of arriving at a model that is usable for inspecting characteristics of DGBL with particular effects remains valid.

Scarcity of studies that evaluate effects on both engagement and motivation

While this study explores effects on learning, engagement and motivation, most of the evaluations (9 of 15) fail to evaluate on **both** engagement and motivation alongside learning. This study, however, still isolates and separates characteristics of DGBL systems with only positive reports. In order to increase the dataset, further study of narrative DGBL under less strict exclusion criteria is warranted.

Broadening future searches to solidify findings

While previous literature reviews referenced in this research had some emphasis on narratives, this research defined the search protocol to identify only papers that referenced narratives in the title. This was a conscious decision to narrow the DGBL systems to a dataset with the main emphasis on narratives. Perhaps this search criterion is the reason why these results show a higher percentage of fully positive effect evaluations than what has been shown in previous research. Further research would be required to verify such a claim. Such research may seek to categorize DGBL systems where narratives are named in the abstract, or among the keywords and may even inspect DGBL system evaluations where narratives are not mentioned, but where narrative components are identifiable through analyzing the DGBL systems' qualitative descriptions.

This research found that the LNVM needed refined category naming in one ontology, Agents and separation of category characteristics in another ontology, Events. Thus, the categorized DGBL systems are only partially comparable to the original systems that were categorized by Aarseth (2012). To further nuance results in future research, the eLNVM should be tested and possibly further extended through the categorization of both commercial games and DGBL systems. eLNVM contributes to the debate on isolation and categorization of narrative development in all games, whether they are created for commercial purposes or if they constitute DGBL systems.

LNVM is part of a larger narrative theory of games. For example, ontologies are either ludic or story drivers, stories are separated by degree of emergence and the games can be categorized on a single axis from a ludic to a narrative pole. These, however, are all aspects that may serve to define games as narratives, but only after they have been categorized ontologically. Since our study concerns itself with determining if the LNVM is usable to categorize narratives in DGBL, further inspection was not conducted. Based on the positive indications revealed here, such aspects warrant further study.

Conclusion

A review of previous research revealed that DGBL has the potential to positively enforce engagement, motivation and learning in broad populations across various subject matter and 21st century skills. Positive enforcement is particularly evident when applying learning theories, such as constructivism, socio-cultural learning and flow theory. Furthermore, narratives are considered a main game element, which can be introduced in DGBL to strengthen such positive effects. In other instructional contexts, narratives have been shown to increase learning, also by engaging and motivating learners. The field, however, is lacking a common model on which to compare and contrast the characteristics of narratives in DGBL. This research fills this gap by proposing such a model, eLNVM. We extended and showed how Aarseth's LNVM is a usable tool to isolate and categorize the narrative from other game elements. Fifteen narrative DGBL that have self-reported evidence related to effect of narratives and a system description available to enable categorization on the eLNVM, have been analyzed and categorized. Thus, we provide a common model that allows separate and comparative investigation of the effects that DGBL systems have on learning and the conditions under which it occurs.

By making two extensions to Aarseth's LNVM, which has implications for work in game studies as well as in studies of DGBL systems, this research has shown that the eLNVM can be used to isolate and categorize narrative DGBL. The study revealed that there are ontological categorization clusters that separate, and to a certain extent isolate, the characteristics of DGBL systems that have positive effects on engagement, motivation and learning from DGBL systems that show less than positive effects. This is an important contribution to current research, since it shows how previous, current and future studies of narratives in DGBL systems can be (re-)categorized and (re-)evaluated, alone and in comparison, using common ontological categorization spanning author to game agency.

In future studies, the eLNVM can be used directly, which has the potential of creating a corpus of studies over time that have been evaluated using the same model, enabling comparison across DGBL systems without further refinement of DGBL system categorization. This requires, however, sufficiently detailed descriptions of the DGBL systems for researchers to be able to plot them using the eLNVM. In future evaluations of DGBL systems, we encourage and recommend the inclusion or direct reference to system descriptions suitable for categorizing the DGBL system. While this study explored effects from narratives in DGBL systems on engagement, motivation, and learning, it is emphasized that the eLNVM is not only useful for evaluation of effects on those three concepts, but also any other concepts or features in DGBL systems under scrutiny.

Finally, this research contributes to the future design of DGBL systems by showing which ontological characteristics that are expected to optimize the potential for positive effects on engagement, motivation and learning. In ongoing work, a process using the eLNVM as basis for efficient design of effective narrative DGBL by multidisciplinary teams is being tested and evaluated.

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Statements on open data, ethics and conflict of interest

A detailed diary, showing all excluded studies, inclusion/exclusion and a reference list of original searches is available from the first author.

The study adheres to the ethical guidelines monitored by the Norwegian Center for Research Data. VilVite has a mandate to advance science teaching in Norway in cooperation with schools.

VilVite is not motivated to affect the research results in any way and the employment there does not constitute a conflict of interest.

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eLuna: A Co-Design Framework for Narrative Digital Game-Based Learning that Support STEAM

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STEAM education enables the cross-curricular study of subjects based on their naturally occurring relationships through holistic and integrated methods. Narratives are enablers of STEAM learning environments, something that is evident in the exploration of narrative learning from pre-recorded history until present. Narrative Digital Game-Based Learning (DGBL) use narratives to drive the game. The extended Ludo Narrative Variable Model (the Variable Model) is a narratological model for categorization of narrative DGBL. Empirical evidence from categorizing narrative DGBL on the Variable Model shows that there is a particular set of categories that incur positive effects on engagement, motivation, and learning. This article introduces the eLuna co-design framework that builds on these categories and empowers educators to participate alongside game developers in multidisciplinary design and development of narrative DGBL. eLuna comprises 1) a four-phase co-design method, and 2) a visual language to support the co-design and co-specification of the game to a blueprint that can be implement by game developers. Idun's Apples, a narrative DGBL co-designed, co-specified, and implemented into a prototype using eLuna, is presented to illustrate the use of the method and visual language. Arguing that narrative DGBL are vessels for STEAM learning, seven eLuna co-designed games are examined to illustrate that they support STEAM. The article concludes that narrative DGBL co-designed using the eLuna framework provide high opportunity and potential for supporting STEAM, providing educators and game developers with a STEAM co-design framework that enforces positive effects on engagement, motivation, and learning.

Keywords: narratives, games, digital game-based learning, co-design framework, co-design, technology enhance learning (TEL)

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INTRODUCTION

Teaching and learning in STEAM allows for cross-curricular study of subjects based on their naturally occurring relationships through holistic and integrated methods. STEAM integrates Arts with STEM (Science, Technology, Engineering, and Mathematics). Yakman (2008) defines the classification of STEAM subjects as:

- Science: *What exists naturally and how it is affected*
- Technology: *What is human made*

- Engineering: *The use of creativity and logic, based in mathematics and science, utilizing technology as a linking agent to create contributions to the world*
- Arts: *How society develops, impacts, is communicated and understood with its attitudes and customs in the past, present and future*
- Mathematics: *Numbers and operations, algebra, geometry, measurement, data analysis and probability, problem solving, reasoning and proof, communication, trigonometry, and calculus,*

Research has shown that games and narrative learning environments have the potential to address Arts and embed it within study of STEM subjects. An example is illustrated by Pant et al. (2020), showing that adding stories and poems to mathematical education creates increased motivation and meaningful engagement towards mathematical classroom education. Another example is provided by Hunter-Doniger et al. (2018) who, realizing that non-arts educators need to learn how to infuse the culturally relevant arts into STEM, created a unique approach to STEAM through storytelling. The approach 1) emboldened children in constructing academic knowledge, 2) gave students the voice or the cultural competence to approach standards in ways that make the information relevant, and 3) gave students the opportunity to develop a socio-political consciousness and evoke change. A third example is found in Bronwyn et al. (2021), who showed that participation in story-worlds lays foundation for STEAM education that led to new understanding in neuroscience, sustainability, physics, and space science.

The research presented in this article enforces this position by first exploring narrative learning traditions in a historic perspective, before placing an emphasis on narratives in digital game-based learning (DGBL) and showing how DGBL, too, are narratives that enable cross-curricular learning environments for STEAM subjects. Having established that narrative (digital) gamed-based learning supports STEAM, the eLuna framework, a multidisciplinary co-design framework for developing narrative DGBL, is presented and its use illustrated through a description of the co-design of a narrative DGBL named Idun's Apples. Then, seven narrative DGBL that were co-designed using the eLuna framework (including Idun's Apples) are investigated for their support of STEAM education. The findings and discussion argue that eLuna is usable as a multidisciplinary co-design and specification framework for creating effective narrative DGBL that supports STEAM education.

BACKGROUND

This section explores narratives and their application for STEAM from a historical perspective, before presenting narrative digital game-based learning (DGBL) and showing how these can be considered STEAM learning environments. Then, perspectives on, and requirements for, co-design frameworks for both STEAM and DGBL are presented.

A Historical Perspective on Narrative Learning and STEAM

Narratives use to support learning dates to prehistoric times. People started formulating narratives alongside developing speech, and these emergent narratives soon included units of information enabling humans to learn about themselves and the worlds in which they lived (Zipes, 2012). In prehistoric times, informative tales were told to "mark an occasion, set an example, warn about danger, procure food, or explain what seemed inexplicable. People told stories to communicate knowledge and experience in social contexts" (Zipes, 2012, p. 2). In the STEAM perspective, for example, the transfer of the 'knowledge' about 'procuring food' (as the 15,000 year old Lascaux cave paintings have been speculated to be used for (Curtis, 2008), may include STEM through methods for hunting and growing (Science), equipment to use, such as spears or traps for hunting, or systems of irrigation and tools for harvesting (Technology), how to plan and build equipment or installations (Engineering), and the laws of physics based constraints in play while developing methods and functional equipment, such as integrity of material to use, depths, diameters, and other measures such as fortifications of installations used for trapping, herding, or storing (Mathematics). Regardless of whether such prehistoric narratives emphasised one or the other of these core STEM subjects, they certainly integrated holistically across curriculums through naturally occurring relationships. These STEM subjects further integrate meaningful Arts subjects by *communicating knowledge and experience in social contexts*. For example, the reasons for, and cultural parameters related to, food procurement provide meaning in the time and place for learning, as would exploring the efforts needed to sustain a society, population development, demographics, climatic and environmental conditions, social goals and norms, laws and rules, culturally dependent ethics and belief systems, political situations. In short, STEAM education encompasses learning, as formulated by Yakman (2008 p.16), *how society develops, impacts, is communicated and understood, with its attitudes and customs in the past, present, and future*. Equally, in a modern perspective more recent philosophical texts apply narratives in inherently STEAM learning environments. This can be seen, for example, in the classic work *The Tragedy of the Commons* (Hardin, 1968), which places an emphasis on the Arts in social sciences, ethics, law, and sustainability, but which also includes natural occurring cross-curricular relationships to biology (Science), construction, manufacturing, and design (Technology), agriculture (Engineering), and numerical operations, measurements, data analysis, reasoning, and problems solving (Mathematics).

Narrative Digital Game-Based Learning

In current research, Digital Game-Based Learning (DGBL) (Prensky, 2001) is regarded to constitute three major variations: 1) Serious Games, full featured video games created with the purpose to teach someone something, 2) Gamification, using a subsets of video game features, and integrating them in non-game learning systems to in some way or another enhance the learning situation, effect, or outcome, and, 3) Commercial off the Shelf (COTS) games used as an integrated part of any form of non-game-based learning and training process (Breien and Wasson, 2021). The Logo educational video game, designed by Feurzeig, Papert, and Solomon in 1967[1], and described 7 years later by Abelson, Goodman, and Rudolph (1974) can, according to Jeremy Chen of Immersed Games, be considered the first educational video game, as it "blended mathematics and programming by allowing teaching players the basics of coding by directing a turtle-shaped cursor to draw lines"[2]. Soon after, and more famous than Logo, came Oregon Trail, a 1971 educational video game published by Minnesota Educational Computing Consortium (MECC)[3]. Oregon Trail was soon assimilated in schools, where the game, through several version lifecycles, remained in use for 30 years[4]. Primarily, Oregon Trail was used in history education for teaching 8th graders in the United States the realities of 19th-century pioneer life through the DGBLs narrative. The game included naturally occurring relationships to STEM subjects in that the game players also needed to 1) balance finances to acquire supplies, 2) manage resources in inventories based on weight and load capacities, 3) procure food and equipment along the way through hunting and trading, and 4) calculate travel speed dependent on load weights, natural topographical, and weather conditions. In their summary of the origin of serious games, Djaouti, Alvarez, Jessel, and Rampnoux (2011) attribute Oregon Trail as being "One of the most famous ancestors of current serious games" (p. 8), a game that shows us how "an educational or serious game is not necessarily the opposite to a popular and commercially successful game" (p. 9).

The trend of narrative DGBL that support cross-curricular learning of naturally occurring relationships in STEAM subjects continues in modern times. An example is found in the Crystal Island DGBL (Rowe et al., 2010; Rowe et al., 2011; Lester, et al., 2014). Crystal Island exists in two versions in a shared setting based on the Arts, in which a social structure constituting the members of a science team with formal roles and responsibilities are isolated on a deserted island and victims to an unknown epidemic. Additionally, one of the Crystal Island versions focuses on microbiology and medicine (Science), and the other on cartographical tools (Technology). Through both versions, Crystal Island emphasises construction (Engineering), and measures, reasoning, and problem solving (Mathematics) as supporting STEAM disciplines. The objective of Crystal Island is to stop the epidemic and diagnose the cause through effective medical research and containment measures, and to escape the island quickly through detailed mapping, orientation, and subsequent effective emergency signalling. Another example is the Cache 17 DGBL (described in Pilegard and Mayer, 2016), which teaches wet-cell battery construction (Engineering) and functionality (Technology), with cross-curricular naturally occurring relationships to chemistry (Science), measurement, probability, and problem solving (Mathematics), using a history, law, and economic (Art) setting, in which two insurance agents penetrate an old war bunker to obtain pieces of stolen art.

Empowering Co-Designers in STEAM and Narrative Digital Game-Based Learning

Narrative DGBL is a media with high potential to enrich STEAM environments in education. STEAM environments allow for holistic and integrated cross-curricular study of subjects based on their naturally occurring relationship with one another requiring multidiscipline educators involved in the development of learning materials. As Hunter-Doniger et al. (2017) have pointed out, STEM educators need methods to integrate culturally relevant arts in education to properly deliver STEAM structures in education. Observing difficulties to transdisciplinary teaching, arts integration, and collaborative learning, Milara et al. (2020) initiated STEAM educator training across subjects to increasing teachers' collaborative awareness, thus scaffolding Communities of Practice for educators' development of STEAM digital fabrication. Pointing to calls for interdisciplinary approaches to education nurturing stronger synergies between STEAM subjects, Finch et al. (2018) use storyline authoring (Reiser et al., 2013) as a workshop-based co-design framework bringing together educators from arts, science, and computing disciplines, blending their expertise to counter stagnant and marginalizing practices in those disciplines. Seeing how STEAM subjects need recognition, embracement, and prioritisation of different forms of disciplinary knowledge that can be identified in the spaces between disciplinary curriculum and pedagogy, MacDonald et al. (2019) compel educators to dissolve and transcend disciplinary boundaries through the enactment of emergent interdisciplinary pedagogies that generate interdisciplinary learning. As these examples show, the need for empowering co-design frameworks and methods are apparent in STEAM learning environment development.

Similarly, the design and development of narrative DGBL requires a multidisciplinary team and an approach that enables and empowers educators and game designers in their co-design of narrative DGBL. As pointed out by Silva (2020), to create a DGBL that is both educationally efficient and fun to play, both game experts and educational experts must be able to communicate efficiently in the design process. Focusing on the role of educators, but implying the need for game designers, Marchiori et al. (2011) emphasises the need to empower educators with no technical background so that they can participate in DGBL design and development. Arnab et al. (2015) point to the lack of tools that allow educators to understand how to implement serious games in education, an observation which is shared by Lameras et al. (2017) who stress the need for pedagogically driven, inclusive processes of serious game design. Focusing on the game designer role, Carvalho et al. (2015) points to a gap between idea and implementation, due to a lack of models, methods, and frameworks to help understand how DGBL requirements are

[1]https://en.wikipedia.org/wiki/Logo_(programming_language).

[2]http://www.immersedgames.com/the-history-of-educational-video-gaming.

[3]https://en.wikipedia.org/wiki/The_Oregon_Trail_(series).

[4]https://www.smithsonianmag.com/innovation/how-you-wound-playing-em-oregon-trailem-computer-class-180959851/.

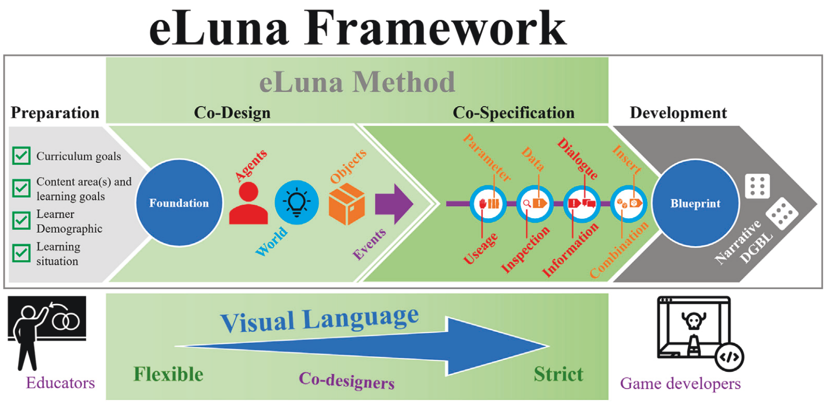


FIGURE 1 | The eLuna framework.

to be concretely satisfied. All in their own way, and combined, this research amplifies the notion that to make effective DGBL that help learners reach their learning goals, educators and game developers needs to be equally empowered in their co-design.

Narrative DGBL is most effective in reaching learning goals when the narratives are designed as non-linear (Breien and Gkini, 2021). Performing a structured search[5] for scientific articles about DGBL design frameworks across five academic databases[6] and in the five highest ranked e-learning journals by impact factor[7] resulted in 67 articles, 17 of which presented frameworks for DGBL. Of these, 17[8] none mention STEAM or STEM. While 12 of the 17 mention narratives or stories, only six articles name narratives as components of the DGBL. Three present a component that exists separately from, and alongside, the game experience (Westera, et al., 2008; Carvalho, et al., 2015; Lameras et al., 2017), and three as a game component equal to any other component in the game, such as the world, the interactions, and the art (Marchiori, et al., 2011; Arnab, et al., 2015; Silva, 2020). According to a narrative theory of games (Aarseth, 2012), this implies borrowing and adapting classical models for narrative design from other dominant media (such as books, films, or theatrical plays). Borrowing models from other media does not lend itself to fully taking advantage of the non-linear narrative structures available through games, since classical models are not able to fully classify non-linear narratives (Breien and Gkini, 2021). According to a narrative theory of games (Aarseth, 2012), games should be considered as a dominant narrative media employing its own models for proper analysis and design. Thus, we identify a need for the development of frameworks for co-design of narrative DGBL that adheres to the narrative theory of games and the categories available through non-linear narratives that are associated with positive learning effects.

THE ELUNA FRAMEWORK

The eLuna framework (see **Figure 1**) supports educators and game developers (co-designers) to methodologically co-design narrative digital game-based learning (DGBL). Beginning with educators defining curricular content, learning objectives content area, learner demographics, and the learning situation in a preparatory phase, eLuna guides co-designers through co-design that produces a game description in table format, and a co-specification phase that results in a narrative DGBL blueprint. In a final development phase, the blueprint is used as basis for development of a narrative DGBL. Through the co-design and co-specification phases, eLuna employs a visual language based on icons, colours, and written descriptions that enables a methodological process that is used partially and flexibly through the design phase, allowing participants to focus on overarching game principles and elements, and fully and strictly through the specification phase, that results in an unambiguous technical blueprint that forms the basis for development of the narrative DGBL.

A DGBL can be categorized according to how it meets elements of a game and a narrative that is defined by ontologies that includes a world, objects, agents, and events, described more fully in **Section 3.2**. These are mapped against scales from narrative to game mechanical. A DGBL's ontological

[5]Using the search string < Design AND (Method* OR Process OR Framework) AND ("Serious Game" OR "Serious Games" OR "Digital Game Based Learning")> with no date/year restriction.
[6]ACM Digital Library, IEEE Explore, PsycINFO, Science Direct, and Web of Science.
[7]As per Scimago Journal and Country Rank, end of year 2019: Internet and Higher Education, Computers and Education, Government Information Quarterly, British Journal of Educational Technology, and Journal of Computer Assisted Learning.
[8]From 67 before a) duplicate removal (8), b) false positive removal (27), and c) excluding articles that concerned the same frameworks, as well as articles that described having used a framework but do not include details about how it worked (15).

TABLE 1 | The extended Ludo Narrative Variable Model, highlighting the categories associated with positive effects on engagement, motivation, and learning (Breien and Wasson, 2021).

Ontology polarity	World	Objects	Agents	Events
Narrative pole	Inaccessible	Non-interactable	Deep, rich, round	Fully plotted
High author agency	Single room	Static, usable	Grounded, consistent	N/A
	Linear corridor	Modifiable	Sensible	Linear fixed kernels, dynamic satellites
	Multicursal labyrinth	Destructible	Flat	Interchangeable fixed kernels, dynamic or fixed satellites
High game agency	Hub shaped quest landscape	Creatable	Stereotypical	Dynamic kernels
Ludic (game) pole	Open landscape	Inventible	Bots, no individual identity	No kernels (pure game)

categorization defines its author and game agency from a narrative pole to a ludic (game pole), each at the cost of expressive freedom of the other; a game high author agency under an ontology allows for narrative expressive freedom, at the sacrifice of game mechanical flexibility, and vice-versa. Consider two examples, a classical narrative and a classical game: The Old Man and the Sea (Hemingway, 1995), and Chess. The former employs high author agency to tell a story about an old man that sustains himself by fishing, and that goes on an existential journey at sea. Providing high mechanical flexibility, adding high game agency to The Old Man and the Sea, could for example imply allowing the observer of the story, the player, to decide that the old man goes somewhere else that day, not heading out to sea at all, which would greatly inhibit the author's (Hemingway's) agency to tell the details of his intended story. Similarly, in chess, accommodating for high author agency by for example dictating the white player to move a certain playing piece in a certain way when making the opening move, because that particular match is to tell a story about how that piece started it all, would sacrifice the mechanical flexibility of the entire match, rendering any opening strategy, a vital part of chess, obsolete.

The eLuna framework targets narrative DGBL categories identified in the extended Ludo Narrative Variable Model (the Variable Model) that have been shown to incur positive effects on engagement, motivation, and learning, termed fully positive effects (Breien and Wasson, 2021). The Variable Model categories, see **Table 1**, are sorted by ontologies World, Objects, Agents, and Events and the highlighted categories are those that are associated with fully positive effects.

As can be seen in **Table 1**, the Variable Model categories exist on polar scales from high author agency, where the design of deep narratives is at the cost of game mechanical flexibility, to high game agency, which allows the design of flexible game mechanics at the cost of narrative depth. The fully positive effects categories, *Hubshaped Quest Landscape* Worlds, *Modifiable* Objects, *Grounded and Consistent* Agents, and *Interchangeable Fixed Kernel* Events are described by what characterizes them, which is as follows:

- Hubshaped Quest Landscape: *A World (landscape) consisting of confined areas (hubs) that are explored at will, and in which completing tasks in sequences (quests) open new hubs in the landscape, depending on player choices.*
- Modifiable Objects: *Objects in the World that may be altered, combined, or configured to overcome challenges and reach objectives through completing tasks.*
- Grounded and Consistent Agents: *Characters in the game narrative with sensible and well described backgrounds, psychologies, and goals.*
- Interchangeable Fixed Kernels: *Storyline events of high importance that are pre-written and interchangeable among each other, allowing for traversing a story in different orders based on player choices*

As seen from the characteristics, a narrative DGBL associated with fully positive effects is a system in which the player/learner guide describes characters using complex objects to perform tasks in select and non-deterministic sequences in an expanding world where pre-written chapters of a story are experienced in optional sequences. The eLuna framework targets the categories that are associated with fully positive effects. The next sections present the eLuna method and visual language.

The eLuna Method

The eLuna method has been iteratively developed through three co-design workshops in which 2 teams of co-designers (20 in all), all with background from education (10 teachers from high school to university college levels), educational technologies (six experts holding PhDs in Technology Enhanced Learning related areas), or DGBL development (four developers from the serious games industry) followed the method. Each workshop was facilitated and moderated by a researcher, was evaluated by the co-designers, and the method was updated before the next workshop. Thus, the three workshops resulted in six narrative DGBL co-designs. **Table 2** presents the 4 phases of the eLuna method.

Educators work alone during the Preparatory phase to identify the curriculum goals, the content area and/or learning objectives, the learner demographic, and the learning situation. Educators and Game developers work together in the Co-Design phase supported by a simplified version of the visual language (see **Section 3.2**). Using the preparatory material as guidance they exploratorily uncover all the elements of the narrative DGBL (in the order of agents, world, objects and events) and show how they work together while conforming to the characteristics of the targeted Variable Model categories; this is presented in a quest and task design. At this stage there is no obligation to tie the entire game flow together in a technical and unambiguous manner. During the third phase, Co-Specification, co-designers use the

TABLE 2 | The eLuna method.

	Phase	Activity	Participants
	1 Preparation	1.1 Summarize curriculum goal(s)	Educators
		1.2 Define content area(s) and learning goals	Educators
		1.3 Describe learner demographic	Educators
		1.4 Describe learning situation	Educators
Simplified and flexible visual language	2 Co-design	2.1 Present preparatory work	Educators and Game Developers
		2.2 Design the Agents	Educators and Game Developers
		2.3 Design the World	Educators and Game Developers
		2.4 Design the Objects	Educators and Game Developers
		2.5 Design the Events	Educators and Game Developers
Complete and strict visual language	3 Co-Specification	3.1 Specifying the hubs and quests	Educators and Game Developers
		3.2 Specifying Agents and Objects in quests	Educators and Game Developers
		3.3 Specifying Agents dialogues	Educators and Game Developers
		3.4 Specifying Events narrative passages	Educators and Game Developers
	4 Development	4.1 Developing the narrative DGBL	Game developers
		4.2 Deploying the narrative DGBL	Game developers

complete visual language (see **Section 3.2**) adhering to its strict rules to translate the Quest and Task design into a Blueprint for the game. The blueprint unambiguously describes the game flow in a technical manner sufficient enough to serve as a basis for a narrative DGBL that can be developed. In the fourth and final phase, Development, game developers develop the narrative DGBL, and deployment of the final narrative DGBL (e.g., through a website, an LMS, etc.).

The eLuna Visual Language

The eLuna visual language has been developed to support the co-design and co-specification phases. By employing colour coding for different ontologies, red for Agents, green, blue, and purple for World, orange for objects, and purple for events, and additionally, graphical notation to indicate elements for all ontologies, the eLuna visual language provides a structured way to describe a narrative DGBL. In the design phase a simplified and flexible version of the visual language is employed, meaning that the participants can, if they need, resort to other descriptive techniques so as not to stop the work due to expressive difficulties or ambiguities. In the specification phase a complete and strict version of the visual language is employed, ensuring that all narrative DGBL elements are unambiguously described. The next four sub-sections present and describe the elements of the eLuna visual language ontology by ontology in the sequence that they are used in the eLuna framework design phase: Agents, World, Objects, and finally Events.

The eLuna Visual Language: Agents

Agents constitute the characters of the narrative DGBL. Agents are drawn as persons using red notation colour, and in the design phase, eLuna co-designers create biographies for them each on a separate paper. The biographies are free form, and contain the personal details of the agents, as well as a description of their role in the narrative DGBL such as which responsibilities and authorities they have, and their skills and competencies related to the learning objectives. To enable grounded and consistent agents, they are also described in terms of personality, such as their goals in life, their worries and fears, and their social and personal lives. **Figure 2A** shows the visual language elements available for the grounded and consistent agent category; eLuna Agent base shape and the four functions they can have in a narrative DGBL. These elements are employed in the specification phase.

As **Figure 2A** shows, in the visual language agents have a base shape and four features that describe the actions the agents can perform in the narrative DGBL: they can participate in dialogues with other agents; they can provide or receive information from other agents or by exploring the world and the objects in it; they can inspect or find agents and objects; or they can use objects or give objects to other agents.

The eLuna Visual Language: World

Worlds are constructed as a set of hubs that are drawn as green circles and labelled and named sequences of tasks drawn as blue circles. Tasks are combined in logical sequences to identify narrative DGBL quests, which are labelled and drawn as purple lines connecting several tasks. Hubs constitute relevant areas in the world where agents can exist and work to solve quests enabling learners to complete the game by completing tasks related to learning objectives. **Figure 2B** shows the visual language elements available for the world category, consisting of Hubs (where things can happen), and Quests (sequences of tasks that can be completed there). These elements are used throughout both the co-design and co-specification phases.

An eLuna world comprise several hubs, all with one or more quest attached to it, drawn using the elements shown in **Figure 2B**. The quests comprise one or more task that must be completed in a particular order. In eLuna narrative DGBL, learners can explore several hubs and quests in parallel.

The eLuna Visual Language: Objects

Objects are drawn as orange boxes and labelled to indicate what they represent. In the eLuna visual language objects can serve four purposes. Two objects can be combined to form a new object (such as adding a seed to soil to get a sprout), or an object can be inserted into another object to alter the purpose (such as changing the bore or screwing bit on an electric drill). Objects can also be

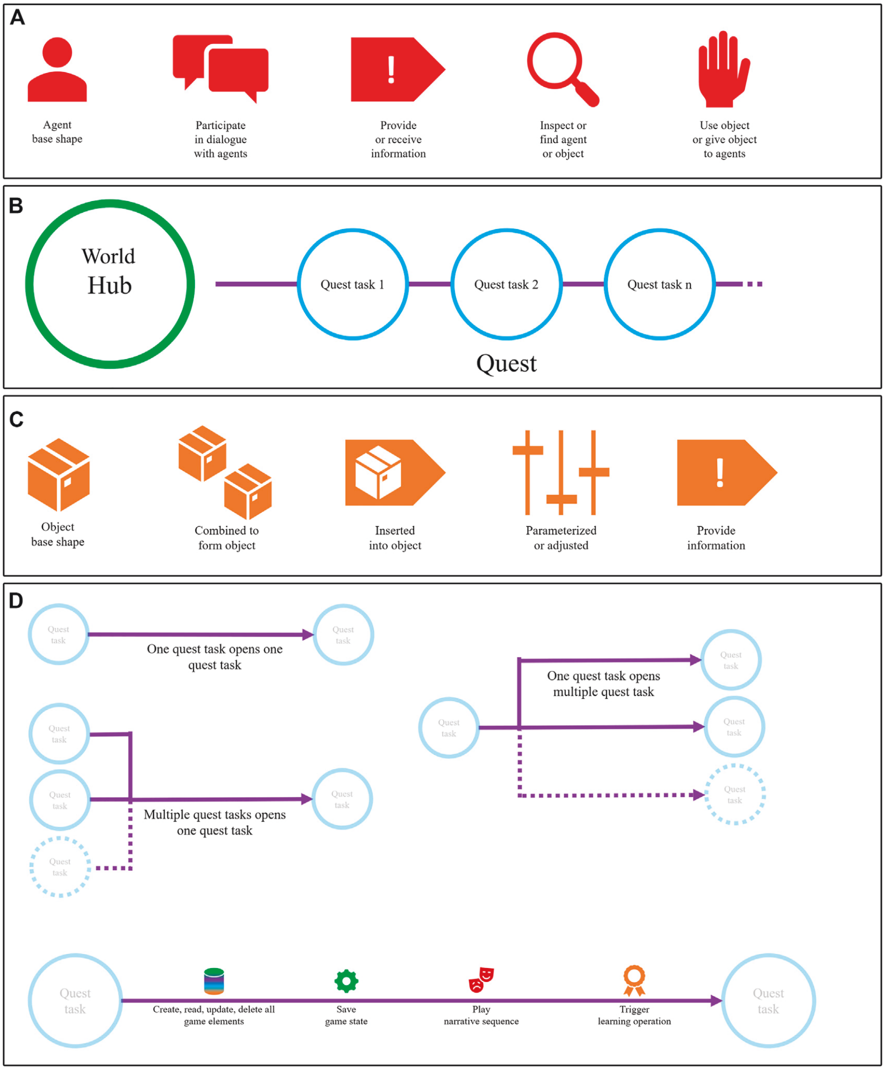


FIGURE 2 | The eLuna visual language.

altered (parameterized) to fit desired functionality (such as setting the program on a washing machine for washing different garments), or objects can provide information (such as searching for something in a browser and following links to relevant content). **Figure 2C** shows the visual language elements available for the modifiable objects category. In the co-design phase objects are listed using the elements, and in the co-specification phase the object elements are further used in combination with agents and other objects to specify their exact usage in quests tasks.

As **Figure 2C** shows, in the visual language objects have a base shape and four features that describe how they can be employed in the narrative DGBL: objects can be combined to form another object; they can be inserted into other objects; parameterized to provide a special functionality; or they can provide information.

The eLuna Visual Language: Events

Events are drawn as purple lines from tasks to other tasks and are triggered by a player's successful completion of quest tasks either by one task opening another, multiple tasks opening another, or by one task opening multiple tasks (see **Figure 2D**). The tasks that are opened can exist in the same hub and quest, in the same hub but a different quest, or in quests that reside in other hubs. Events are associated with defined learning objectives. As the narrative DGBL is played, it is through an event being triggered that the game unfolds and progresses. When events are triggered, all game elements can be manipulated, the game progress can be saved in the current state, narrative sequences can be presented, and out-of-game learning operations can be directed. **Figure 2D** shows the visual language elements available for the events. These elements are used both in the design and specification phases.

Every time an event occurs, all elements (actors, hubs, quests, tasks, or objects) can be created, read, updated, or deleted in the narrative DGBL. Furthermore, the game state can be saved to conserve the progression and allow for breaks, and to provide data for learning analytics. At event occurrences, narrative sequence can also be defined and transmitted. Finally, the learner can be directed to complete learning objective related operations outside of the narrative DGBL, such as completing a quiz, submitting an assignment, participating in a group session, and similar.

IDUN'S APPLES: THE ELUNA FRAMEWORK IN USE

This section illustrates the use of the eLuna framework by one educator and two game designers to develop a narrative digital game-based learning (DGBL), Idun's Apples, from the preparatory work to the final game prototype. Idun's Apples is related to a learning program envisioned at the Bergen Science Centre[9] addressing UN Sustainability Goal 12: Responsible Production and Consumption[10].

Preparation

The Responsible Production and Consumption program at VilVite focuses partially on a curriculum related to climate challenges from food produce production and logistics, and the opportunities and advantages related to local food production. The program is targeted at upper elementary and high school pupils. The learning objectives are related to the content areas: 1) climate gas emissions from food and produce production and logistics, 2) health regulations for food production and commerce, and 3) finances and economics related to sustaining local production and sales of produce. The learning situation is part of a threefold program structure where the narrative DGBL is intended to be part of a preparatory experience in which pupils explore the concept in a school's computer lab before visiting the science center to conduct related physical experiments using interactive science exhibits. The preparatory foundation for the further work on Idun's Apples is summarized as the following:

- Curriculum goal(s): *Climate challenges from food produce production, and the opportunities and advantages related to local food production.*
- Content area(s) and learning objective(s): *1) Climate gas emissions from food and produce logistics, 2) Health regulations for food production and commerce, and 3) Finances and economics related to sustaining local production and sales of produce.*
- Learner demographic: *Upper elementary and high school.*
- Learning situation: *Science center at school preparatory experience.*

Co-design

During this phase the educator and the two game developers worked together using the information from **Table 3** to design the agents, world, objects, and events. The phase begins with the educators presenting the information to the developers to establish a common understanding of the game context.

Designing the Agents

eLuna targets grounded and consistent agents, and these are described first. In the design phase, the co-designers focus on the details of the agents, who they are, their roles, responsibilities, and authority, their backgrounds, and their goals. As such, co-designers in the design phase do not use the elements of the visual language when describing actors, these details are added during the following specification phase. In the Idun's Apples game, the protagonist Idun was described first. **Figure 3A** shows how Idun is described in the design document that emerged from the design phase.

The co-designers also identified 13 additional agents for the narrative DGBL:

1. Idun's Son, Rubin: *Happy and curious, with a mild asthma*
2. Farmer's Market representative, Steinar: *Organisational secretary with responsibility to assist development of local Farmer's Markets*
3. Bureaucrat, Lars: *Forgetful and overworked, not always on top of getting formal processes right*
4. Politician, Hildegunn: *Francophile and more interested in imports than local products. Likes good media coverage*
5. Urban farmer, Lise: *Advanced hobby grower selling produce on social media who is terrified of health regulations*
6. Food and sanitation inspector, Günther: *Would be FBI agent turned very thorough inspector in his hometown*
7. Café owner, James: *Wants to use local produce in kitchen but has little access. Very helpful with ideas and marketing*
8. Librarian, Rikke: *Very helpful with PR about Farmer's Market at the local library*
9. Park owner, Konstantin: *Has plot where Farmer's Market can be established*
10. Supermarket clerk, Ivan: *Thinks imported fruits are the best, since they taste sweeter than local ones*
11. Supermarket clerk, Igor: *Thinks local fruits are the best, since they taste more real than imported ones*

[9]The Bergen Science Centre (VilVite) is a partner in this research through the first author's industrial PhD grant from the Research Council of Norway (RCN).
[10]https://sdgs.un.org/goals/goal12.

TABLE 3 | Co-designed eLuna narrative DGBL 1 through 6, elements identified by category.

#	Grounded and consistent agents	Hubshaped quest landscape	Modifiable objects	Interchangeable fixed kernels
1	• The man in the woods • The entrepreneur • Politicians • Construction workers	• The man's farm • The forest • The build-site • Town square • Town hall	• Physical barriers • Traps • Computer • Car	• The man making barriers and traps • Meetings at town hall • Meetings at entrepreneur • Confrontations at the build-site
2	• The wife • The husband • The assassin	• The married couples house • The fishing boat • Local bar • Social media radical	• Fishing equipment • Assassins weapons • Computer with social media	• The husband going to and returning from fishing • Quarrel at the house • Meeting at the bar • Assassination • Reading conspiracy theories
3	• The intern • The reception clerk • The ambulance driver • The doctor • Other nurses	• Reception • Ambulance arrivals • Doctors office • Operation theatre • X-ray room	• Registration tablet • Medical equipment like bandages and casts, x-ray, operating equipment, ventilators, stethoscopes, syringes, medicine, and more	• Arrival and registration of patients • Sending patients to treatments • Orders to assist treatments
4	• The old man • Pupils • Professionals encountered at workplaces	• The classroom • The old man's apartment • Professional places where work is conducted, e.g., offices, bank, media station, fire department, hospital, school or university, construction site, and so on	• Any kind of equipment used in the professions that can be explored, e.g., fire hoses, medical equipment, computer programs, machines, and so on	• Visiting the old man • Talking to the old man • Being sent to places by the old man • Performing work activities at workplaces
5	• The girl • Her mountain bike friends • Politicians • NGO manager • Private investors • Building entrepreneurs	• Mountain bike tracks • Club house plot • Town hall • Local NGO • Girl's home	• Bikes • Construction materials • Computer with internet • Transportation means	• Getting public or private funding • Choosing building materials • Constructing club house • Using various forms of transport to mountain • Mountain biking
6	• The juveniles with various appearances and concerns related to puberty • Teachers • Older kids • Doctor and nurse	• The classroom • The schoolyard • The locker room at the school gym • The youths' homes • At the doctors • Social media platforms	• Pop artifacts • Fashion items • The mobile phone • Glasses • Schoolbooks • Food	• Posting something on social media, or seeing a post • Having physical or mental challenges caused by puberty • Visiting the doctor • Parent/teacher meeting

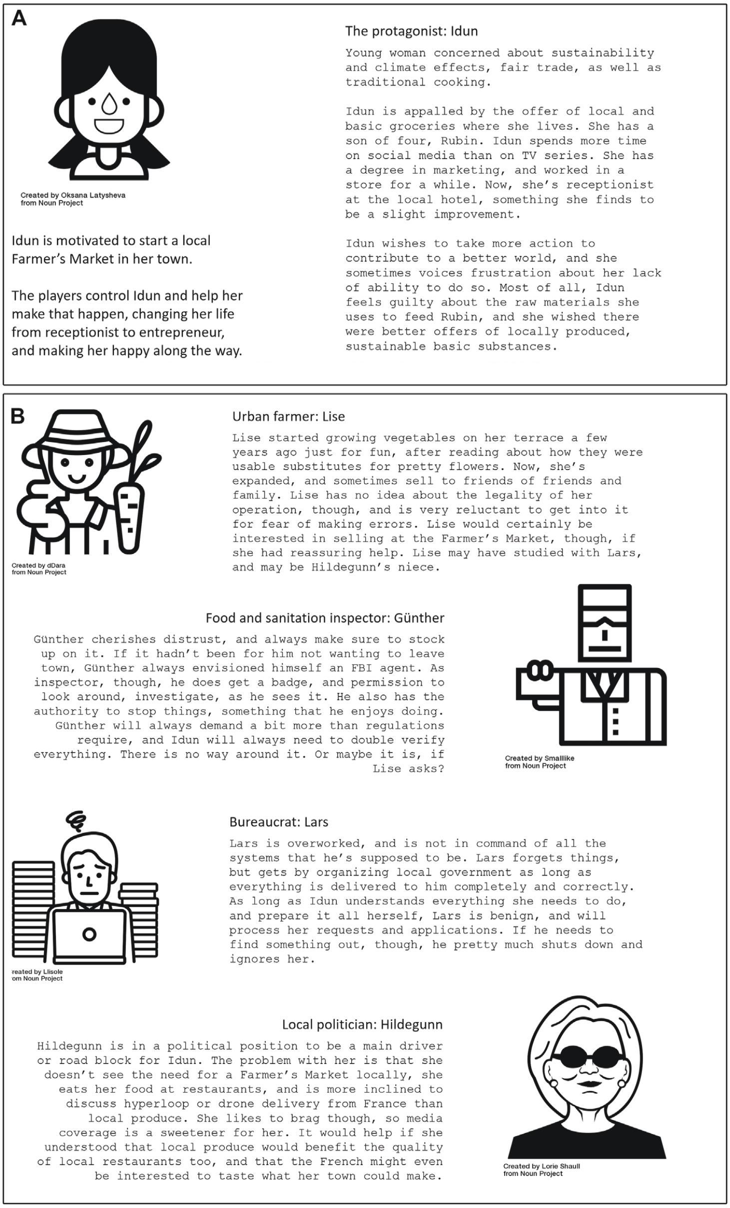


FIGURE 3 | eLuna agents design phase.

12. Culture fund manager, Dina: *Can support funding for events like the Farmer's Market, provided public support is also in place*
13. Gallery owner, Sara: C*an provide advertising in gallery store, and can initiate local arts and crafts stall at the market*

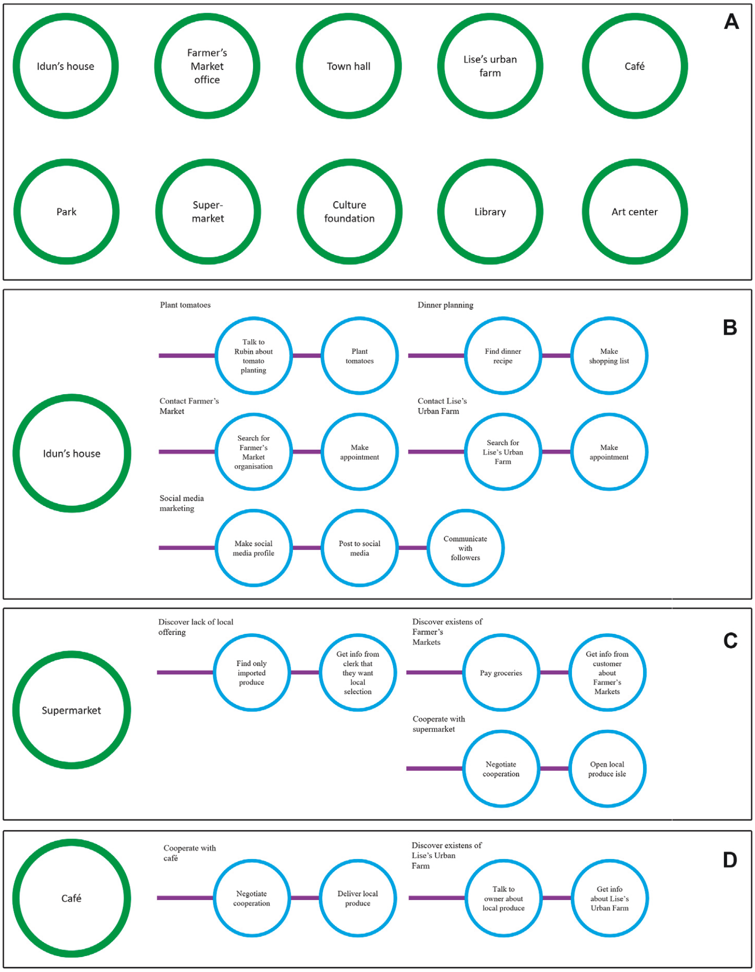


FIGURE 4 | eLuna hubs and quests design phase.

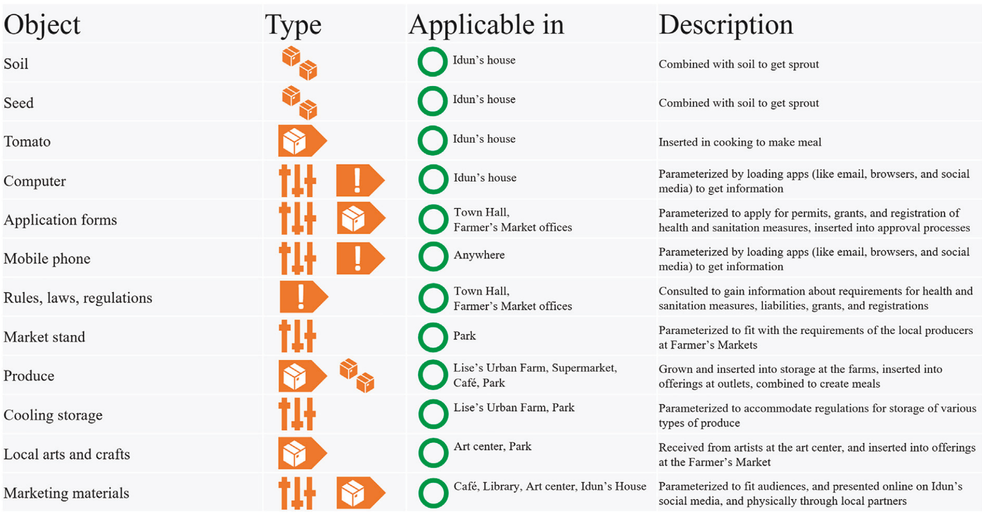
Figure 3B describes four of the agents in more detail.

Designing the World

In eLuna, the world is constructed as a set of locations (hubs) where sequences of tasks may be performed to reach objectives (quests). Co-designers are encouraged to brainstorm hubs and to define quests that logically belong at the locations. Then, in as much detail as possible, the quests are broken down into sequences of tasks that must be completed in sequence to complete the quest. In Idun's Apples, the co-designers identified 10 hubs of relevance, shown in **Figure 4A**.

In the next step, the co-designers identified 27 quests related to the 10 hubs. The quests were broken down from between one and three tasks per quest (there are no minimum or maximum number of tasks in quests, this was only the range that came out of the Idun's Apples design phase), resulting in a total of 63 tasks in the game. **Figure 4** (B through D) shows the developed quests for Idun's house (B), the supermarket (C), and the café (D).

As seen from **Figure 4** (B through D), ten quests totalling 21 tasks are identified under the three hubs Idun's house, Supermarket, and Café. At her house, Idun can 1) plant tomatoes with her son Rubin, 2) plan dinner for the two of them and make a shopping list, 3) use the Internet to find out about the Farmer's Markets organization and contact it, 4) use the Internet to find out about Lise's Urban Farm and



Object	Type	Applicable in	Description
Soil		Idun's house	Combined with soil to get sprout
Seed		Idun's house	Combined with soil to get sprout
Tomato		Idun's house	Inserted in cooking to make meal
Computer		Idun's house	Parameterized by loading apps (like email, browsers, and social media) to get information
Application forms		Town Hall, Farmer's Market offices	Parameterized to apply for permits, grants, and registration of health and sanitation measures, inserted into approval processes
Mobile phone		Anywhere	Parameterized by loading apps (like email, browsers, and social media) to get information
Rules, laws, regulations		Town Hall, Farmer's Market offices	Consulted to gain information about requirements for health and sanitation measures, liabilities, grants, and registrations
Market stand		Park	Parameterized to fit with the requirements of the local producers at Farmer's Markets
Produce		Lise's Urban Farm, Supermarket, Café, Park	Grown and inserted into storage at the farms, inserted into offerings at outlets, combined to create meals
Cooling storage		Lise's Urban Farm, Park	Parameterized to accommodate regulations for storage of various types of produce
Local arts and crafts		Art center, Park	Received from artists at the art center, and inserted into offerings at the Farmer's Market
Marketing materials		Café, Library, Art center, Idun's House	Parameterized to fit audiences, and presented online on Idun's social media, and physically through local partners

FIGURE 5 | eLuna objects design phase.

contact her, and 5) create and manage a social media page to market her own local Farmer's Market initiative. At the Supermarket, Idun can 1) discover that there is no local produce available, 2) learn that there exists a central organization to help facilitate local Farmer's Markets, and 3) make a deal with the Supermarket to sell local produce once supply has been established. At the Café she can 1) learn about the existence of Lise who has an urban farm from which she sells local produce on the Internet, and 2) as with the Supermarket, establish a deal to supply the café with local produce. Including those three shown in **Figure 4** (B through D), the following quests were designed for the following hubs in the game:

- Lise's house: *Plant tomatoes, Dinner planning, Contact Farmer's Market, Contact Lise's Urban Farm, Social media marketing*
- Supermarket: *Discover lack of local offering, Discover existence of Farmer's Market, Cooperate with Supermarket*
- Café: *Cooperate with Café, Discover existence of Lise's Urban Farm*
- Farmer's Market central office: *Learn public health and sanitation requirements, Learn Farmer's Market policy, Incorporate as Farmer's Market, Approve Lise as vendor*
- Town Hall: *Get approval for Farmer's Market, Incorporate legal business, Get health and sanitation approval, Apply for public grant*
- Lise's Urban Farm: *Learn about Lise's life, Health and sanitation preparation, Farmer's Market policy preparation*
- Park: *Visit Park, Secure venue for Farmer's Market, Health and sanitation preparation, Hold first Farmer's Market*
- Culture foundation: *Apply for culture fund grant*
- Library: *Make deal for PR*
- Art Center: *Make deal for sales stall*

The individual tasks in the quests are left out of the above list, however, they are described in **Section 4.2.5** where the full design for Idun's Apples is shown.

Designing the Objects

eLuna places emphasis on objects that can be modified in three ways: combinable, insertable, or parameterizable. Furthermore, objects can provide information, be observed by agents, used by agents, or given by agents to other agents. During this step, co-designers are encouraged to identify as many objects as possible that are applicable for the game, define their types, and indicate in which hub these objects belong if any, as some objects, like mobile phones or credit cards, can be carried around and used many places. When designing Idun's Apples, the co-design process resulted in 12 modifiable objects. **Figure 5** shows the object definitions, their type, where they are applicable, and their general description.

As seen in **Figure 5**, objects can be of one or more type, and can be applicable in one or more hub. The description of the objects in the co-design phase is used in the co-specification phase to identify exactly how they are applied by whom, where, and at what time.

Designing the Events

The final step is to design the events. eLuna events are interchangeable and fixed, meaning that they are pre-written (fixed), and that they can be observed by the players in various

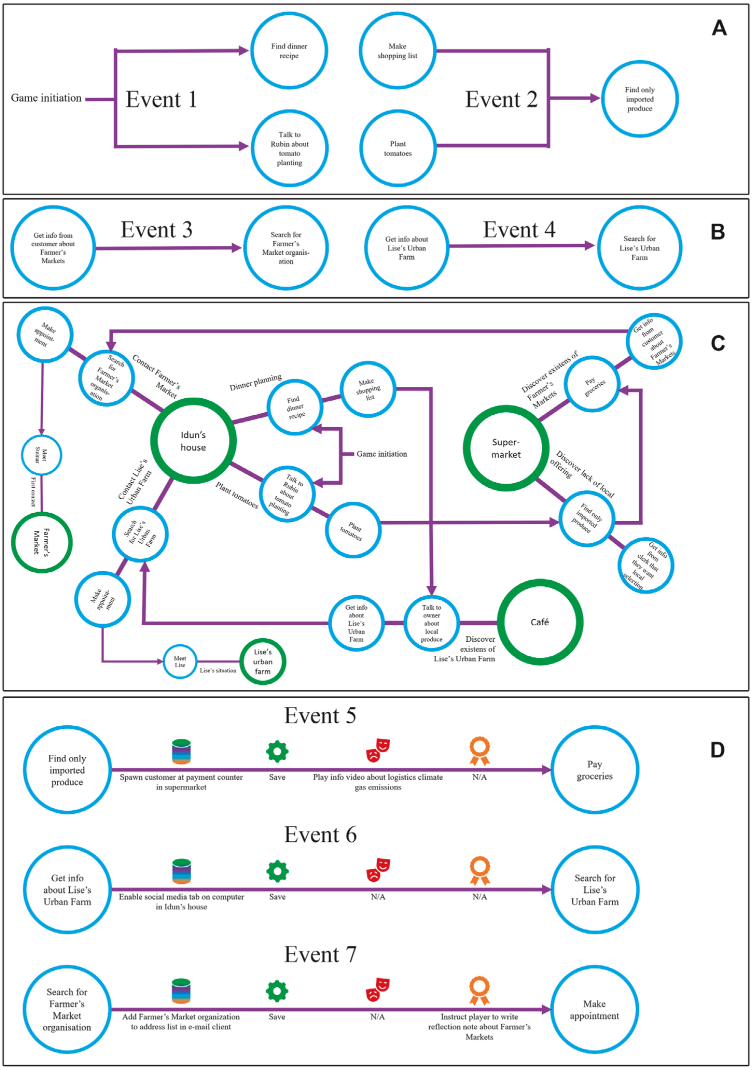


FIGURE 6 | eLuna events design phase.

sequences from play through to play through (interchangeable), depending on how different players decide to proceed with the game. Revisiting the design of the world (chapter 3.2.2), the first events to be identified are all the lines that have been drawn between tasks belonging to the same quests. Further events are identified by examining the logic of the game that has been designed so far and using the visual language lines to draw events as they occur between tasks that belong to different quests in the same hub or in other hubs. At the start of events design, a special one-off event that initiates the game is defined, pointing to all tasks that will be available when a player starts a new game play session.

For the Idun's Apples world design, it is known that Idun wants to plant tomatoes with Rubin and make a shopping list for dinner. The co-designers decided to allow both quests to be available at game start, and that both should be completed before Idun can go to the supermarket to make her purchases. At the supermarket she will discover that the supermarket only carries imported goods. As shown in **Figure 6A**, the above logic identifies two new events; the first (Even 1) is an event that starts by initiating the game, opening the first two game tasks, the second (Event 2) is completing two different tasks to open a new task.

At the supermarket, Idun also gets the opportunity to learn about Farmer's Markets from a fellow customer, which is a one-to-one event (Event 3) opening a task allowing her to search for information about Farmer's Markets on the computer in her house. Similarly, the co-designers decided to allow Idun to visit the café, where she can talk to the owner and learn about Lise, a conversation leading to another one-to-one event (Event 4), opening a task at her computer where she can search out Lise on social media. **Figure 6B** shows the two one-to-one events.

In the Idun's Apples design, the co-designers mapped out events to the point in the game where Idun travels to meet Steinar at the Farmer's Market, and Lise at her Urban Farm, as this was as far as the narrative DGBL prototype would be implemented. **Figure 6C** shows the full set of events identified by the co-designers through linking quests tasks together, leaving out three quests that are shown in addition in **Figure 4** (C through D) (cooperate with café, cooperate with supermarket, and social media marketing) since these do not become available until Idun has done other quests after meeting with Steinar and Lise.

As seen from **Figure 6C**, eLuna supports interchangeable fixed kernel events. Two quests are opened when the player starts the game, and they can be explored in any sequence. After each task an event is triggered. Furthermore, following the event paths through the structure reveals that Idun may visit the supermarket and the café in any order, and that the information received from agents at either of the hubs can be explored further as the player wants to go about it. The visits to the Farmer's Market and Lise's Urban Farm can be completed in any sequence, in fact, it's possible for Idun to complete contact and visit to one of these, without even knowing about the other. Notice that a quest does not have to be completed to trigger an event to a new task in another quest, as seen by the route straight to the payment counter after finding the imported produce. Idun can also talk longer to the clerk to learn that the supermarket would be interested in local purchases.

After identifying and connecting all events in the design, the co-designers carry on using the visual language to indicate what the individual events causes. The events are listed as connected through tasks, and details are provided. For example, when Idun has found imported produce and is ready to pay, the co-designers want to move a fellow customer to the payment counter so that Idun can have the talk about the Farmer's Market, save the game, and play a narrative sequence about climate gas emission from logistics. Equally, when Idun has received information about Lise at the café, they want Idun's computer at home to get a social media tab under its browser where Lise's Urban Farm can be found and save the game. Once the Farmer's Market organization has been found, they want to allow Idun to send them an email through her computer's mail client, save the game, and instruct the player to leave the game to complete a reflection note about Farmer's Markets based on what they have discovered so far. **Figure 6D** show these three events and append them with visual language structures for including the above.

The three examples show events can go from tasks in different quests in the same hub (Event 5), from tasks in quests in one hub to tasks in quests in other hubs (Event 6), and from one task to the next task in the same quest (Event 7).

Summary of the Co-Design Phase

Whereas **Figure 6C** shows the quests and events that will be worked on through co-specification and prototype development phases (and is the delivery from the co-design phase), the co-designers actually designed a full quests and events structure for the Idun's Apples game, The full Quest and event structure for Idun's Apples, that illustrates the full potential and complexity of eLuna designs, is included in the supplementary materials for this article.

With regards to game structure, The full design in the supplementary materials differs from **Figure 6C** in three details: 1) it shows planting tomatoes and making shopping list as one quest, which was altered later since it gives more flexibility to the player, 2) it only opens the café after Idun has been to the supermarket, in the later version both become available at the same time, also to allow more flexibility, and 3) it shows Idun learning about both the Farmer's Market and Lise's Urban Farm when visiting the supermarket, which in the later version was changed to Idun learning about Lise at the café, a place where the co-designers felt it was more natural that Lise would have connections. The full design in the supplementary materials also shows the full game unfold where Idun learns everything she needs about Farmer's Markets legalities and policies, and goes on to organize, finance, and promote one, before successfully opening a Farmer's Market in a park in her town.

Co-Specification Phase

In the co-specification phase, the co-designers employ the full eLuna visual language to create a strict and unambiguous blueprint of the narrative DGBL to a point where it can be developed and deployed for the learner demographic. The co-specification phase involves four steps. First, hubs and quests are revisited to ensure that all events can be followed in a logical manner, and that all tasks are programmable. Second, the actors and objects visual language elements are added to tasks to show clearly what is used by whom, when and where. Third, concrete dialogues are added to tasks. Fourth, narrative passages are added to events.

Revisiting eLuna Hubs and Quests

In this step, co-designers inspect the event flow of the eLuna design, and ensure that everything can be reached in a logical manner, and that everything that happens is clearly and unambiguously described for programmers to make a narrative DGBL from the design. In the Idun's Apples design, consider the two quests 'Contact Farmer's Market' and 'Contact Lise's Urban Farm'. Both end in tasks where Idun can make appointments, which trigger events where she can visit one of two new hubs where she is introduced to either Steinar or Lise. A question arose about how she gets there. eLuna narrative DGBL targets hubshaped quest landscapes and use interchangeable fixed kernel events, so Idun should not be immediately transported to

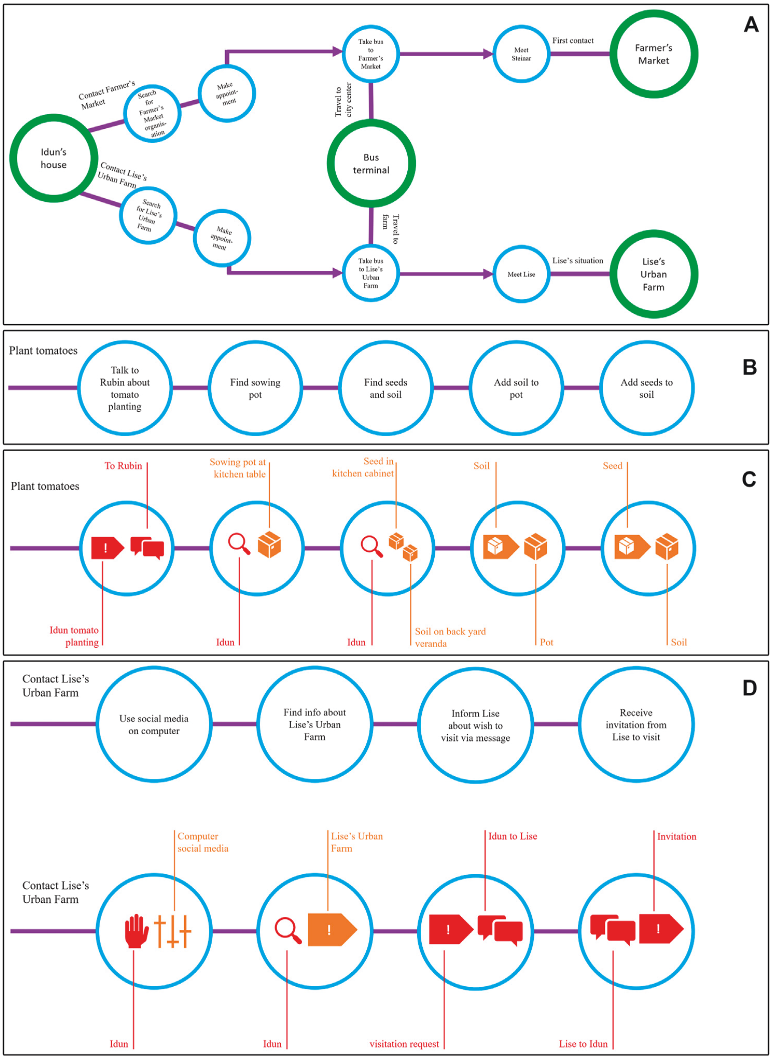


FIGURE 7 | eLuna revisit hub quests, add objects and agents to tasks.

these locations after appointments have been made. Rather, she should be able to get appointments set up, but then be free to explore the world (e.g., visit the café if she has not already done so after being at the supermarket), heading to the newly opened hubs at her own leisure and time. The co-designers decide that it is plausible that Idun could reach both hubs by bus, so they add a bus station as a new hub in the game, as shown in **Figure 7A**.

After scrutinizing the design and adding hubs as needed the co-designers focus on the quests that have been designed and break them down into tasks that each have unambiguous meanings. The quest 'plant tomatoes' consists of two tasks: 1) Talk to Rubin about planting tomatoes, and 2) Plant tomatoes. A question arose about how the second task 'plant tomatoes' is carried out in detail, since as it stands it is not a description that can be unambiguously programmed. To resolve this, the co-designers revisit the design's agents and objects, and use them to divide the single task into an unambiguous string of tasks. **Figure 7B** shows the new plant tomatoes quest.

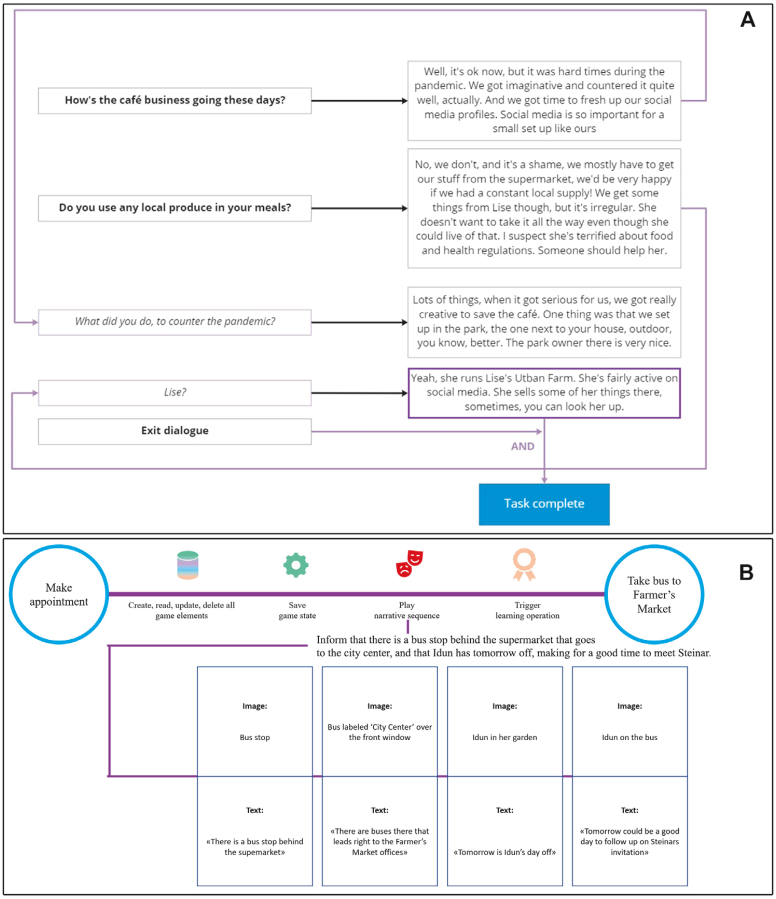


FIGURE 8 | eLuna specifying dialogues and adding narrative sequences.

Adding eLuna Visual Language Agents and Object Elements to Quest Tasks

After dividing tasks in quests as shown in **Figure 7B**, the blueprint also needs to specify all the elements inside the tasks by defining who does what when and where. This is done by exchanging the task text with the elements of the visual language for agents and objects, making pairs of them, annotating which objects and agents are involved in the task, and where the objects and agents are in the related hub. Revisiting the plant tomatoes quest, the co-designers observe that Idun and Rubin are involved in the conversation in which Idun informs Rubin about the planting task. The sowing pot is in Idun's house, and it was decided to be more precise and indicate that it be located on Idun's kitchen table. The seeds are determined to be in her kitchen cabinet, and the soil on the veranda in her back yard. **Figure 7C** shows the complete specification with added objects and agents to tasks that will appear in the blueprint for the plant tomatoes quest, using the annotated eLuna visual language.

To show the remaining elements of the agents and objects visual language in use, **Figure 7D** (top) shows how Contact Lise's Urban Farm is broken down to unambiguous quest tasks in which 1) Idun opens social media on her computer, 2) Idun searches for and finds Lise's Urban Farm, 3) Idun informs Lise about her desire to visit, and 4) Lise responds with an invitation, and illustrates how it will be specified in the blueprint (bottom).

Specifying eLuna Dialogues

eLuna dialogues occur as part of quest tasks and are conducted between agents. In eLuna, dialogues are created by co-designers as trees in which a player-controlled agent engages another agent in conversation, selecting from an initial set of dialogue lines. Once dialogue lines have been communicated, they vanish from the options,

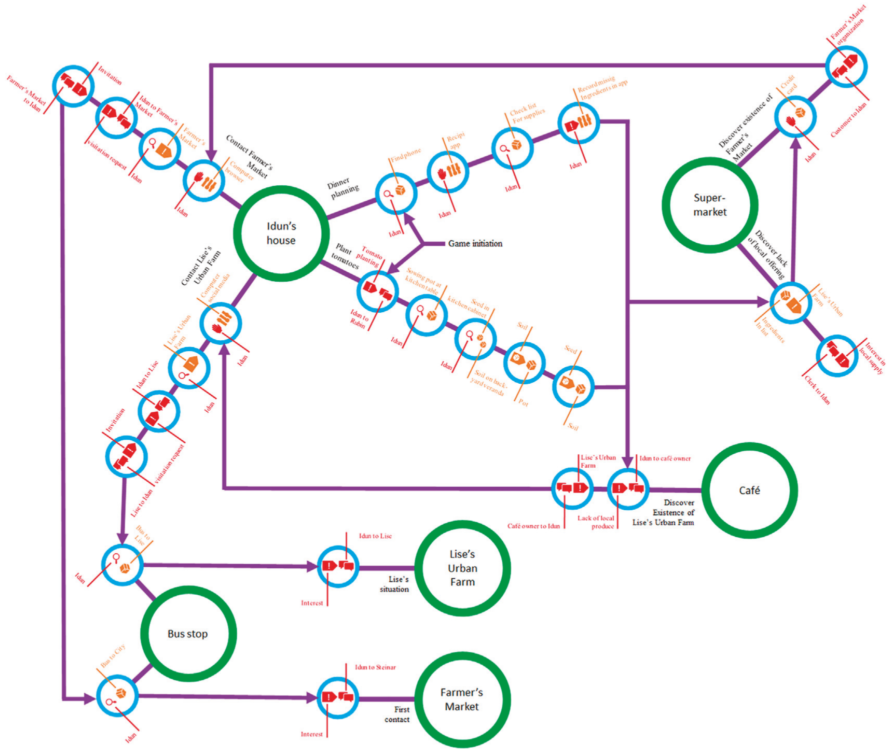


FIGURE 9 | Idun's Apples blueprint.

and may be replaced by new dialogue lines, naturally emerging to follow up the conversation as new information is brought up. If dialogues end, they restart from the beginning the next time the agent is engaged. **Figure 8A** shows a dialogue in which Idun engages the café owner and learns about the existence of Lise's Urban Farm.

In the dialogue, lines that are available at the start are highlighted in bold, and lines that may be made available later are in italic. A single statement has a single response, indicated with a black arrow. New lines are made available after responses are presented, indicated by purple arrows. From the example in **Figure 8A**, it can be seen that Idun needs to ask if the café uses local produce to first hear about Lise. By following up, Idun learns about the Urban Farm and how Lise has a presence on social media. Once that response is received, and the dialogue has been actively ended by Idun, the task is completed, and the event leading out from it is triggered. Idun does not need to ask the café owner how business is going and follow up on the conversation about the pandemic (indicated by italics). However, as seen, the response that comes from that line hints that the park owner is helpful, something that will be important information later in the game, once Idun is ready to look for a location for her own Farmer's Market.

Adding eLuna Narrative Sequences

The events in eLuna have integrated narrative sequences as shown in **Figures 2D**, **6D**. These are briefly described by the co-designers when designing the events, and in the co-specification phase they are revisited and detailed to completion. Different narrative DGBL can resort to different media formats for these. For example, they can be video sequences, often referred to as cut-scenes in video games, they can be text only, audio, or animated clips, all depending on the project's resources and art direction. In Idun's Apples, the narrative sequences are determined to comprise sequential panels showing pictures accompanied by text. In narrative DGBL these sequences play two roles; they drive the story forward and provide hints and instructions to guide the player onwards to new tasks that need to be accomplished. **Figure 8B** shows the task named 'Make appointment' (from the Contact Farmer's Market quest) that leads to the 'Take bus to Farmer's Market' task (from the Travel to city center quest). Here the co-designers now define a detailed narrative sequence fitted to the narrative DGBL's art direction.

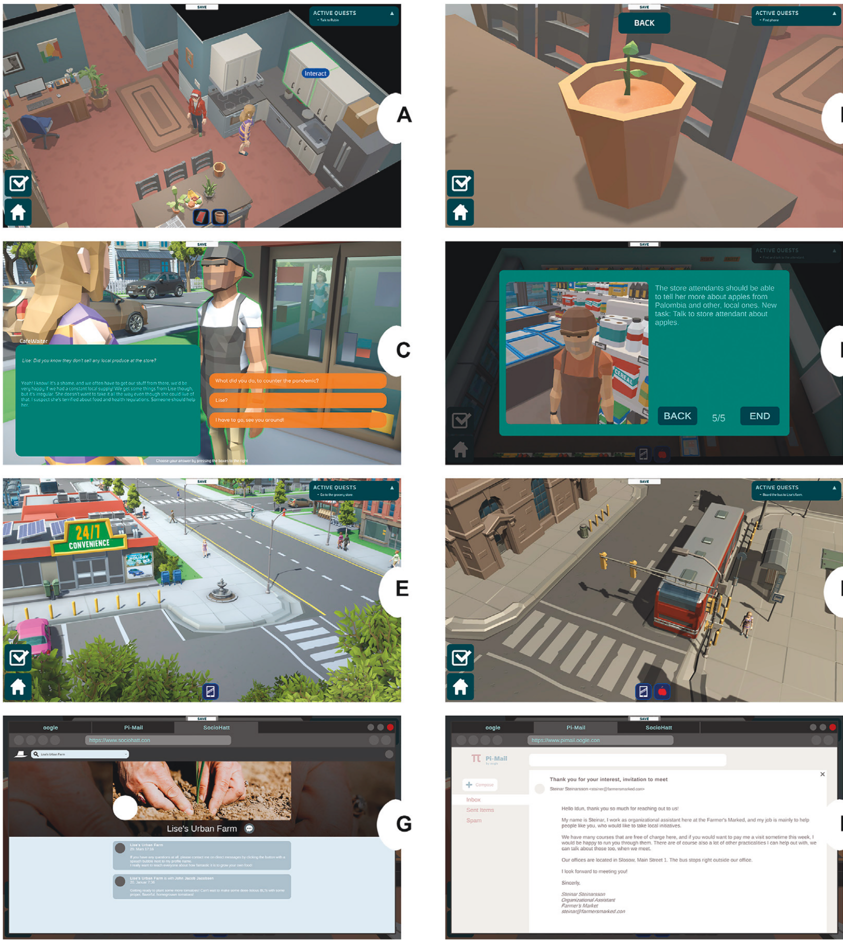


FIGURE 10 | Iduns Apples prototype screenshots.

Idun's Apples Blueprint

Figure 9 shows the Idun's Apples blueprint after revisiting hubs and quests and adding agents and objects to tasks using the strict visual language. The blueprint is used to develop the Idun's Apples prototype, which is described in the next section.

Compared to **Figure 6C**, **Figure 9** contains one additional hub, the Bus stop. The number of quests is increased from 9 to 11 with the addition of two new quests at the bus stop, and the number of tasks has increased to 16 to 27 as more detail was needed to make a blueprint that unambiguously specifies a narrative DGBL that can be implemented. All conversations in tasks and all narrative sequences in events, were further specified as exemplified in **Figures 8A,B**. These specifications are available from the authors on request.

Development Phase

During this phase the blueprint for Idun's Apples is developed by the game developers into a narrative DGBL prototype[11]. **Figure 10** show eight scenes from the developed prototype, conforming to the blueprint from the specification phase:

- (A) Idun in her house with her son Rubin, interacting with a cabinet,

[11]To demonstrate all elements of eLuna, and to accommodate for time and development costs of the project, only three of the hubs (vertical slice in game development terms) have been developed.

TABLE 4 | Brief description of the co-designed eLuna narrative DGBLs.

#	Participants	Curriculum	Learning objectives	Demographic	Learning situation	Synopsis
1	Three Technology Enhanced Learning (TEL) experts	General sustainability (no particular subjects' curriculum, since the participants are TEL experts and not practitioners)	Consequence of deforestation • Democratic processes • Civil disobedience	University bachelor level	Envisioned for students to play as preparation for group discussion	With goal to protect local flora and fauns, a man living in the forest resort to political processes and civil disobedience to prevent a local build-out project
2	Three TEL experts	General sustainability (no particular subjects' curriculum, since the participants are TEL experts and not practitioners)	Consequences of overfishing • Internet extremism • Ecologism	University bachelor level	Envisioned for students to play as preparation for group discussion	A wife goes eco-extremist after following dark-web influencers and hires an assassin to kill her husband because he is a fisherman, and she decides that he is part of the global sustainability problem
3	Two high-school teachers. One game developer	Health care management and administration	• Emergency room diagnostics and prioritization • Nurse medical assistance tasks and responsibilities	High-school level	Played as homework before and after classes concerning related topics through the semester	A newly educated nurse interns at a hospital emergency room, aiding diagnostics, and prioritization of patients as they arrive, and assist procedures with doctors as required based on the diagnostics and prioritization
4	Two high-school teachers. One game developer	Career counselling	• Career path options and required education/ skills • Workplace tasks and responsibilities	High-school level	Played in class, while discussing career options and educational paths	Learners visit an old man living in their school's basement who has had all jobs imaginable. The old man has a magic ability to send the learners into any workplace that he has held, where they can experience the realities of performing various jobs
5	Two secondary to high-school museum teachers. One TEL expert (same as in 1). One university college teacher. One game developer	Regional sustainability	• Nature conservation • Sustainable construction and engineering • Accessibility	Elementary and high-school levels	Played before or during class visits to the science center, in combination with exploring the same topic using interactive exhibits	A young woman establishes a mountain biking club, before commencing to plan and build a club house and tracks at a local mountain, taking care to perform all processes as sustainable as possible, while still allowing bikers to access the tracks in an uncumbersom manner
6	Three secondary to high-school museum teachers. One university college teacher.One game developer (same as in 4)	Human biology	• Adolescent development • Social stigma • Medical diagnostics and treatment	Elementary and high-school levels	Played before or during class visits to the science center, in combination with exploring the same topic using interactive exhibits	Illustrating various challenges of adolescents going through puberty, and, through depicting social problems arising from them, explains the biological reasons for human development from child to adult

- (B) a close-up screen resulting from her combining soil and seeds in a pot to sprout a tomato
- (C) Idun talking to the café owner, learning from him that he would gladly purchase local produce if more were available, that there is a woman called Lise that grows vegetables, that Lise needs help to increase production,
- (D) a narrative event screen tasking Idun to talk to a store clerk about imported apples,
- (E) Idun on the street, walking between Hubs with the supermarket in front, the bus station behind it, the café on the other side of the street, and her house up the road behind the café,
- (F) her arrival in the city center, to where she can take the bus when she wants to visit central farmer's market organization, town hall, and other agencies,
- (G) Idun having found Lise's Urban Farm on social media, from where she can contact Lise,
- (H) Idun reading an e-mail from the farmer's market organization, that she receives after having contacted them with her interest to incorporate a market in her area.

EVALUATING ELUNA DIGITAL GAME-BASED LEARNING FOR STEAM EDUCATION

As mentioned earlier, during the development of the eLuna method there were six narrative digital game-based learning (DGBL) designs produced during three workshops. During the workshops there was no mention of STEM or STEAM when introducing the task of designing a digital game. Thus, an evaluation of the designs to see if they conform to STEAM has been carried out. In this section a summary of the designed narrative DGBLs is given, followed by their evaluation against the STEAM subject's science, technology, engineering, arts, and mathematics.

Summary of the E-Luna Narrative Digital Game-Based Learnings

The eLuna framework has been used to develop six narrative DGBL designs, see **Table 4** for brief descriptions, through the co-design phase, and Idun's Apples, as described in detail in **Section 4**, through the development phase.

Table 3 presents the content of the six co-designed games according to identified agents, worlds, objects, and events.

Evaluating the E-Luna Narrative Digital Game-Based Learnings Against STEAM

To see if the seven narrative DGBLs meet support the integrated and holistic cross-disciplinary education targeted by STEAM, each design was evaluated for content related to science, technology, engineering, arts, and mathematics. As shown by Yakman (2008), there is already a conceptual trend in STEM education of purposefully integrated education related to hard sciences, with either one subject being a dominant base discipline, or where several subjects are planned to be equally represented. STEAM formally links these hard sciences to those of the Arts, creating holistic learning structures. At a multidisciplinary level, Yakman (2008) argues that the best way to teach naturally occurring interrelations, is through reality-based units. This requires disciplines from the Arts to provide context but does not necessarily need to involve all disciplines in STEM. Thus, a narrative DGBL that supports STEAM integrates one or more subjects from STEM with subjects from the Arts through naturally occurring relationships, with one or more subject being dominant. **Table 5** presents the evaluation of the eLuna designs against the STEAM disciplines (the dominant base subject(s) are highlighted in bold) as defined by Yakman (2008). Some subjects, such as sustainability, belong to different disciplines based on how the subjects are covered in the designs. For example, in the mountain bike game (design number 5), sustainability is defined as the Arts, since sustainability in that design concerns attitudes and customs in society, whereas in the Idun's Apples (design number 7), sustainability is covered as a Science subject, related to what exists naturally and how it is affected. As **Table 5** shows, four of the designs have main subjects related to Science and the Arts, two of the designs have main subjects related to Science, the Arts, and Mathematics, and one has a main subject related to the Arts only. All designs cover topics from all disciplines, however, none of the designs have main subjects in Technology or Engineering. The evaluation shows that the designs certainly support STEAM, and the evaluation can be used to decide in which subjects the narrative DGBL (if developed in a game) could be used to support learning.

Future Work

The narrative digital game-based learning (DGBL) investigated in this research did not consciously take STEAM into account when designed. In future eLuna research, creating new narrative DGBL, STEAM should be formally integrated, targeting STEM and Arts subjects from the beginning to explore how the framework functions when such targets are made; to see how such goals are obtainable, and to see if the support for STEAM strengthens in such cases. Furthermore, while both STEAM and narrative DGBL have been shown to have common interests in empowering stakeholders in co-design disciplines, solidifying the cross curricular subjects in the narrative DGBL, and making designs that can be specified, developed, and deployed, there is a difference in granularity between the two. In STEAM, there is emphasis on involving and empowering educators from different disciplinary backgrounds, whereas in narrative DGBL, eLuna included, the distinction is drawn between educators on one side, and developers with technical competencies on the other. In future work on the eLuna design phase, lessons should be learnt from STEAM, and, when making attempts to make consciously STEAM supporting narrative DGBL using it, eLuna, too, should distinguish between educators' areas of expertise, and strive to diversify the educator group to cover the required STEM and Arts disciplines that are to be targeted.

Inspecting the synopsis of the resulting co-designs in this research as shown in **Table 4** and comparing them to

TABLE 5 | eLuna designs support STEAM.

Candidate # and topic	Science	Technology	Engineering	Arts	Mathematics
1 - Deforestation	**Flora/fauna** **Sustainability** **Eco systems**	Barriers Traps Construction tools Vehicles	Construction work Road blocking Trap setting	Language Politics **Environmentalism** Law Rhetoric	Area measurements and calculations
2 - Overfishing	**Fishing techniques** Assassination techniques	Fishing equipment Fishing boat Weapons	Making fishing equipment	Crime Law Social media **Environmentalist**	Fish population measurements and calculations
3 - Health care	**Medical diagnosis and procedures**	Medical equipment used to diagnose and treat	Parameterizing or outfitting medical equipment for different purposes	**Health Care systems** Privacy Social economics Organizational structures	Calculating dosages based on patient physical measures
4 - Study counselling	Any relevant process at the workplaces, e.g., in a hospital, at a lab, or in a university	Any tool that can be used at the workplaces, e.g., medical equipment, computer programs, machines, and so on	Any relevant process that can be explored at the workplaces, e.g., construction engineering, or software engineering, and so on	**Career counselling and path options** Work regulation Others, as relevant to the workplaces, e.g., media science, social sciences, and so on	Any mathematical principle applicable at the workplaces, e.g., in economics, physics, construction, and so on
5 - Local sustainability	**Environmental sciences for achieving minimal impact**	Bikes Building tools and materials Computers and/or mobile phones	Club house construction Bike modification	**Sustainability** Marketing Finance and investments Economics Organizational structures Politics	Area measurements and calculations **Environmental measurements and calculations**
6 - Puberty biology	**Biology** Medicine	Mobile phones On-line platforms Medical equipment	Social engineering	Stigma Ethics Law **Social structures** Media science Popular culture	Physical performance statistics Social media performance statistics
7 - Sustainability goal 12 (Idun's Apples)	Agriculture **Sustainability**	Computers Irrigation systems Grow houses and confinements Measuring equipment (health and sanitation related)	Farming Site planning and construction	Public regulations Organizational structures Finances and investments Business management Marketing and PR **Environmentalism** Law	Financial balancing and calculations **Environmental measurements and calculations**

entertainment games found in the commercial marketplace[12], shows a mismatch of topics and subjects among the two. At time of writing, six out of the top 10 bestselling PC video games[13] concerns fantasy or science fiction synopsises, whereas only co-design 4 (**Table 4**) shows any hint of those among the eLuna narrative games discussed here. During the eLuna Framework development, one of the educators commented that s/he though the educators had been too dominant when co-designing particularly the agents and the world of the narrative DGBL. The educator speculated that was because the educators were the authorities concerning the curriculum and the learning

[12]E.g. https://store.steampowered.com/.

[13]https://store.steampowered.com/search/?filter=topsellers (retrieved 13th November 2021).

content, something that rendered the game developers' passive. This, the educator argued, was a possible short coming, given that game developers are more attuned to telling fantastic stories, stories that may just as well contain the learning material, and be more engaging to the target audience. In the next iteration, a phase to describe the setting could be introduced at the end of the eLuna preparatory phase, in which the game developers participate to create an overall setting before the co-design phase starts.

The eLuna method is built upon previous research (Breien and Wasson, 2021) that identified a particular set of categories associated with positive effects found in narrative theories for games. In future research, the eLuna framework will be refined with increased support for Variable Model categories (Breien and Wasson, 2021). For example, STEAM concepts will be included as part of the design phase, wherein the educator role will be further refined to recommend true co-design, including relevant educators from fields in STEM and the Arts, not only between educators and game developers as defined groups.

Finally, the eLuna Framework targets categories associated with positive effects, but does not ensure that these effects are obtained. Games developed on eLuna designs need to be implemented in educational settings, evaluated for their effects to inspect whether they reach their intended effects, and studied for their role in classrooms. How do teachers integrate the eLuna games into their teaching and learning activities? Do the games address the learning goals that were established in the Preparation phased? What do students learn from playing the games? After discussing such questions and evaluating effects, the eLuna Framework could fortunately become part of an iterative design and development process in which games are tuned and improved based on findings.

CONCLUSION

This article has argued that narratives are a good basis for STEAM learning and shown that the eLuna framework provides a co-design method and supporting visual language that when used by multidisciplinary co-designers results in the design of narrative digital games that can support STEAM education. We do not argue that narrative digital game-based learning (DGBL), and by extension all narratives used for learning, always and inherently supports STEAM structures, however, the designs developed in eLuna workshops resulted in narrative DGBL designs that provide high opportunity and potential for supporting STEAM education.

The co-design groups included educators, sometimes technology specialists, and game developers which enables the outcome of the co-design and co-specification processes, a blueprint, to be understood by educators and to easily be implemented by game developers. Thus, the eLuna visual language acts as a boundary object (Star and Griesemer, 1989) enabling cross-disciplinary work and meaningful collaboration between educators and game developers. The educators see the learning content presented in an organised way and the game developers can read the blueprint in a way that enables them to develop the game.

Thus, the eLuna framework empowers educators and game developers to co-design, co-specify, develop, and deploy narrative DGBL that enforce positive effects on engagement, motivation, and learning, while providing support for STEAM education in cross-curricular, integrated, and holistic learning through naturally occurring relationships. The results have been encouraging and the authors encourage the adaptation of the eLuna framework in future narrative DGBL research and development.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

FB has contributed the ideas, the eLuna framework, and had the main responsibility for writing the text. BW has contributed to the development of the eLuna framework through supervision and has contributed both the editing and writing the text.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2021.775746/full#supplementary-material

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Article 3

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The eLuna mixed-reality visual language for co-design of narrative game-based learning trails

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Increased focus on out-of-school learning has led to extended use of Science Centers as learning arenas for junior and high school students in formal learning situations. The creation of learning trails, semantic collections of science center exhibits based on formal learning plans for interdisciplinary STEAM education, has become an area of focus. Previous design research has resulted in the definition of story-driven learning trails that foster flow and engagement in learners. In science centers, equal emphasis is placed on the physical real-world domain, represented by the exhibits themselves, as the virtual components, represented as collaborative positions-based portables carried between exhibits, linking the exhibits into virtual storylines using sensors and control assignments. This defines science center learning trails as mixed reality systems; holistic systems that integrate real and virtual elements, existing on the axis between real and virtual poles on the reality–virtuality continuum. Research has shown that a set of characteristics of narrative game-based learning has positive effects on engagement, motivation, and learning. The eLuna Framework comprises a co-design method and a visual language that emphasizes these characteristics, and that supports educators and game developers to co-specify blueprints of screen-based narrative learning game experiences. Applying thematic analysis and heuristic usability methods to interview data from two design studies completed by six science center educators based on a STEAM enabled exhibit cluster at the Bergen Science Centre VilVite, this research extends the eLuna Visual Language to distinguish between real and virtual elements for the eLuna Framework to achieve its full potential to co-design and co-specify science center mixed reality narrative game-based learning trails. The resulting extension can be plugged into the eLuna method and applied in future co-design and co-specification of mixed-reality narrative game-based learning trails which promote flow in learners, and affords positive effects on engagement, motivation, and learning.

KEYWORDS

game-based learning (GBL), mixed-reality (MR), narratives, learning trails, co-design, design methods, science center education, STEAM education

Introduction

Over the course of an extended decade, Nordic science centers have built a strong tradition of developing and applying learning trails (e.g., Quistgaard and Kahr-Højland, 2010; Leister et al., 2019) for use in formal learning situations by junior and high school classes of students (13–17 years olds). Learning trails consist of semantically related collections of scientific learning exhibits that are tied together through position-based tablet or mobile phone digital companions; apps, webapps, or software. Learning trails assist a student's traversal of their subject matters in a varying degree of linearity among relevant sets of exhibits and are used as part of natural science education in science centers, targeting relevant national STEM learning plan objectives for the age groups. Furthermore, they are typically supported by learning plan objectives in social sciences, history, and the Arts, to underline and showcase the application and relevance of STEM subjects in the real world, culture, and society through interdisciplinary study. The learning trail concept was scientifically described as embedded learning environments by Nils Petter Hauan in his industrial Ph.D. work (Hauan, 2017) for the Bergen Science Centre VilVite and the University of Bergen. Several learning trails have been developed at VilVite, many of which utilize digital game companions in which the learning objectives and content are tied together using narratives. These narrative game-based learning trails enforce a holistic understanding of scientific concepts inside social scientific and humanitarian philosophic contexts and are in effect STEAM (Yakman, 2008) learning environments in which STEM concepts are enforced *via* their naturally occurring relationships to each other as well as disciplines from the Arts.

This article presents research showing that narrative game-based learning trails are complex systems designed, specified, developed, and employed by a wide variety of professionals with diverse technical and non-technical as well as pedagogical and non-pedagogical backgrounds and competencies. Furthermore, it establishes narrative game-based learning trails in science centers as mixed-reality (Milgram and Kishino, 1994) systems containing both physical (science exhibits) and virtual (video game-based apps and programs) elements that communicate with one another automatically or as initiated by the users. Additionally, the research responds to a call from the research community to provide tangible co-design methods that enable participants in various roles to actively partake in development processes, as summarized in the previous study by Breien and Wasson (2022). By extending the eLuna Visual Language (Breien and Wasson, 2022) with features that enable the distinction of real and virtual elements from one another, this research improves the usability of stakeholder co-design of effective narrative game-based learning trails for use in science center learning environments. This article describes this extension named the eLuna Mixed-Reality Visual Language (eLuna MRVL) and illustrates its use.

Background

The result of this research empowers co-designers from diverse backgrounds, competencies, and responsibilities to co-design and co-specify mixed-reality game-based learning trails by extending the eLuna Framework's visual language with the ability to distinguish real and virtual elements from one another. In this section, examples of narrative game-based learning trails developed and deployed in the Nordic countries of Norway and Denmark are described. Narrative game-based learning trails are then defined as mixed-reality systems, before stakeholders are presented, alongside their responsibilities in the design, development, and use of the resulting trails. Finally, the original eLuna Framework is presented before the research objectives for extending its visual language are detailed in the next section.

Narrative game-based learning trails

Among narrative game-based learning trails of note offered to learners by the Bergen Science Centre VilVite between the years of 2011 and 2018, one finds Antilantis, Adversaries of Waste, and Vilde Vite. In Antilantis, pupils work in groups to sustain energy economics on a fictional island in the Atlantic Ocean. The island itself is represented in a city-builder style video game accessible by the pupils in a computer lab; in 2011, tablets and mobile phones were less commonplace than they are today, and 11 years later, the pupils returned to a lab to interact with the virtual parts of the trail. However, Antilantis can still be said to be position-based, since the game on the computers directed the pupils to visit specific exhibits on the center floor, based on the state of the game. The energy technologies accessible on the island are unlocked by the pupils through visiting energy-based exhibits on the center floor and solving game-based challenges related to the exhibits' subject matters, the energy technologies enabling societal development, and the consequential effects of that development on the environment, politics, and social structures.

In Adversaries of Waste, pupils are given assignments from ecological guerrilla leader Eco *via* a big screen display on which he poses sustainability challenges to them and urges them to find solutions using sustainability themed exhibits on the center floor. After finding the solutions, the pupils report back and receive new objectives in the struggle to generate a sustainable world. In Vilde Vite, a follow-up to Adversaries of Waste, Eco's assistant Vilde has been trapped by a pollution monster who has minions (that are invisible, to begin with) around the science center. The pupils communicate with Vilde from her captivity through a game-based encrypted communication mobile phone app. Using the app, she directs them to various exhibits where they, after identifying themselves at the location of the exhibits and solving the challenges posed there, gain technologies that can reveal the various forms of pollution minions which they can then capture and subdue one by one in a self-directed order. The narrative in Vilde Vite cumulates in a dramatic fight against the main pollution monster, and the freeing of Vilde after the monster has been defeated.

These three narrative digital game-based learning trails were practically designed and developed by science center staff,[1] external creative writers, and game developers and have to date not been described or evaluated scientifically. A narrative game-based learning trail that has been described and evaluated scientifically is EGO-TRAP, which has been designed and developed at a Danish science center (Kahr-Højland, 2011). Kahr-Højland's research shows that increased focus is placed on learning outside the school system, increasing the use of science centers as learning venues (Henriksen and Frøyland, 2000; Drotner, 2007), but also that science center visits are often unstructured and unfocused with visitors rushing from one exhibit to the next without completing them (Paris, 1997), leading to research emphasis on personalized visitor experiences where exhibitions can be explored tied together using narrative structures (Kahr-Højland, 2010; Roberts, 2014). EGO-TRAP is a mobile phone-driven narrative game-based learning trail in which the pupil is the main agent and is consulted by another, virtual, agent known as The Woman. The Woman directs the pupils from exhibit to exhibit and places them inside two elective narratives. First, The Personal Test, in which the pupils are posed as test-subjects that gain insight into their own abilities guided by The Woman, and second, The Meta Narrative, in which the pupils gain insight into the premise of the exhibits, and who The Woman really is. Kahr-Højland proposes that EGO-TRAP, due to its qualities as a digital narrative, scaffolds pleasurable engagement in the pupils' interaction with science exhibits and counteracts the tendency of rushed incompletion of experiments, a phenomenon Kahr-Højland vividly and accurately label button mashing. Insights gained from EGO-TRAP user studies suggest that The Personal Test framed the students' experiences at the hands-on exhibits in a meaningful way. As for the Meta Narrative, the findings show that pupils engage in it; however, it is also seen that interaction with The Personal Test happens more, and at the expense of, interaction with the Meta-Narrative, rendering The Personal Test as the narrative with the strongest impression on the learners.

[1] The fourth author of this article was involved in the design and development of all three systems, the first author was involved in the design of Adversaries of Waste.

Narrative game-based learning trails as mixed-reality systems

The study of Hauan shows how both the venue and the visitors are resources for learning (Hauan et al., 2017), and that learning trails have the potential to increase pupils' flow and engagement when interacting with multimodal entities to explore science inside and between real and virtual domains (Hauan and DeWitt, 2017). Following up on Hauan's study, Breien and Wasson (2021) provided a systematic literature review revealing a set of characteristics for narrative digital game-based learning that is associated with positive effects on engagement, motivation, and learning (Breien and Wasson, 2021). This study was further used as the basis for the eLuna Framework (Breien and Wasson, 2022), a co-design and co-specification methodology that empowers educators and game developers to develop and deploy digital game-based learning systems that enforce the characteristics associated with positive effects in STEAM learning environments.

A main motivator for developing the eLuna Framework is based on various calls from the digital game-based learning research community to develop comprehensive co-design methods that allowed educators to come together across disciplines, and to collaborate with game developers to efficiently co-design digital game-based learning systems that are both entertaining to use and effective in reaching learning objectives. Hunter-Doniger et al. (2018) point to the current rise of STEAM education, and the need for STEM educators to integrate the Arts into educational materials in a way that is culturally relevant to students. Milara et al. (2020) call for increased collaborative awareness to scaffold Communities of Practice in STEAM digital material development. Finch et al. (2018) show stagnant practices in arts, science, and computing and propose a workshop-based co-design framework to bring the disciplines together. Silva (2020) realizes that, while there are design frameworks to aid educators and developers to make game-based learning systems, these rarely distinguish the fun from the learning content, making communication difficult, and thus proposes a methodology that separates the learning content from the game mechanisms. Marchiori et al. (2011) bridge the gap between educators and developers in game-based learning development by offering a visual language for educational game development usable for non-technical personnel. This authoring tool, the DSVL, however, limits itself to the development of a single type of game and is not flexible beyond the genre of point-and-click games. Arnab et al. (2015) point to a general lack of methodologies and tools for the design, analysis, and assessment of game-based learning and propose the Learning Mechanics–Game Mechanics (LM-GM) model of predefined game mechanics and pedagogical elements from game studies and learning theories. After exploring 165 papers on planning, designing, and implementing learning attributes and game mechanics, Lameras et al. (2017) stress the need for pedagogically driven and inclusive processes in game-based learning design, which is further enforced by Gurbuz and Celik (2022), who in a systematic literature review on game-based learning design uncovers 2,466 articles spanning 20 years, of which only 32 provide a design approach with specific steps in form of a method, framework, or model. Carvalho et al. (2015) acknowledge that there are several models, frameworks, and methods for the design and analysis of game-based learning, but that these, however, focus on high-level aspects and requirements and do not help understand how the games can be concretely satisfied. While the eLuna Framework was evaluated to be an efficient co-design framework, it is thus far only intended for the co-design and co-specification of narrative digital game-based learning systems that are fully virtual and screen-based. Conversely, learning trails in science centers allow the learners to interact with STEAM subjects represented both in real and virtual domains. As such, these learning trails are mixed-reality systems that can best be categorized and described on the reality–virtuality continuum (Milgram and Kishino, 1994). The reality–virtuality continuum is a continuous scale ranging between the completely virtual and the completely real and that encompasses all possible variations and compositions of real and virtual elements, in which any element that lays between the fully real and fully virtual constitute a mixed reality.

Stakeholders in the design, specification, development, and deployment of narrative game-based learning trails

Experience[2] shows that when designing and developing narrative game-based learning trails at science centers, a wide variety of roles that are both employed by science centers and that are hired externally are involved. Which roles are required to fill in a particular project depends upon the subject matter of the curricular goals of the learning trails and the exhibits used in them, and on the form and format of the learning trail companions and the exhibits themselves. Roles will in any instance include pedagogical employees of the centers themselves, very often working alongside pedagogues and/or scientists from domain expert external organizations such as universities, research centers, or industry actors with relevant competencies for correctly assembling and quality assuring the factual content. Furthermore, roles will include internal staff working with exhibit planning, conceptual design, and technical development. These roles encompass high-level managers that ensure that the centers stay on target regarding the core sciences that have been defined by the board of directors to be the focus area for the individual center, exhibit management executives, engineers (such as electrical, mechanical, technical, and others as required), marketing managers and personnel, art directors, content developers, and managers, as well as museum educators that detail the educational programs in which the learning trails are used. In most instances, the before-mentioned roles are internally employed, however, depending on the size and financials of the centers, they may also be external in such instances where special competencies are required (e.g., plumbers, masons, carpenters, glass workers, foil workers, etc.). Among typical external roles in most given projects, one finds script writers and creative authors, software and game developers and designers, middleware suppliers, artists, public relations and profiling agents, special purpose hardware suppliers and engineers, sensors suppliers and engineers, sponsoring partner organizations from the public and private scientific communities, funds and trusts, and potentially other experts (VilVite, for example, has since 2008 drawn on external experience from working with musicians, glass-blowers, NGOs, architects, philosophers, emergency response units, sports clubs, and many other special purpose roles).

Once narrative game-based learning trails have been developed and deployed for practical use to visiting learners, further sets of roles are engaged during the visits. Two of these are the students themselves and their teachers. Internal science center roles include schedule planners, meeting hosts, area planners, and science center teachers and mediators and may include actors participating in enactments and roleplays, and technical personnel preparing exhibit and digital companion states and statuses for use by the pupils.

As one can see from the lists of roles above, not all these people can be expected to have technical competencies sufficient

2 The first author of this article worked as an external developer of science center exhibits from 2008 to 2018 and has been employed by a science center since 2018. The fourth author of this article has been employed by a science center since 2006. Among them the two has participated in well over 100 exhibits, learning trail and program development projects. The article section text is based on their combined experience.

10.3389/feduc.2022.1061640

to understand the complexities of any given learning trail, and the exhibits and companions applied therein. Similarly, not all these people can be expected to understand the complexities of the subject matters taught to the pupils during the visits in its most factual form. While this is not required for the roles to uphold all their individual responsibilities in the design, development, and subsequent use of the trails, it is important that the blueprints that result from the eLuna Framework distinguish the real and virtual components of the systems, how they transfer data between one another, and how the varied roles know their responsibilities in successfully designing, developing, deploying, and using the learning trails. The research presented in this article describes the heuristic usability inspection of the eLuna Visual Language, with the goal of extending it to enable the distinction of the real from the virtual in mixed-reality narrative game-based learning trails.

The eLuna Framework

The eLuna Framework (Breien and Wasson, 2022), as shown in **Figure 1**, comprises four phases for the design and development of digital game-based learning systems: Preparation, Co-design, Co-specification, and Development. In the Preparation phase, educators define curricular goals, content area and learning goals, learner demographics, and the learning situation. The next two phases Co-design and Co-specification constitute the eLuna Method, which is accompanied by a visual language that is applied in a flexible manner during co-design and more strictly and formally during co-specification. In its current state of development, the eLuna Method exists as a conceptual graph for co-design and co-specification, which after further iterative evaluation is envisioned and realized as a digital tool. The result of these two phases is a blueprint for a digital game-based learning system that feeds into the final phase of Development, where game developers will produce a digital game.

The eLuna Framework is based on two rationales:

1. To provide a framework for the design, specification, and development of narrative digital game-based learning systems that empower educators and developers to fully participate in the process from beginning to end, drawing on the strengths of all stakeholders to make learning games that are both fun to use and that conserves the learning goals for the defined demographic working toward curricular goals in well-defined learning situations, and
2. To ensure that the resulting narrative digital game-based learning systems optimize the potential for positive effects on engagement, motivation, and learning, by basing the methodological work on characteristics that have been empirically shown to incur such effects (Breien and Wasson, 2021).

The first of these rationales is achieved by the creation of the visual language which is a non-technical description of the system that is being designed and specified. The second of the rationales is achieved by modeling the visual language in such a way that it conforms to the desired characteristics, which were shown by Breien and Wasson (2021) to be as follows:

1. ***Hub-shaped quest landscapes:*** areas of exploration that allow learners to focus on the learning content in a non-linear manner placing the individual emphasis of learners on learning content and exploratory depth attuned to their level of understanding,
2. ***Modifiable objects:*** objects for use in the situation that learners not only need to apply as finished pieces but as something that they need to understand the workings of,
3. ***Grounded and consistent agents:*** characters in the game narratives that have psychological depth and that exhibit consistent behaviors that learners can understand and relate to on a human level, and

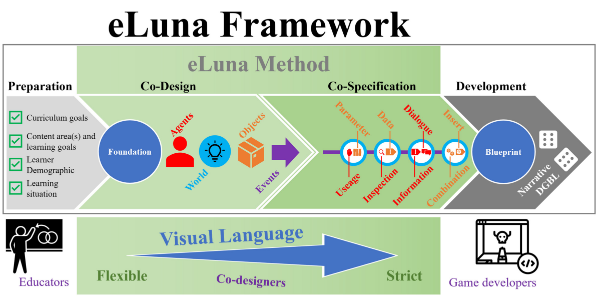

FIGURE 1
The eLuna Framework overview (Breien and Wasson, 2022).

4. ***Interchangeable fixed kernels:*** story elements in form of required chapters that allow the learners to traverse the narrative content of the games by solving tasks in a sequence that is, potentially, unique to them, and which allows them to consume the story in meaningful and individually tailored manners.

As shown by Breien and Wasson (2022) during user testing and evaluation, educators and developers confirm that eLuna is usable and understandable to them, conforms to the characteristics associated with the positive effects, and support the design of games for STEAM education.

The Loop exhibition

The Loop exhibition teaches biodiversity through five physical and semantically related exhibits and is the candidate for which game-based learning trails are co-designed by the participants in the research presented here. Alongside biodiversity as taught in natural sciences under the interdisciplinary topic of sustainable development, Loop focuses on the, also interdisciplinary, topic of democracy and citizenship as taught in social sciences as defined in the Norwegian Directorate of Education's learning plan for junior high school and high school education.[3] Thus, the Loop pavilion is a STEAM (Yakman, 2008) learning environment. The five exhibits that constitute the Loop exhibition are the following:

1. The Apple Garden

In this exhibit, visitors learn about photosynthesis using a touch screen to combine elements in the right sequence while observing a dead world return to life on a large screen display, ultimately spawning an apple on a growing three.

2. Wood Wide Web

In this exhibit, visitors learn about fungal networks between three roots by physically connecting them with one another by pressing and holding combinations of wall mounted buttons, so that the threes can communicate with one another and create resistance against dangers.

3. Life in the Earth Cave

In this exhibit, visitors learn about microorganic life below ground and the dangers posed to them by waste produced by human society by illuminating pieces of an interactive wall using infrared light beams that allows the organisms to move where they need and collaborate to fertilize the ground.

4. From Waste to Food

In this five-step exhibit, visitors learn how CO_2 from properly sorted human waste can, instead of being released in the atmosphere, be used in the growth of algae and end up as a resource for fish food. The exhibit starts with the sorting of waste through an arcade style video game, and the waste is then manually guided through a three step light/water/heat process and ends up as algae pellets that are fed to fish which can be seen to multiply and grow on a screen simulating a fish tank.

5. The Ant Hill

In this exhibit, visitors explore a live ant hill exposed through glass-dome windows in the center wall, can further learn about the various roles of the observable ants therein, and relate them to roles found in human society.

Research objective

The objective of this research is to enable the eLuna Framework to be useful and usable for stakeholders to co-design and co-specify mixed-reality narrative game-based learning trails in Science Centers, but also elsewhere, like in museums or at other venues where learning is offered telling a story over a distributed physical space using digital companions. Research that explores how the eLuna Visual Language should be extended and used to represent mixed reality by distinguishing between the real and the virtual domains was carried out. In this research, the definition of what distinguishes real and virtual adheres to Milgram and Kishino's (1994) first definition, substituting the word object with element, given that Milgram and Kirhino's original study focused on visual observation, however, noting that the reality–virtuality continuum applies to all modalities, like audio and haptics. The operational definition for distinguishing real from virtual underpinning the study presented herein, thus, becomes:

- Real elements are any elements that have an actual objective existence.
- Virtual elements are elements that exist in essence or effect, but not formally or actually.

The resulting eLuna MRVL, a pluggable component in the eLuna Framework, is a contribution that enables the development of future mixed-reality narrative game-based

3 As described in the learning plans from the Directorate of Education's core curriculum – values and principles for primary and secondary education interdisciplinary subjects: https://www.udir.no/lk20/overordnet-del/prinsipper-for-laring-utvikling-og-danning/tverrfaglige-temaer/2.5.3-barekraftig-utvikling?kode=nat01-04&lang=eng and https://www.udir.no/lk20/overordnet-del/prinsipper-for-laring-utvikling-og-danning/tverrfaglige-temaer/demokrati-og-medborgerskap/?lang=eng retrieved 9 June 2022.

learning trails that optimize the potential to achieve stronger engagement, motivation, and learning in formal school visits to science centers as part of interdisciplinary STEAM education.

Materials and methods

To explore how the eLuna Visual Language could be extended with mixed-reality distinction, mixed qualitative research methods were used. Two groups, each consisting of three expert science center employees working with either education programs or exhibits development, and one serious game developer,[4] participated in two separate eLuna workshops spanning 2 h to co-design two narrative digital game-based learning trails revolving around the Bergen Science Centre's Loop exhibition.[5] Table 1 shows the workshop participants sorted by ID number, current division and role of work, years of experience, previous experience with eLuna, and their individual workshop group number.

The day before the workshops, all participants received a half-hour lecture about the topics' interdisciplinary learning goals as they relate to Loop, and a presentation of the eLuna Framework was used in the Idun's Apples prototype (Breien and Wasson, 2022).

While conducting the workshops, the groups are instructed to make active use of the Loop exhibition's exhibits in the co-designs, and furthermore, to place them in the context of a narrative conforming to the elements of the eLuna methodology. The groups were also instructed to add a virtual game and story elements as they saw fit, without worrying about budgets to make such elements, in which a story related to biodiversity and digital democracy learning plan goals is told. When conducting the workshops, the current eLuna Visual Language was used, which at the time of the workshops did not allow for distinguishing between real and virtual elements.

After the workshops, participants 1 through 6, excluding the serious game developer, went through half-hour-long individual semi-structured expert interviews which were video-recorded and transcribed according to best practices as described by Oates (2006). During the interviews, eLuna Visual Language co-design schematics constructed by the researchers based on the workshops were available as a foundation for the discussions. The participants were challenged to identify the real and the virtual elements and to describe to the best of their ability how these could be visually distinguished from one another by suggesting extensions to the original visual language. While the workshop only completed the eLuna co-design phase and thus did not use the iconographic representation of objects and agents as detailed in co-specification, these iconographic representations were particularly discussed at the start of the interviews, with the examples provided related to the co-designs, so that the respondents could take iconographic into account during the interview sessions. In addition to the six interviews with workshop participants, the eLuna co-designs were also presented to two serious game developers.[6] Table 2 shows the respondent IDs, divisions, main work area, years of experience, and experience with eLuna. Group does not apply, as these respondents did not participate in the workshops.

As with the workshop participants, the two serious game developers were also challenged to discuss the real and virtual elements, and how they could best be distinguished from one another. All interviews were conducted within 2 days after the workshops. Table 3 shows the activity, the number of iterations, time used, participants count, and input and output from the preparation, workshop, and interview phases.

4 The workshops were conducted physically during COVID-19 restrictions. It was possible to arrange for the science center employees and the researcher to attend within regulations, but not external serious game developers. However, the first author of this article has worked as a serious game developer for 10 years (2008–2018) and could thus actively fill this role in the eLuna co-design phase. The serious game developer did not participate in the subsequent interviews as a respondent, and thus has no ID in this research.

5 https://www.vilvite.no/opplev/utstillinger/loop (in Norwegian) retrieved 10 June 2022.

6 These were unable to participate in the workshops due to COVID-19 restrictions. They were however the same two developers that prototyped the Idun's Apples eLuna prototype, and thus both had extensive eLuna experience, something which made it possible for them to contribute well to the interviews.

TABLE 1 Workshop participants.

ID	Division	Main area	Work experience	eLuna experience	Group
1	Exhibitions	Exhibitions development	5 years	No	1
2	Education	Learning program development	4 years	Yes	2
3	Education	School program coordination	8 years	No	2
4	Education	Learning program development	9 years	Yes	1
5	Exhibitions	Technical development	3 years	No	2
6	Exhibitions	Development project manager	15 years	Yes	1
N/A	Research and development	Serious game design and development	10 years	Yes	1 and 2

TABLE 2 Serious game developer respondents.

ID	Division	Main area	Work experience	eLuna experience	Group
7	External development company	Serious game programming	5 years	Yes	N/A
8	External development company	Serious game design and technical art	7 years	Yes	N/A

The eight interviews were subsequently transcribed, and a spreadsheet containing the respondents' own words when identifying something that could be real or virtual, alongside their suggested extensions to the visual language were recorded. Following the thematic analysis six-step approach (Braun and Clarke, 2006, 2022), deductive common themes of identifications and semantically phrased extension suggestions associated with them in interview transcripts were organized. **Table 4** shows the thematic analysis conducted in this research.

After the identifications and extension suggestions had been thematized, usability heuristics (Nielsen and Mack, 1994) were applied to make the selections for an extension to the eLuna Visual Language that distinguishes between the real and the virtual and that also are clear to understand on their own as well as across the eLuna methodology as a whole. As shown by Jimenez et al. (2016) and Quiñones and Rusu (2017), the usability heuristic is an extensively applied method for the design of user interfaces used across multiple domains. Usability heuristics consider not only separated elements but also system consistency so that interfaces are designed in a comprehensive and consistent manner resulting in an interface that can be effectively used by the target audience. Usability heuristics comprise a set of rules to which usability challenges (in this case the identifications) are related individually and on the whole and are, thus, a useful method for which to propose a holistic and overarching extension to the eLuna Visual Language to support mixed-reality designs. **Table 5** summarizes the 10 usability heuristics that were applied in this research.

After selecting the extensions for the thematically organized identifications of elements that should be distinguished as real or virtual, the researchers revisited the participants' co-designs and re-designed parts of them in accordance with the extended visual language, to test the validity of the extensions.

Results

The results of this research are twofold. It resulted in two co-designs for narrative game-based learning trails for the VilVite Loop exhibition after the 2-h long workshops, and the eLuna MRVL pluggable extension after the eight 30-min interviews, and subsequent thematic analysis and heuristic usability inspection. First, the two original co-designs are presented before the extension is described. Finally, the extension is applied to subsections of the co-designs, highlighting the changes that have occurred, and validating the extension's usefulness.

eLuna co-designs

The co-designs were created following the eLuna co-design phase structure as described in Breien and Wasson (2022). The co-designs are first briefly described before a list of hubs, objects, agents, and events are presented for both. Both co-designs' full eLuna schematics can be found in this article's **Supplementary material** "eLuna co-designs Loop."

Co-design descriptions

The first co-design is named Save the Future and is a story in which pupils use a time-traversing communication device to send information to the future to restore biodiversity there. The group referenced the 1985 movie Back to the Future[7] as something similar in both theme and atmosphere, even though in Save the Future, the pupils are not the travelers from the future, but the helpers in the past. In Save the Future, groups of pupils arrive at the science center and immediately as the learning trail commences find a tablet device after a short narrative introduction by a host (the workshop group discussed whether the pupils were to complete a form of the labyrinth to find the tablet, but for practical reasons decided, it was to be given to them by a host telling a story about how they had found it, given that the tablets are expensive devices that cannot be left unattended in the center and that having hosts watching them until the pupils found them would be a logistic problem

7 https://www.backtothefuture.com/movies/backtothefuture1

TABLE 3 Preparation, workshop, and interview details.

Activity	Iterations	Time	Participants	Input	Output
Preparatory lecture	1×	30 min	7	Learning plan and eLuna presentation	
Workshop	2×	120 min	7	Pen and paper	eLuna co-design
Interview	8×	30 min	8	eLuna co-design	Recommendations

TABLE 4 Activity steps for thematic analysis.

Thematic analysis step	Activity
Familiarization	Transcribing the data and sorting individual identifications of real and virtual, accompanied by suggested visual language extensions
Initial coding	Using color coding across identifications to highlight identifications related to parts of the visual language; hubs, quests, tasks, agents, objects, and events
Themes search	Inside each part of the visual language, sub-categorizing identifications that are the same, expressed in different uses of natural language by respondents, using color coding to identify suggestions to identical identifications that are also the same
Reviewing themes	Organizing based on themes for identifications, and under them suggestions, keeping track of reviewer number and identification number
Defining and naming themes	Reformulating identification and suggestion themes in short and clear language
Reporting	Counting occurrences of identifications and suggestions, conducting heuristic inspection of extension suggestions, proposing a holistic set of extensions to the visual language

for scheduling at the center). Upon activating the tablet, a pre-recorded video is played back. On it, the pupils are greeted by someone who calls him or herself the Time-Traveler. The Time-Traveler informs them that the future is in grave peril and that the pupils must establish communication through the tablet, which he references to as the Time Walkie-Talkie, with a group of five children in the future, and aid them to restore biodiversity in their time. To initiate the communication, the Time-Traveler informs, the pupils must, in any sequence, enter the year that the future children live in, a year which can be found by visiting the science center's Match Corner exhibition and solving an arithmetic task there for which the answer is the year, complete the Centrifugal Madness exhibit, and to generate the required g-force to energize the Time Walkie-Talkie. The group noted that the exact exhibit to produce a year (the groups idea was to set it as 2077) does not currently exist at the science center, but that one could be created inexpensively since it could be made from, e.g., wood in the science center's own workshop, and that the competencies exist to design the content and mathematical puzzle, resulting in 2077 among the center's employees. After the requirements have been met, the pupils enter the year and a code received from a host at the Centrifugal Madness exhibit. The pupils are then directed to a simulated chat app interface, on which the background image is a five-part collage of a future that is dead and barren. Each part of the collage is a clickable link to a text-based diary by each of the five future children, explaining how problems related to politics and climate in the future have led to the breakdown of five biological processes, effectively killing Earth. Each of the

TABLE 5 Usability heuristics (Nielsen and Mack, 1994).

Label	Description
Visibility of system status	The design should always keep users informed about what is going on, through appropriate feedback within a reasonable amount of time.
Match between system and the real world	The design should speak the users' language. Use words, phrases, and concepts familiar to the user, rather than internal jargon. Follow real-world conventions, making information appear in a natural and logical order.
User control and freedom	Users often perform actions by mistake. They need a clearly marked "emergency exit" to leave the unwanted action without having to go through an extended process.
Consistency and standards	Users should not have to wonder whether different words, situations, or actions mean the same thing. Follow platform and industry conventions.
Error prevention	Good error messages are important, but the best designs carefully prevent problems from occurring in the first place. Either eliminate error-prone conditions, or check for them and present users with a confirmation option before they commit to the action.
Recognition rather than recall	Minimize the user's memory load by making elements, actions, and options visible. The user should not have to remember information from one part of the interface to another. Information required to use the design (e.g., field labels or menu items) should be visible or easily retrievable when needed.
Flexibility and efficiency of use	Shortcuts—hidden from novice users—may speed up the interaction for the expert user such that the design can cater to both inexperienced and experienced users. Allow users to tailor frequent actions.
Aesthetic and minimalist design	Interfaces should not contain information that is irrelevant or rarely needed. Every extra unit of information in an interface competes with the relevant units of information and diminishes their relative visibility.
Help users recognize, diagnose, and recover from errors	Error messages should be expressed in plain language (no error codes), precisely indicate the problem, and constructively suggest a solution.
Help and documentation	It is best if the system does not need any additional explanation. However, it may be necessary to provide documentation to help users understand how to complete their tasks.

problems is directly linked to one of the exhibits in the Loop exhibition. At the end of each diary is a request to the pupils to explore the aspects of the exhibits and to use a message box under the diary entries to transmit lost information about biodiversity and democratic processes to the future youth, so that they can re-implement it in their world and return life to the future. The pupils then visit the exhibits in a self-directed order, find the information, and transmit it using the Time Walkie-Talkie. Each time a piece of information is successfully transmitted, one part of the collage interface changes to a living

 10.3389/feduc.2022.1061640

version of itself. The narrative game-based learning trail is over once all collage elements have been changed, upon which the pupils receive a thank you message from the future youths, which can be used in post-visit reflection.

The second co-design is named Move Now and is a story in which the planet Earth is discovered to be scheduled for deconstruction in the very near future, and in which pupils must gather a list of requirements necessary to establish a permanent colony on Mars, pack a spaceship with the items on the list, travel to Mars, and establish the colony. The group determined the narrative style as absurdly humorous, referencing the book The Hitchhiker's Guide to the Galaxy (Adams, 1979) as the main source of inspiration for both the premise and the atmosphere of the story. In Move Now, groups of pupils are met by a host enacting an agent called The Mentor, who informs the pupils about the deconstruction plans and challenge them to visit all the five exhibits of the Loop exhibition, explore and complete them in a self-directed sequence, before using a tablet to create an inventory list of what will be needed to bring to Mars to establish the colony. The Mentor agent is throughout this part available as a help system that can be accessed through the tablet. Before departing for the red planet, the pupils must also complete the Centrifugal Madness exhibit, after which they become certified astronauts and gain access to the spaceship. Using the tablet, the pupils fill the spaceships cargo hold with the required items from the inventory list by solving a series of puzzles based on the learning content of the Loop exhibits, and once done, the spaceship can be launched, an action which is performed on the tablet, and which launches a prerecorded video. In the video, the pupils learn how the spaceship suffers a catastrophic failure during flight (undetermined as to what by the group but noted to be something absurd in line with the inspirational work), resulting in The Mentor being flushed into space and several of the items in the cargo hold being damaged in some way. Upon arrival on Mars, the pupils must repair the damaged items one by one without help from The Mentor. Repairs are done by re-visiting the Loop exhibits and solving new tablet challenges based on the learning content that they provide. Each time an exhibit challenge is completed for the second time, a visual of the Mars colony is visualized on the tablet, revealing a new and vital structure in place and operational. The narrative game-based learning trail ends once the entire colony is completed.

Co-designs hubs, objects, agents, and events

In accordance with the eLuna co-design phase, the groups constructed sets of hubs, objects, agents, and events. The full eLuna Visual Language co-designs are found in **Supplementary material**. **Table 6** lists the elements that are part of the narrative game-based learning trail co-designs.

TABLE 6 Hubs, objects, agents, and events of Save the Future and Move Now.

	Save the Future	Move Now
Hubs	Loop Lobby Maths Kitchen Centrifugal Madness Wood Wide Web The Ants The Apple Garden Earth-Cave The Future	The Earth Centrifugal Madness Wood Wide Web The Ants The Apple Garden Earth-Cave The Spaceship Mars
Agents	The Time-Traveler The Five Future Youths The Pupils	The Mentor The Pupils Astronaut
Objects	Time Walkie-Talkie Schematic of society structure List of insects living conditions Schematic for protein reclamation Formula for photosynthesis List of plants living conditions	Cataclysmic event Objectives list Roots Nanorobots Seed bank Species bank Picture Protein resource knowledge Settlement Air Parasites Base Emergency rations
Kernels	Get TWT Get year Open TWT Receive challenges from future Explore ant society Explore insects Sort waste and create protein Describe photosynthesis Cultivate tree roots Transmit solutions Observe changes	Observe event Get objectives Train astronaut Get roots Get nanorobots Get seed bank Get species bank Take picture Get protein knowledge Pack spaceship Depart on spaceship Disaster on board Arrive Mars Create air Repair nanorobots Eliminate parasites Build base Produce emergency rations Observe constructed settlement

Deductive semantic thematic analysis of identifications and extension suggestions, and heuristic usability inspection to select extensions from themes

The respondents produced a total of 36 identifications and 47 extension suggestions were reported. **Table 7** shows the number of identifications and extension suggestions provided by each respondent.

TABLE 7 Respondents identifications and extension suggestions distribution.

Respondent	Identifications	Extension suggestions
1	6	7
2	7	10
3	4	4
4	6	8
5	3	3
6	3	4
7	4	4
8	3	7
Total	36	47

After analyzing the identifications, three identifications and nine related extension suggestions were discarded since they did not concern the distinction between real and virtual, bringing the number of relevant identifications down to 33, and extension suggestions down to 38.

- For 12 of the identifications, no extension suggestions were proposed,
- For 11 of the identifications, one single extension suggestion was proposed,
- For six of the identifications, two alternative extension suggestions were proposed,
- For two identifications, three alternative extension suggestions were proposed,
- For one identification, four alternative extension suggestions were proposed, and
- For one final identification, five extension suggestions were proposed.

Through conducting a thematic analysis, the 33 identifications were generalized into eight deductive eLuna themes which were technically the same, albeit described using different semantics by the individual respondents. All the combined extension suggestions that were given by the respondents for the identifications were then organized under the relevant themes, and a new iteration of the thematic analysis was conducted on the eight resulting lists of extension suggestions, generalizing them into themed suggestions that again were technically the same, evaluators using different semantic descriptions. The eight themes, accompanied by their associated list of extension suggestions, how many respondents suggested the semantically same extension, alongside respondent IDs linked to identification running number, are available in the article's **Supplementary material** "respondent identification and extension suggestion themes." After thematizing the identifications and their extension suggestions, the eight themes and their lists of extension suggestions were evaluated based on the usability heuristics before an extension for each identification to facilitate the distinction of the real from the virtual in the eLuna MRVL was proposed. The following eight subsections list the eight themes and their extension suggestions and then apply the usability heuristics to discuss and propose a single extension for each theme that can be used to distinguish the real from the virtual in the eLuna MRVL.

Theme 1: Hubs that are real-world and virtual should be distinguishable from one another

Theme 1 identifies that there is a need to distinguish between real and virtual hubs. The list of extension suggestions for the theme was as follows:

A – Make the hub types using different shape
B – Make the hub types using different outlines
C – Use pop-up descriptions on clicking any element in the design to get further descriptions
D – Use a different color for it
E – Use shades of the same color
F – Put images inside the hubs (maybe only the physical ones)
G – Use a double circle on one hub type
H – Use different design schemas for each domain, link between them, and view them in different windows.

All but one reviewer identified this with the suggestion to use different shapes or outlines given the most, three times each. Suggestions C and H breach heuristic #1: Visibility of system status and does particularly not present feedback to the user as quickly as possible, when compared to A and B. Furthermore, C and H breach heuristic #4: Consistency and standards, as a pop-up or a link to another design schema do not exist anywhere else in eLuna blueprints, it does not follow platform standards. Finally, C and H breach heuristic #6: Recognition rather than recall, since for example, A and B allow the users to recognize information by looking at the interface, rather than remembering that they must activate a pop-up window or follow a link to another schema to access the same information. While distinguishing real from virtual in the eLuna Visual Language will add complexity, and while one may argue that changing hub shapes A, making different hub outlines B and G, and changing color or color shades on the hubs D and E all as such breach heuristic #8: Aesthetic and minimalist design, it is further possible to argue that the D and E options are a larger breach of this heuristic than the other options. The argument for this is that color changes may induce larger complexities than changing forms and outlines, the latter causing lesser problems for users with color blindness, while, particularly in the case of A, being easier to see immediately. Furthermore, one reviewer particularly commented on the decreased usability of the overall system that would come from changing colors. F breaches heuristic #4: Consistency and standards, as the whole eLuna

 10.3389/feduc.2022.1061640

Visual Language bases itself on shapes, colors, and icons, and adding pictures would not be consistent with this. Furthermore, while it is not a heuristic, finding images to indicate hubs may be practically difficult when making blueprints, particularly when taking copyrights into account. Also, F may compromise heuristic #8: Aesthetic and minimalist design, since obtained pictures from different sources most likely will have very different styles, resolutions, and lighting effects, making the blueprint result in something not very aesthetic at all. B and G can be seen as similar variant solutions, in which the outline is manipulated or doubled to indicate whether a hub is real or virtual. When taking heuristic #1: Visibility of system status into account, understanding that eLuna blueprints are large and should be visible at different zoom levels, and comparing the two solutions to A, it becomes apparent that solution A will be more visible, when looking at the blueprints. Based on the extensions proposed and the discussion related to the heuristics, the researchers suggest using different shapes for distinguishing virtual and real hubs from one another.

Theme 2: Some hubs can be both real and virtual; one representation of the same place in both domains

Theme 2 identifies that some hubs may appear as both real and virtual in different parts of the narrative game-based learning trail. The list of extension suggestions for the theme was as follows:

A – Use hubs that are right next to each other
B – Overlay a smaller hub on top of the other
C – Use pop-up descriptions on clicking any element in the design to get further descriptions
D – No solution.

To distinguish hubs that exist as both types means that a third distinction should be included in the eLuna Visual Language for these instances. While five respondents identified this issue, three did not pose extension solutions. Solution C breaches heuristics #1: Visibility of system status, #4: Consistency and standards, and #6: Recognition rather than recall. Solutions A and B are similar to one another and propose to either place two hubs next to one another or to make hubs that overlap These solutions will breach heuristic #8: Aesthetic and minimalist design. Thus, even if no respondent suggested the extension, it is proposed to adopt the same solution as for theme 1 and use a different shape for hubs that can be both real and virtual.

Theme 3: Quests can contain tasks that use both real world and virtual object/agent pairs

Theme 3 identifies that tasks can pair both two real and two virtual objects and agents. The list of extension suggestions for the theme was as follows:

A – Use different event lines from the tasks that show the domain of the proceeding task
B – No solution
C – Make the task types using different shape
D – Make the task types using different outlines.

Only three respondents made this identification, whereof one did not make an extension suggestion and one made the same identification twice and offered two different extension suggestions. Given that different outlines were rejected in themes 1 and 2, extension suggestion D can be rejected to uphold heuristic #4: Consistency and standards. Extension suggestion A can also be rejected to uphold heuristic #4 since introducing different lines leading from task to task, and keeping the task shapes the same between real and virtual would not be consistent. Therefore, to keep consistency with the solutions for themes 1 and 2 (and to meet heuristic #4), the proposal is to distinguish virtual and real tasks by introducing different shapes for them, based on the agent/object pairs inside them.

Theme 4: Quests can contain tasks that mix real world and virtual objects and/or agents

Theme 4 identifies that pairs of one real and one virtual agent or object may exist inside a single eLuna task and that such occurrences will require a separate distinction of mixed tasks from fully real or fully virtual ones. The list of extension suggestions for the theme was as follows:

A – No solution
B – Use similar but distinguishable symbols inside tasks
C – Use a distinguishable shape on tasks that include both.

Only two of the six respondents who made this identification proposed extensions. To select between solutions B and C, one can follow the same line of argumentation as in themes 2 and 3 where it was established that consistency (heuristic #4) is best kept by extending the use of different shapes. Since hubs already apply an intersection of real and virtual shapes to illustrate hubs that incorporate both, the proposal to use the same solution for tasks and to use the same intersect shape for tasks that encompass object/agent pairs from both domains, extension C is best.

Theme 5: Objects that are real-world must be distinguishable from objects that are virtual

This theme identifies a need to distinguish real and virtual objects. The list of extension suggestions for the theme was as follows:

A – Use different fonts or font formatting (e.g., italics) for the domains
B – Use notations like arrow-parenthesis or tilde for one of the domains

C – Use (V) behind virtual and/or (R) behind real
D – Inverse the text or icon and use a negative background to distinguish one of the domains
E – Respondent particularly notes do not add colors to the eLuna pallet to fix this
F – Use different colors for real and virtual
G – Use different symbol sets for real and virtual
H – Use pop-up descriptions on clicking any element in the design to get further descriptions
I – Use similar but distinguishable symbols to distinguish domains
J – Use different design schemas for each domain, link between them, and view them in different windows.

Six respondents made this identification, producing a total of 10 unique extension suggestions, whereof one, E, was a negative suggestion stating that color changes should not be made to distinguish real and virtual objects from one another. In contrast to E, two respondents suggested using different color sets for real and virtual, F. As already discussed under theme 1, changing colors for the two domains may breach heuristic #8: Aesthetic and minimalist design and may cause problems of visibility for users with color blindness. Two respondents suggested A, use different fonts or font formatting. However, one respondent commented that this extension might be too subtle since it would be hard to see when zooming out in the blueprint, and this also breaches heuristic #1: Visibility of system status. Furthermore, the respondents who suggested this extension failed to consider that the eLuna Visual Language uses texts for objects in the co-design phase, but that the texts are substituted by icons in co-specification, something which makes A not functional throughout the methodology.

As already discussed under clusters 1 and 2, H and J breach heuristics #1: Visibility of system status, #4: Consistency and standards, and #6: Recognition rather than recall. G and I are variants of one another, with the small distinction of suggesting similar and different symbol sets for one of the domains, real or virtual. However, this would double the number of icons that will have to be remembered by eLuna Visual Language users and add to the memory load, which breaches heuristic #6: Recognition rather than recall. It also breaches heuristic #4: Consistency and standards, which states that users should never need to wonder if different words, situations, or actions mean the same thing. Furthermore, while this extension would work in the co-specification phase, the respondents suggesting these extensions failed to consider that text is used during co-design, making these solutions not functional throughout the methodology. Both B and C suggest adding notation from text-based Ascii sets to distinguish between the domains. While this would be possible during co-design, where text is in use, once the objects are transformed into icons in co-specification, this would require adding text to them, which breaches heuristic #7: Flexibility and efficiency of use. After eliminating the solutions, D is left, which is also commented by one respondent to probably be the best of their five different solutions to the theme.

Having both domains use the same icons in co-specification, inversing the background of one, does not add colors to the eLuna Visual Language. The inversion would be very visible in the blueprints, and it would also work with text in co-design. As such, the proposal is to use inverse colors for text and icons for objects to distinguish real from virtual.

Theme 6: Agents that are real-world must be distinguishable from agents that are virtual

Theme 6 identifies a need to distinguish real and virtual agents in the eLuna Visual Language. This identification is different from the theme 5 identification; only in that, it is for agents instead of tasks, and that one more respondent made this identification. The list of extension suggestions for the theme was as follows:

A – Use different fonts or font formatting (e.g., italics) for the domains
B – Use notations like arrow-parenthesis or tilde for one of the domains
C – Use (V) behind virtual and/or (R) behind real
D – Inverse the text or icon and use a negative background to distinguish one of the domains
E – Respondent particularly notes to not add colors to the eLuna pallet to fix this
F – Use different colors for real and virtual
G – Use different symbol sets for real and virtual
H – Use pop-up descriptions on clicking any element in the design to get further descriptions
I – Use similar but distinguishable symbols to distinguish domains
J – Use different design schemas for each domain, link between them, and view them in different windows

1. K – No solution.

Following the same argumentation as for theme 5, the proposal is to use inverse colors for text and icons for agents to distinguish real from virtual.

Theme 7: It must be possible to see what type of task (virtual/real combination) an event leads to

Theme 7 identifies the need to make visible whether an event leads to a virtual or physical task. The list of extension suggestions for the theme was as follows:

10.3389/feduc.2022.1061640

A – No solution
B – Using different shapes to indicate the types of the tasks themselves makes it visible without using different arrows
C – Use a special purpose arrow to show if the next task is real or virtual
D – Contain virtual and real parts of the entire co-design on separate sides of the design document
E – Use a color splash map under virtual and real parts of the design
F – Use a special node on the event arrow that can be clicked on to see what type of task the event goes to and from.

Only three respondents made this identification, one of them twice. One respondent suggested no extension and the other two suggested five extensions. Since themes 2 and 4 have already revealed that hubs and tasks may be both real and virtual at the same time, solutions D and E are not feasible and must be discarded since they cannot meaningfully work with mixed elements. As already discussed under several clusters above, F breaches heuristics #1: Visibility of system status, #4: Consistency and standards, and #6: Recognition rather than recall. These leaves B and C, however, as one respondent points out, providing that different domain tasks are distinguished by different shapes and there is no need to use separate arrow types for events; as it will already be clear in the blueprint the domain of both the initiating and resulting task, and the arrows may remain as they are in the original eLuna Visual Language. Thus, the proposal is extension B.

Theme 8: There are agents that can be physical at one task but virtual at others

Theme 8 identifies that the same agent can appear as physical in some occurrences and virtual in others. The list of extension suggestions for the theme was as follows:

A – No solution.

This theme contains only one identification that was made by a single respondent, and to which no solution was proposed. Whereas it is true that an agent in an eLuna specification can appear more than once, and that this agent can potentially be represented as physical in some occurrences and virtually in others, the eLuna Visual Language already has a way to distinguish the agent as physical or virtual. In the co-design phase, the agent is referenced by its textual name, and in the co-specification phase, the agent is represented by an icon alongside a name tag. As per theme 6, where real and virtual agents are already distinguished, and given that the agent names are exposed and available throughout the eLuna phases up to and including the blueprint, there is no further need to identify the agents that are the same when appearing across domains. While none of the respondents identified it, objects, too, maybe both physical and virtual in an eLuna blueprint, and, as with agents, no further distinction is required.

eLuna Visual Language extensions to support mixed reality

This subsection describes the eLuna MRVL extensions proposed in the thematic analysis and subsequent heuristic usability inspection described above. Figure 2 shows how the distinguishing of hubs will be visualized in the eLuna MRVL according to the proposed extensions for themes 1 and 2.

Hubs are distinguished using different shapes for three different domains; hubs that are real world locations, hubs that are virtual locations, and hubs that are manifested both as real and virtual locations through the learning trail, termed mixed hubs. A real hub is represented by a circle since this is often associated with something organic (e.g., our planet) and a Virtual hub is represented by a square since a square is often associated with something digital (e.g., a pixel). The Mixed domain, representing hubs that are both real and virtual in the narrative digital game-based learning trail, could be represented both as a four-sided rhombus or as an octagon, both of which can be said to be a middle ground between a circle and a square. In the practical application of the eLuna Visual Language, however, it is, in general, useful to allow as much space as possible for text in co-design and icon pairs in co-specification. The octagon renders more space (practically fully encompassing a circle, something that the rhombus does not) and is visually clearly distinguishable from the two other shapes.

Figure 3 combines clusters 3 and 4 and shows how the distinguishing of tasks will be visualized in the eLuna MRVL.

Following the same argumentation as for hubs, tasks are represented as circles for real, squares for virtual, and octagons for mixed domains. Whereas hubs, however, are shaped by the user selection when using the eLuna MRVL, the shapes of tasks can automatically be determined by the objects and agents contained in them; that is, if a task contains only real elements, it automatically becomes a circle, if it contains only virtual elements, it automatically becomes a square, and if it contains elements of both types, it becomes an octagon.

Figures 4, 5 combine the proposals from themes 5 and 6 and show how the distinguishing of objects and agents will be visualized in the eLuna MRVL in the text-based co-design phase and the icon-based co-specification phase, respectively.

Figure 4 shows how real objects and agents (top) are represented in yellow and red text on a blue task background

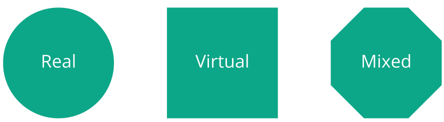

FIGURE 2
Distinguishing real, virtual, and mixed hubs.

FIGURE 3
Distinguishing real, virtual, and mixed tasks.

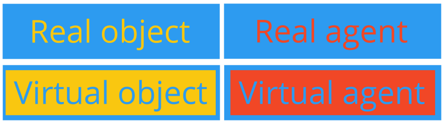

FIGURE 4
Distinguishing real and virtual objects and agents in eLuna MR co-design.

in the eLuna co-designs since objects and agents are always represented inside tasks that are blue. Furthermore, virtual objects and agents (bottom) are inversed using blue text for both yellow (object) and red (agent) backgrounds. While not as obvious as the circle/square metaphors applied for real and virtual hubs and tasks, it is speculated that it is intuitive to use negative versions of the texts for the virtual variants, since these will become squares around the texts inside the blue tasks, something which follows up on the digital/pixel metaphor used for hubs and tasks.

Figure 5 shows how real and virtual objects (top), and agents (bottom) are distinguished in the eLuna MRVL co-specification. As in the co-design phase, real elements use yellow or red colors respectively on a blue task background and are inversed using blue elements on yellow or red squares when representing the virtual domain.

The proposed extension from theme 7 was to leave the event lines as they are in the original eLuna Visual Language, since the tasks that they point from and to distinguish clearly whether the event lines point to and from real, virtual, or mixed events. Figure 6 shows four examples that illustrate this.

Figure 6A shows an event leading from real to real, Figure 6B shows an event that leads from real to virtual, Figure 6C shows three events of mixed, real, and virtual domains that lead to a mixed, and Figure 6D shows an event leading from virtual to one of each mixed, real, and virtual. There are many other combinations, the point being that the figure shows how following an event line distinguishes the domains in each end without the need to change the event lines themselves in the eLuna MRVL.

Theme 8 identified that the same agents may appear both as real and virtually represented in eLuna. The respondent observing this, however, does not provide a solution, and upon analyzing the theme, the proposal is that a distinction is not required since the eLuna Visual Language explicitly

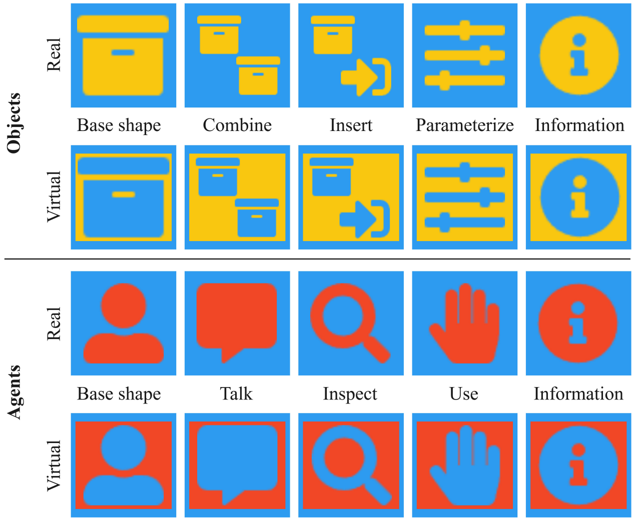

FIGURE 5
Distinguishing real and virtual objects and agents in eLuna MR co-specification.

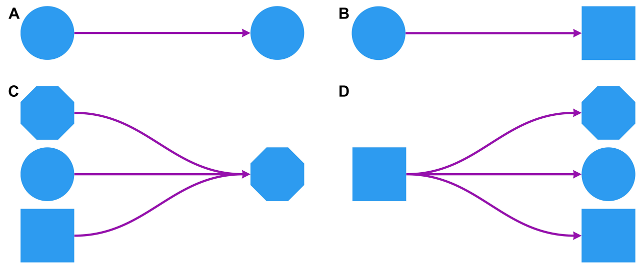

FIGURE 6
Examples of events connecting tasks; real to real **(A)**, real to virtual **(B)**, mixed, real, and virtual to mixed **(C)**, and virtual to mixed, real, and virtual **(D)**.

identifies the agent using direct text in co-design, and a text tag accompanying the agent icons in co-specification.

Exemplifying the eLuna Mixed-Reality Visual Language by revisiting the co-designs

During the workshops conducted in this research, two eLuna co-designs were created by the respondents. To exemplify the eLuna MRVL extension as proposed in this research, subsets from the two co-designs are revisited to illustrate the practical use of the extensions, as shown in **Figure 7**.

Using examples from the Save the Future co-design, **Figure 7A** shows three hubs from left to right, which exemplifies themes 1 and 2 and the resulting extensions. The three hubs are as follows:

- The Centrifugal Madness physical exhibit, which is a real-world hub,
- The Future, which is a virtual hub,
- The Ants, which in one part of the narrative digital game-based learning trail is visited physically as an exhibit to learn about the ants, and which is later virtually represented in a challenge where the pupils sort ant types to illustrate the structure of a functional society.

Also using the Save the Future co-design, **Figure 7B** exemplifies three tasks accompanied by virtual and real agents and objects in co-design (above) and co-specification (below) to illustrate the extensions brought forth by themes 3 and 4. These three tasks are as follows:

- Group solve the puzzle to get a year, a real-world task where the pupils solve a math puzzle to arrive at the year to input into the Time Walkie-Talkie,
- Future Youth get Society Structure, a virtual task in which virtual agents receive virtual information that has been inputted to them through the Time Walkie-Talkie,
- Time-Traveler inform Group and Group get Mission, a mixed task in which the Time-Traveler, represented virtually, informs the real-world group of pupils about their mission parameters.

Using the Move Now co-design as an example, **Figure 7C** exemplifies three variants of events connecting real, virtual, and mixed tasks. These three examples are as follows:

- The Mentor (physically enacted by a host in the real world) orders astronaut training in the form of a real-world instruction set (a fully real task), resulting in one of the virtual roles in the game becoming the virtual astronaut of the spaceship (a fully virtual task),
- The Mentor (virtually represented on the virtual spaceship) is shown disappearing as a virtual information element about the agent (a fully virtual task), resulting in the group (enacted by the pupils in the real world) arriving on the virtual hub Mars to construct the virtual settlement (a mixed task),
- The group (enacted by the pupils in the real world) generates a real world list of necessities (a real parameterizable object), and the virtual role that is in charge of collecting species selecting these from a virtual list for placement on the spaceship (a mixed task), resulting in both a virtual task in which the virtual role packs knowledge and resources into the spaceship and in a real world task, in which the group of pupils is enabled to take a picture of themselves in the real world.

Finally, **Figure 7D**, using Move Now as an example, shows how an agent can appear as both real and virtual in different parts of the narrative game-based learning trail, here shown as the notification would be in co-specification (the co-design

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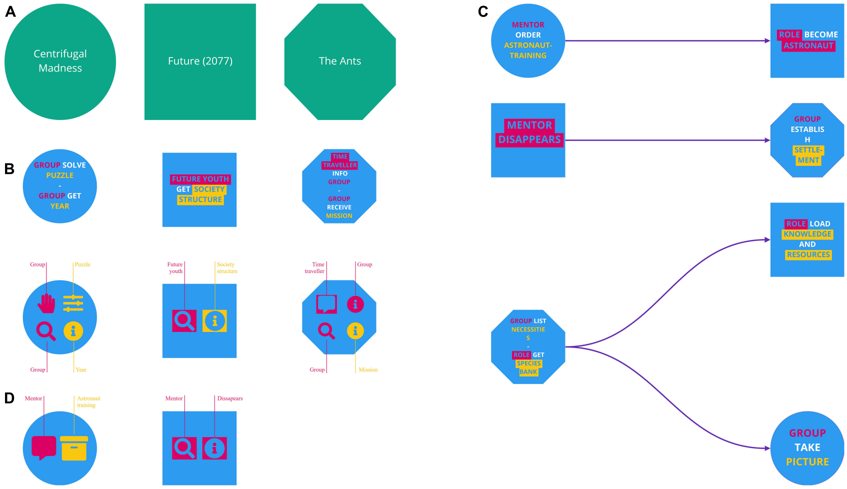

FIGURE 7
Practical application examples of eLuna MRVL extensions; types of hubs **(A)**, tasks with real and virtual elements **(B)**, variants of events connecting real, virtual, and mixed tasks **(C)**, and same agent as real and virtual **(D)**.

variants of these two tasks are shown in **Figure 7C**, top and middle left), using icons with names attached inside two tasks:

- The Mentor (physically enacted) ordering astronaut training,
- The Mentor (virtually represented) disappears from the spaceship.

Discussion

Realizing the importance of distinguishing real from virtual elements of mixed-reality narrative game-based learning trails since there are so many stake holders in both co-design, co-specification, development, and use of them, this article proposes a pluggable extension to the eLuna Framework in the eLuna MRVL. The results have provided extensions to the eLuna hubs, tasks, objects, and agents and have left the events as they were in the original visual language. These extensions have yielded a distinction between real and virtual elements and have, for hubs and tasks, identified the need for the distinction of mixed elements alongside the two former ones, extensions that have also been proposed. In their systematic review of future skills development in a serious game, Gurbuz and Celik (2022) identify 32 studies in which a framework, model, or methodology is selected. Visiting these 32 studies shows that none of them targets mixed reality by referencing real-world elements as distinct parts of the game-based learning experience. This does not imply that these 32 approaches cannot effectively be used in the design of mixed-reality game-based learning systems, and the eLuna Framework is one of the 32 identified studies, and as explored by Gurbuz and Celic neither did it make the distinction between the real and the virtual. It can be assumed that many of the other studies too can be extended or used as they are in mixed-reality game-based learning development. The review by Gurbuz and Celic does however show that among the frameworks, models, and methodologies uncovered, there is not a focus on mixed-reality development as required particularly to develop mixed-reality game-based learning trails in science centers. The eLuna MRVL is such a novel contribution to the co-design of learning trails, which could be followed up by extending other methodologies in a similar manner to enable mixed-reality game-based learning in science centers and museums, and possibly also in other domains. In addition to the eLuna MRVL, this research has provided two eLuna co-designs, Move Now and Save the Future. Six of the respondents in the research project participated in the co-design workshops, and the interviews, as well as the workshop conductions, indicate that none of them had any challenges in understanding or using the eLuna Framework, something which reconfirms Breien and Wasson's (2022) previous findings that eLuna is a usable method in co-design of narrative game-based learning systems. Three of the respondents as well as the participating researcher had previous experience with eLuna. Since experience with the Framework was not an area of focus in this research, the participants with experience were distributed as evenly as possible between the two workshops group, effectively two in one group and three in the other, since the researcher participated in both. In future research, it would be interesting to evaluate experience's effects on eLuna co-design efficiency, by performing workshops with and without experienced participants and analyzing the extent of their co-design elaboration. Due to COVID-19 restrictions, two serious game developers from an external organization to the participating science center were unable to attend the workshops for this research. While this was unintended and a shortcoming, it does also allow for a reflection about their immediate understanding of eLuna co-design documents that they themselves had not participated in creating, something which has not been done before in the original research on the eLuna Framework. While this was not accounted for methodologically, the results from the interviews, where the serious game designers were presented with what was for them completely novel co-designs from which they were both able to contribute identifications and extension suggestions in numbers that did not deviate from the ones produced by other respondents, indicate that eLuna co-designs are understandable to at least game developers even if they have not made them themselves. The understandability of eLuna co-designs and co-specification blueprints by stakeholders is an interesting avenue for future research, given that a wide range of stakeholders that have not participated in making them should be able to reference them in practical environments where narrative game-based learning trails are created for and offered to learners.

Thematic evaluation with a deductive and semantic premise, in which the researcher has a preconception about the core subjects of themes that might emerge from interview transcriptions (e.g., hubs, tasks, events, agents, and objects), and where concrete verbalized challenges (identifications) and solutions to them (extension suggestions) are of interest to the research, worked well in organizing identifications of distinction requirements and suggested extensions based on them to the visual language. The eight themes that emerged from the iterative process and their suggestions were clearly formulated, the application of the extensions to the original co-designs revealed that they achieved their intent, and there is no part of the original visual language that has not been addressed by the extensions. In scrutinizing the themes, the researchers are unable to identify any element extensions that are missing, with the exception that none of the evaluators mention that objects too, alongside agents, may potentially appear as both real and virtual in different parts of the narrative game-based learning trails, something that would have added a ninth theme, identical to theme eight, but about objects. However, since theme eight was concluded to not require any extension at all, given the naming properties of agents, and since these naming properties are the same for objects, a ninth theme would not have resulted in further extensions to the eLuna MRVL.

Heuristic usability inspection also proved a valuable method as added to this research. By inspecting the themes one by one, using the heuristics to select the clearest and most usable suggestions, and, where relevant, revisiting already determined extensions in other themes to make proposals based on overall understandability, the heuristics allowed for a concrete and practical extension set that could be applied to the co-designs. Out of the 10 original usability heuristics, only five (1, 4, 6, 7, and 8) were employed in this research. Usability heuristics are originally intended for user interface design. While the eLuna Visual Language, and by effect, it is MRVL extension, is a user interface, it is in its current state paper-based and thus renders redundant some of the heuristics, which are related to, e.g., effective use of shortcuts, and the accessibility of help and guidance systems. The eLuna method is, however, envisioned as a digital tool in future development, and as such a tool emerges, it would be of interest to revisit it using heuristic inspection methods, to refine the interface's usability both for educators and game developers, a process in which the more technically related heuristics is expected to have relevance.

The two designs are well elaborated and show promise and may be realized as functional mixed-reality narrative game-based learning trails at science centers, the progress that the two groups made during the relative workshops came as a surprise and suggest that eLuna could be further explored as a rapid design method. The co-designs could be further refined to co-specifications and presented in future research following up on what is presented here. The objective of this research was to propose and present a pluggable mixed-reality extension to the eLuna Visual Language, allowing for the co-design of mixed-reality learning trails alongside narrative game-based learning systems for which the eLuna Framework is originally intended. In effectively distinguishing the real from the virtual in eLuna co-design, a side result of this research is that eLuna is now usable to create fully real-world narrative game-based learning trails, in which all locations, agents, objects, tasks, and so on are represented in the real world. To date, research on eLuna has focused on fully virtual and mixed-reality systems. Future research on eLuna used to create fully real-world learning environments would be of interest.

Conclusion

Through two workshop-based co-designs, subsequent respondent interviews, thematic analysis, and heuristic usability inspection, this research has resulted in the eLuna MRVL, an extension to the eLuna Framework that enables the distinction of real from virtual elements, adding mixed elements, in mixed-reality narrative game-based learning trails for use in interdisciplinary education during high-school visits to science centers. The extensions have been exemplified on the subsets of the two co-designs presented in this article, and on revisiting the thematic list of identifications reported by the respondents, the researchers cannot find elements that are now not distinguished, possibly except for one missing theme that would not have resulted in any extensions. In addition to the new extension adding mixed-reality capabilities to eLuna, an effect of this research is that eLuna can now also be used to create learning environments that are fully real, not applying virtual elements at all. Further research to explore this as well as many other aspects of interest to improve eLuna has been proposed.

Previous research on the presentation of the eLuna Framework has shown that it is a useful methodology for the co-design and co-specification of narrative digital game-based learning (Breien and Wasson, 2022). This research has extended the framework and added capabilities to also enable the development of mixed-reality narrative game-based learning trails at science centers and further encourages similar extensions to be made in other methodologies for game-based learning design. The resulting eLuna MRVL does not change the functional color palette of eLuna and provides a comprehensive and consistent metaphor focusing on shapes and inversed colors that represent real elements as rounded and natural, virtual elements as squares and inversions, and mixed elements as intersects between the real and virtual. In future research, an eLuna co-design should be fully co-specified into an eLuna blueprint, developed, and deployed to visiting high-school pupils as a mixed-reality narrative game-based learning trail. The contribution of this research, the eLuna VRLM itself, should be scrutinized after practical use by co-designers, to explore whether the extensions use of colors and shapes are in fact functional to distinguish the real from the virtual, or whether the further distinction is required in practical use. The eLuna Framework should be evaluated, and the eLuna Methodology should be developed into a tool. The engagement, motivation, and learning outcomes should be evaluated after pupils use.

Data availability statement

The original contributions presented in this study are included in the article/**Supplementary material**, further inquiries can be directed to the corresponding author.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The patients/participants provided their written informed consent to participate in this study.

Author contributions

FB contributed the ideas, the eLuna MRVL, and had the main responsibility for writing the manuscript. BW contributed to the development of the eLuna Framework through supervision and contributed to both the editing and writing the manuscript. SG contributed structural input for the method and the writing of the manuscript. NH contributed read throughs and comments on the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/feduc.2022.1061640/full#supplementary-material

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