



# Gamification Strategies: A Characterization Using Formal Argumentation Theory

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## Abstract

*Gamified* software applications are omnipresent in everyday life. The idea of using game design elements in non-game contexts to engage and motivate tasks has rapidly gained traction in the human–computer interaction and the psychology fields, but scarcely in the artificial intelligence (AI) research area. In this paper, we propose a *software agent* perspective of gamification elements to solve two specific problems: (1) a *reactive* perspective that gamification designers have for those gamified affordances, i.e. the visual cue (*output*) is only triggered by user interaction, and (2) a lack of formal treatment of gamified software, where strict characterization of software behavior as done in AI, guarantee that the information-based output follows the intended goal of the software. Our contributions presented in this paper are (1) two taxonomies of affordances based on the type of information that every element communicates, and the type of agency that is capable; (2) a framework to formalize the decision-making process for gamified software agents; and (3) a characterization of gamified *stories* using *formal argumentation theory* dialogues. We exemplify our contributions with two gamified platforms in the healthcare and financial literacy fields.

**Keywords** Gamification · Argumentation theory · Taxonomy · Dialogues · Stories · Software agents

## Introduction

*Gamification*, understood as the use of game design elements in non-game contexts [1] is a research field integrating approaches from the human–computer interaction, psychology, and computer science fields. Usually, persuasive gamification constructs (e.g. social orientation [2], emotion-orientation [3], etc.) are used as a means for tailoring software, which although promising, presents a problem of high specialization without general theories or frameworks,

drifting toward an apparent *immaturity* of formal foundations and validated methods [4]. However, gamification has increased popularity for designing software that covers enjoyment, immersion, and goal-orientation being a conventional approach for *behavior change* [5, 6]. Key in these persuasive designs are well-used visual cues such as leader boards, rankings, levels, stories, etc. These gamification affordances have been the subject of different studies to understand user orientation and the relationship with those elements [7–9], to explore affordances to motivate and induce emotions [3, 4], and for assessing the suitability of those game objects for social-oriented tasks (e.g. cooperative or competitive) [2, 10]. Previous research has classified these gamified elements considering user motivation, engagement, and effects on user’s behavior [11, 12], depending on the type of *artifacts* from a development perspective [13] and classifying affordances types depending on the application of different levels of design principles [14]. Despite this body of investigation, an evident research gap exists in the intersection between gamification and artificial intelligence (AI), specifically from one of its branches, the design of *autonomous software agents*. The two specific problems that we challenge in this paper are:

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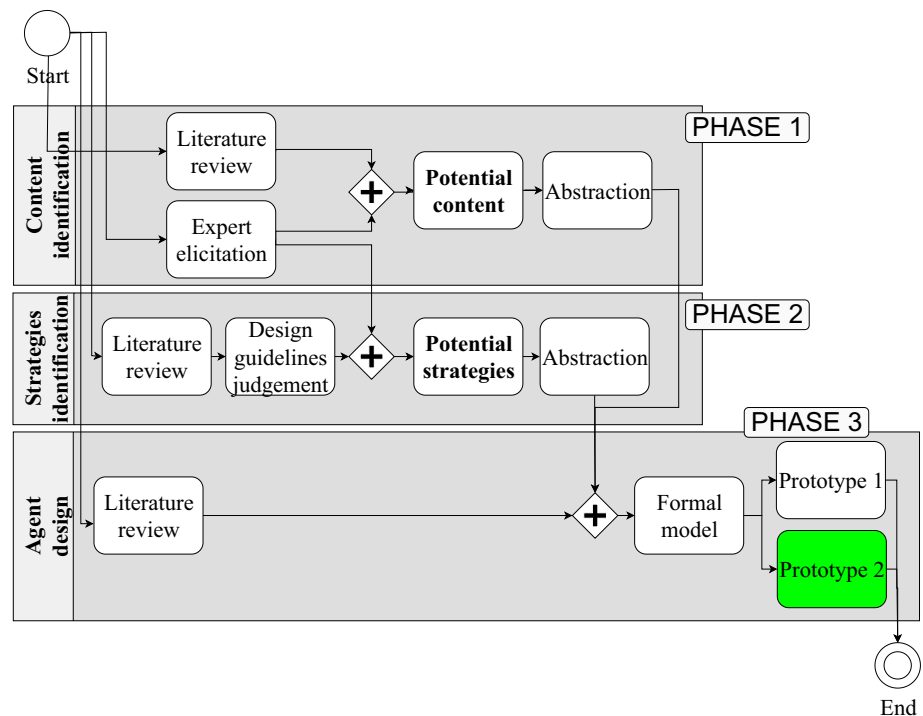
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**Fig. 1** Methodological process: Phase (1) content identification, Phase 2 strategies identification, and Phase (3) agent design



1. Previous research considers gamified software as *static* artifacts (see reviews [15, 16]), being common that affordances have only a *reactive* behavior, i.e. their output is only triggered by user interaction, and its behavior is handcrafted to a specific game task. The notions of *proactive*, *semi-autonomous*, or *autonomous* gamified elements have been disregarded in the gamification literature.
2. Research on persuasive gamification lacks mathematical characterizations of gamified software, which is valuable to ensure the correct behavior of such affordances. Formalization of software behavior, as done in AI, guarantees that the information-based output follows the intended goal of the software. The use of formal approaches to describe gamification elements and mechanisms is almost nonexistent (see review [4]).

In this paper, we propose a software-agents perspective of gamification elements introducing two taxonomies of affordances based on the type of information that every element communicates and the type of agency that is capable. We also introduce a framework to formalize the decision-making process that such gamified software agents should have, presenting an algorithm that allows such agents to make decisions about what gamification affordance is most suitable for a user. Finally, we present a characterization of one type of gamification strategy called *stories*, where *formal argumentation theory* [17] (active research line of AI) is used to precisely describe the behavior of the software and user interaction. Concretely, three contributions are presented: (1)

a set of typologies of persuasive strategies and content, (2) a mapping between those typologies and formal persuasive dialogue games, and (3) a novel algorithm for strategy and content selection that can be used in persuasive technology. We exemplify our framework using two software platforms as persuasive gamified stories, one in the context of health-care and the other for financial literacy. This paper is an extended and improved version of the paper presented in [18].<sup>1</sup>

This paper is organized as follows, we present our methodological approach in "Methodology" where we include a necessary background. "Results" introduces the main results, which are divided into three subsections presenting the three aforementioned contributions. Experiments implementing our framework are presented in "Experimentation", and an in-depth discussion about the results is presented in "Discussion and Future Work". We end our paper by highlighting our conclusions and future research paths in "Conclusions".

## Methodology

This paper followed a three-arm methodological approach (see Fig. 1). In the following, we present methods used in the three phases.

<sup>1</sup> In this version of the paper, we extended our work considering an additional experiment setting, supplementary discussion material, integrating valuable feedback from anonymous reviewers.

**Table 1** Consulted databases with their number of potential papers

Database	Potential
IEEE Xplore	64
SCOPUS	19 (set 1) + 15 (set 2)
EBSCOhost	1
ACM Digital Library	39
Total	138

## Persuasive Content and Strategies Identification (Phase 1 and 2)

Identification of general features of persuasive systems was performed using two data collection mechanisms: (1) a *systematic literature review* (SLR), aiming at identifying features (or content) used in persuasive systems within the health-care and financial literacy literature;<sup>2</sup> and (2) *expert elicitation process* in which a multidisciplinary group of researchers identified features of those systems focused on specific scientific areas. We describe the data collection procedure in the following.

### Literature Review on Features Identification

We followed Kitchenham's protocol in [19] to perform our systematic literature reviews (SLR), which was part of the methodological procedure used in this paper.

**SLR Research questions.** The questions that the SLR was aiming to solve were:

- Q1 What type of gamification content is usually used in persuasive coaching systems?  
Q2 What gamification strategies are usually used in persuasive coaching systems?

**Databases** We collect results from seven databases: IEEE Xplore, Scopus, EBSCOhost, and ACM Digital Library. The time frame selected for this review was from January 2000 to December 2021.<sup>3</sup>

**Databases queries** We use systematically two sets of keywords in our search strategy to evaluate publications by a different team, depending on the field background *w.r.t.* financial literacy or health.

Set 1 (“ALL METADATA”:“COACHING SYSTEM”) OR (“ALL METADATA”: “PERSUASIVE SYSTEM”) OR (“ALL METADATA”:“BEHAVIOR CHANGE SYSTEM”) AND (“ALL METADATA”:GAMIFI\*) AND (“ALL METADATA”:HEALTH\* ) AND (“ALL METADATA”:“BEHAVIOR CHANGE”),

Set 2 (“ALL METADATA”:“COACHING SYSTEM”) OR (“ALL METADATA”:“PERSUASIVE SYSTEM”) OR (“ALL METADATA”:“BEHAVIOR CHANGE SYSTEM”) AND (“ALL METADATA”:GAMIFI\*) AND (“ALL METADATA”:“FINANC\* LITERACY”) AND (“ALL METADATA”:“BEHAVIOR CHANGE”)

### Inclusion and exclusion criteria

We removed duplicates ( $n = 4$ ) and no-single articles such as collections ( $n = 4$ ), no-fully access ( $n = 2$ ), no-complete or mature publications ( $n = 2$ ), and reviews ( $n = 6$ ), which were used in the Discussion section to compare our results with the state of the art.

Four criteria (CR) were defined to assess every paper (see below), every criterion had a quantitative score of 1, 0, or  $-1$ , which correspond to answering the criteria with values: Yes, Partially or Not, respectively. A total score is calculated by adding the individual criteria values. Our total selection score was equal or greater than zero.

- CR1: It is connected with health-related or financial literacy-related persuasive systems.
- CR2: Describes any AI-based approach used to detect, predict, anticipate, infer or deduce a (un)desired/(un) wanted specific behavior.
- CR3: Describes the type of gamification content used for coaching.
- CR4: Describes the type of gamification strategies used for coaching.

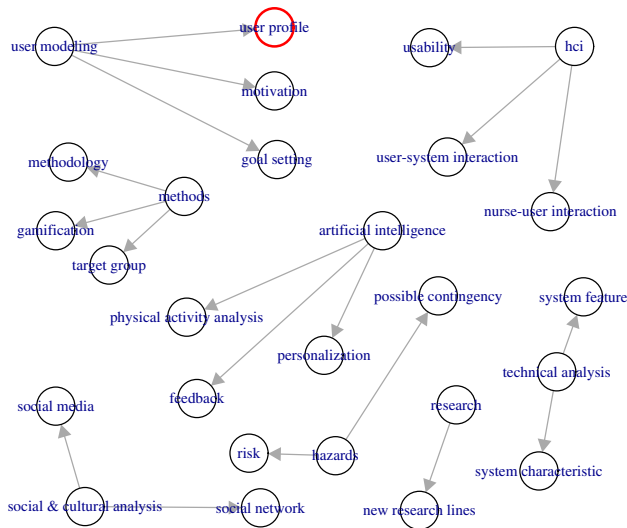
### Expert Elicitation

The expert elicitation process was oriented to capture the perspective of senior researchers about gamification in the specific aim of this project. Eight volunteers were recruited to participate in the study. They had no expertise in software development, user experience, or software design. However, they were part of the project, and the recruitment process was through direct contact. No rewards were offered. The following are general characteristics of the participants:

- Number of participants: eight
- Age: avg: 47.5 sd: 7.59
- Research areas expertise: physical activity and sedentary behaviour, ageing and disability, social work, social welfare, nutrition, psychology and governance, finance and economics, and health economics.

<sup>2</sup> In [18] a SLR for only the health-care field was included, in this version of this paper, literature on financial literacy was added.

<sup>3</sup> In this extended version of our previous work [18], we updated the search parameters to include academic work in 2021.



**Fig. 2** Themes and codes used for interpreting interviews entries

A five-items questionnaire directed a one-hour interview containing the following questions:

1. What should be the main goal for the digital coach?
2. What are the main functionalities of the system?
3. How the visual aspect of the main functionality would be?
4. What direct benefits a user should receive from the digital coach use?
5. What direct risks could the user have when using the digital coach?

**Analysis** *Grounded theory* [20] was used as an inductive, comparative process for gathering, synthesizing, and identifying features and strategies of persuasive/coaching systems. We used the RQDA: Qualitative Data Analysis<sup>4</sup> package with RStudio<sup>5</sup> v1.2.5 and R language<sup>6</sup> to make the codes, code categories, and the analysis of cases of every interview. Then, a follow-up short questionnaire with identical questions was fulfilled by the same experts after six months, as a validation process to confirm/disapprove potential features and strategies. We used 19 codes grouped into nine categories as is presented in Fig. 2.

### Agent Design Background (Phase 3)

In this paper, we make the following design assumptions of our agents ( $Ag$ ): (1) an  $Ag$  has an independent knowledge

<sup>4</sup> RQDA site: <http://rqda.r-forge.r-project.org>.

<sup>5</sup> RStudio site: <https://rstudio.com>.

<sup>6</sup> R lang. version 3.6.3 site: <https://www.r-project.org>.

base  $\Sigma$ , potentially inconsistent, and contains formulas of a propositional language  $\mathcal{L}$ . (2) Formal argumentation is used in the  $Ag$ 's decision-making process, and in the communication process (argument-based dialogue) that has a persuasive nature, between a persuadee ( $Ag_c$ ) and a persuader ( $Ag_p$ ). We use a propositional logic with connectives:  $\wedge$ ,  $\leftarrow$ ,  $\neg$ ,  $\top$ ; the consequence operator:  $\leftarrow$  is non-monotonic.

### Formal Argumentation Reasoning

An *argument* is a tuple  $Arg = \langle support, conclusion \rangle$ , fulfilling next conditions: (1)  $supp \subseteq \Sigma$ ; (2)  $supp$  is consistent; (3)  $supp \vdash conc$  and 4)  $\nexists supp' \subset supp$  such that  $supp' \vdash conc$ .  $supp$  and  $conc$  are usually called the *support* and *conclusion* of an argument. All the arguments built from  $\Sigma$  are noted as  $\mathcal{A}$ .

### Argumentation-Based Dialogue

A *dialogue* ( $\mathcal{D}$ ) has two agents, both have an argument-based decision-making process and they communicate through a *moves-based protocol*. Agents have a shared knowledge base called *commitment store* (CS) that is updated at every agent's move. A move in  $\mathcal{D}$  contains: (1) a *speech act* ( $sa \in SA$ ) that is a function defining the move intention; (2) a move *content* ( $ct$ ); and (3) the targeted or opponent agent towards is directed the speech act and the content. Formally, a move is a tuple  $m = \langle sa, ct, Ag_i \rangle$ , which will be defined in the following sections. We use the following speech acts *assert*, *accept*, *challenge*, *question*, *ignore* and *reject*. Then, agents may have different *attitudes* towards propositional speech-acts from other agents: (1) assertion attitude: an agent is confident if it can assert any proposition  $p$  for which it can build an argument  $\langle S, p \rangle$ , or it is thoughtful if asserts any proposition  $p$  for which it can build an *acceptable* argument  $\langle S, p \rangle$ . (2) Acceptance attitudes: an agent is credulous if it accepts any proposition  $p$  that is backed by an argument, or it is skeptical if accepts any proposition  $p$  if there is an *acceptable* argument  $\langle S, p \rangle$ . (3) Challenging attitudes: an agent is curious if it challenges or questions any proposition  $p$  that has an argument, or it is inquisitive if it challenges or questions proposition  $p$  backed by an acceptable argument  $\langle S, p \rangle$ . *ignore* and *reject* speech acts do not change CS, ending the dialogue as an outcome.

### Results

This section summarizes two main results: (1) a classification of gamification strategies and content from a software agent perspective as *typologies* in "[Typologies of Gamification Strategies and Content](#)", and (2) a formalization of

**Table 2** Evaluated papers using the proposed criteria with their respective ASReview ranking

Authors	References	Inclusion/exclusion criteria				Assess	ASReview
		CR1	CR2	CR3	CR4	Sum	Ranking
Orji, Oyibo, et al., 2017	[21]	- 1	- 1	0	1	- 1	20
Klein et al., 2013	[22]	1	1	1	1	4	15
Ndulue Orji, 2021	[23]	1	- 1	1	1	2	13
Klaassen et al., 2018	[24]	1	1	1	1	4	4
Offi et al., 2016	[25]	1	0	1	0	2	3
Kekkonen Oinas-Kukkonen, 2021	[26]	1	- 1	1	1	2	21
Ndulue Orji, 2019	[27]	1	- 1	0	1	1	2
Kappen Orji, 2017	[28]	1	- 1	0	1	1	9
Ndulue Orji, 2021	[29]	1	- 1	1	1	2	11
Orji, Mandryk, et al., 2017	[30]	- 1	- 1	0	1	- 1	6
den Akker et al., 2017	[31]	1	- 1	0	1	1	1
Ross et al., 2021	[32]	1	- 1	0	1	1	7
Senette et al., 2018	[33]	1	- 1	1	1	2	17
Omar et al., 2019	[34]	1	- 1	1	1	2	5
Orji, Nacke, et al., 2017	[35]	1	- 1	0	1	1	8
Dikken, et al., 2020	[36]	1	- 1	0	1	1	8
Chaouali, et al., 2020	[37]	1	- 1	1	1	2	12
Rasco, et al., 2021	[38]	1	- 1	0	1	1	14
Raman, Prashant, 2021	[39]	1	- 1	0	1	1	16
Rasco, et al., 2020	[40]	1	1	- 1	1	2	18
Pal, et al., 2021	[41]	1	- 1	0	0	0	19
Bauer, et al., 2020	[42]	1	- 1	0	1	1	8
Inchamnan, et al., 2019	[43]	1	- 1	0	1	1	22
Steinemann et al., 2015	[44]	1	- 1	0	1	1	23
Arcand et al., 2017	[45]	1	- 1	0	0	0	24
Rasco, et al., 2020	[46]	1	- 1	0	1	1	8
Soni, et al., 2021	[47]	1	- 1	0	0	0	25
Chun et al., 2021	[48]	1	- 1	0	0	0	26
Baptista et al., 2017	[49]	1	- 1	0	0	0	27

gamification mechanisms as argument-based dialogues in "Formal Framework for Content and Strategy Selection".

### Typologies of Gamification Strategies and Content

This section presents the joint results of our systematic literature review and the expert elicitation process that we performed to define typologies of gamification strategies that can be characterized as different variations of software agency.

#### SLR Results

Based on the list of selected papers (Table 2), and a set of review/survey papers [4, 15, 16, 50–53], we obtained a list of gamification strategies and gamification content presented in Table 3. In summary, persuasive strategies and content are

combined in different forms to evaluate progress and levels of human activities [22, 24, 25, 27, 28, 31, 33–35], as well as the use of rewards, which was confirmed with the state of the art i.e. the reviews and surveys that we assessed. We also found that nudges, leader boards, and simulations are used in different other fields, as other reviews and surveys show.

#### Results of the Expert Elicitation

The analysis of interviews with experts revealed three main trends: (1) few of them were describing gamification strategies based on specific known mobile applications, not novel types of interactions were suggested, (2) from those three interviewees suggesting gamification strategies, progress, avatars and nudges were mentioned as a potential for behavior change, and (3) interviewees did not mention specific gamification content in the user interface (Table 4).

**Table 3** List of gamified persuasive strategies and content obtained from the SLR

Strategies									
	Nudges	Avatars	Leader boards	Challenges	Simulations	Levels	Stories	Progress	Rewards
Content									
Activity-based				[28, 28]		[24, 25, 27, 31, 33]	[28]	[22, 24, 25, 27, 28, 33–35]	[24, 33, 35] ***
Location-based	***							[33]	
Time-based					[36, 38]			[26, 33, 34]	
Facts and knowledge	**	[31]				[23, 27, 31]	[23, 27]		
Questions/Info gathering						[33]		[22, 33]	
Goal-based	***								
Value-based [37]			***	[47]	* [38]	[27, 43]	[23, 27]	[22, 24, 31, 36]	[43]
Emotion/feelings-based					[44]		[23, 27]	[26]	[26, 42]
Cooperative goal	***			[47]	*				[39]
Cooperative value	***								[39]
Cooperative emotions	***								
Competitive goal	*** [48]					[27]			***
Competitive value	***								***
Competitive emotions	***								***

**Bold asterisks (\*)** indicate the use of strategies and content in other fields and contexts. We identify those categories using surveys and systematic literature reviews [4, 15, 16, 50, 50–53]

\*: less used.

\*\*: partial used.

\*\*\*: highly used

**Table 4** Results of expert elicitation where ☑ symbolizes that an interviewee mentioned a specific strategy during the interview highly used

	Strategies								
	Nudges	Avatars	Leader boards	Challenges	Simulations	Levels	Stories	Progress	Rewards
Interviewee 1									
Interviewee 2									
Interviewee 3	☑	☑						☑	
Interviewee 4	☑					☑		☑	☑
Interviewee 5		☑	☑					☑	
Interviewee 6									
Interviewee 7									
Interviewee 8									

### Content Typology

The elicitation process with multidisciplinary experts and our systematic literature review revealed three types of content that are preferred and expected by experts, and well-known used in the state of the art: (1) *measuring and monitoring* content; (2) *information-based* content, and (3) *social-oriented* content. In this taxonomy of content (Taxonomy 1), different general types were found for example *motion* type relates to complex activities or simple motion logs or data tracking, *location* relates to context or specific spatial information, *facts* regarding to information-based content presented in different modalities (text, audio, visual, haptic, etc.), and *goal-targeted advises* or *value-targeted advises* or *emotion-targeted advises* relate to information-based content integrating a goal or a value or an emotion to stimulate another individual (or agent in general)). For lack of space, we do not provide the full list of papers linked to every branch of the taxonomy.

### Persuasive Strategies Typology

Our systematic review of persuasive strategies in gamification, revealed the existence of nine main types of strategies commonly used in persuasive and coaching systems, as is presented in Taxonomy 2. We mapped these gamification strategies with three key software *agency* characteristics: *proactiveness*, *reactiveness*, and *social awareness* [54]. From a software agent perspective, a *reactive* strategy generates an *output after* the execution of an action by another agent (e.g. an individual). A *proactive* strategy refers to action-based outputs that are not-preceded by other agents' actions, and *social behavior* is any output where collective relations information regarding cooperation and competition is shared.

### Content and Strategies Compatibility

Not all the content can be used in different gamification strategies [55], therefore we propose a set of dynamic constraints that the persuader agent should use during the strategy-protocol-content selection, presented in Table 5. This matrix between content and strategies of gamification uses three *levels* (w.r.t complete, partial compatible, and incompatible) to assess how compatible the content is for every strategy. We used the literature review and expert opinion to design the matrix (see "[Methodology](#)"). The compatibility matrix is not exhaustive but suggests important differences among strategies. Moreover, compatibilities/incompatibilities may change when multiple types of content are used for individual strategies. We leave for future work the examination of dynamic compatibility when multiple contents are used in a gamification strategy.

### Formal Framework for Content and Strategy Selection

In this section, we introduce a framework that a persuader agent can use to select content and strategies considering the persuadee's goals, values, and emotions. We also present a decision-making algorithm that has as input relevant information about the persuadee's status, and as an outcome, it generates a set of hypothetical situations where some content and strategies are used, influencing the persuadee's goals, values and emotions.

In this paper, the persuader agent is modeled as a tuple  $Ag_c = \langle S, Act, G, V, E, \leq^* \rangle$ , where  $S, Act, G, V, E \subseteq \Sigma$ ,  $G, V, E$  are mental states representing *beliefs*, *values* and *emotions*, respectively, extending the Belief-Desire-Intention (BDI) model [56] by following recent work on the *attitudinal theory of emotions* [57] and the value orientations theory [58]. This extension allows us to model a *human agent* (the persuadee perspective) with capabilities closer to a real individual, endowing a software agent with possibilities to perceive and make decisions given the potential emotions and values of a person. The rationale for such a design is that the identification of beliefs, desires, and intentions (including emotions and values) is useful when the system must communicate with humans [59].

The decision-making process that we propose (see Algorithm 1) takes as *input* observations of the world in terms of rule-based facts, and the agents model, and it returns as *output* an ordered set of hypotheses about the current state of the persuadee agent, from which the persuader may take a preferred explanation. For example generating sets of goal hypotheses such as:

$$h_{g1} = \langle \underbrace{\{ S \}}_{\text{background}} \wedge \underbrace{\text{show(goal\_oriented\_content)}}_{\text{action}} \wedge \underbrace{\text{“be healthy”}}_{\text{value}} \wedge \underbrace{\text{amazement}}_{\text{emotion}} \rangle, \underbrace{\langle \text{“improve physical activity”} \rangle}_{\text{goal}} \rangle$$

support

conclusion

A hypothesis such as  $h_{g1}$  intuitively says: “in order to improve physical activity as a goal, then it is necessary to show goal-oriented content when the persuadee’s values are aiming to be healthy, and she/he is amazed”. This algorithm is an extension of an argument-based practical reasoning mechanism [60], generating goal, emotion, and value-oriented hypotheses.

Our proposed strategies’ classification w.r.t the type of agency is based on the underlying assumption that the protocol selection depends on an *uncertainty level* of the persuadee’s  $G, V, E$ . In other words, gamification strategies (and their respective protocols) for proactive or social behavior cannot be used when there is limited information (high

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**Algorithm 1** Generation and selection of goal, value, emotion-oriented hypotheses

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**INPUT:**  $Ag' = \langle S, Act, G, V, E, \preceq^* \rangle$  {Agent framework}

**Model update**  $S, Act, G, V, E, \preceq^*$

1:  $GHypoth, VHypoth, EHypoth, Support, RelatedRules \leftarrow \emptyset$

2:  $G = \text{UpdateAttitude}G', \preceq^G, p(G)$

3:  $V = \text{UpdateAttitude}V', \preceq^V, p(V)$

4:  $E = \text{UpdateAttitude}E', \preceq^E, p(E)$

**Hypotheses generation**  $G, V, E$  conclusion  $\in G, V, E$

5:  $S = \text{ConnectedRulesconclusion}$

6:  $RelatedRules = 2^S$  set  $\in RelatedRules$  Support  $\neq \perp$

7:  $Support = \min(Support) \cup ASPset$

8:  $GHypoth = \cup GHypoth = \langle Support, conclusion \rangle$

**Hypotheses selection**  $GHypoth, SEM$

9:  $Graph = \text{buildGraph}GHypoth, Conflicts$

10:  $P = \sum_{i \in Graph} p(i)$

11:  $NonConflicting = SEMGraph$  {Argumentation semantics process}

**OUTPUT:**  $\langle Graph, \preceq^*, P \rangle$   $\{ * \in \{G, V, E\} \}$

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Algorithm 1 has three phases or procedures: a model update (lines 1–4), a hypotheses generation (lines 5–14), and a hypotheses selection (lines 15–17). The `UpdateAttitude` function updates the  $G, V, E$  attitudes with their respective preferences. In the hypotheses generation, `ASP()` (line 10) is an *answer-set* solver function that generates *stable models* (see [61]). In line 15, `Conflicts` is a logical relation set that emerges from different hypotheses. `buildGraph` (in line 15) is a function creating a graph with the entire set of hypotheses  $\mathcal{H}$  as nodes, and `Conflicts` as edges, and in line 17 `SEM()` is an argument-based pattern of selection where conflicting hypotheses are discarded [62]. Finally, the output of the algorithm is an ordered set of hypotheses that are selected to be used by the persuader agent during a dialogue exchange.

uncertainty) about goals, values, or emotions modeling the agent persuadee, which suggests that the persuader should adapt to the persuadee’s needs, and the need for managing incomplete information during and for gamification, as it has been suggested by previous work on persuasive gamification [7, 63].

In this paper, uncertainty about the persuadee is modeled as a *probabilistic distribution* representing an ambiguity degree in the hypotheses premises for which  $G, V, E$  are *believed* to be true. More formally, such uncertainty is represented as a belief function on  $U \subseteq \Sigma$  where  $p : \Sigma \rightarrow [0, 1]$ .

In the following, we introduce an informative example where a persuader agent has to generate different hypotheses about the persuadee status. This example is part of our two-branch experimentation presented in “[Experimentation](#)”.



**Example 1** (Generating value-oriented hypothetical actions) A persuader uses Algorithm 1 to establish the status of a persuadee, knowing that it has a preference to follow emotional cues, i.e.  $\exists e_i, e_j \in E$  such that  $e_i \leq^e e_j$ , saying that  $e_j$  is preferred than  $e_i$ , for example, the persuadee prefers to be *amazed* than feel *grief*. Let  $P$  be a *program* capturing the persuadee behavior with the following rules:

$$P = \left\{ \begin{array}{l} g1 \leftarrow S_1 \wedge v_1 \wedge e_1 \wedge act_1 \\ g2 \leftarrow S_2 \wedge v_2 \wedge e_2 \wedge act_2 \\ g3 \leftarrow S_3 \wedge v_3 \wedge e_3 \wedge act_3 \\ act_1, act_2, act_3 \leftarrow \top \\ v_1, v_2, v_3 \leftarrow \top \\ e_1, e_2, e_3 \leftarrow \top \\ S_1, S_2, S_3 \leftarrow \top \end{array} \right\} \tag{1}$$

where  $g_1$  = “improve physical activity”,  $g_2$  = “stay in bed”,  $g_3$  = “keep social network”,  $v_1$  = “be healthy”,  $v_2$  = “seek pleasure”,  $v_3$  = “be social”,  $e_1$  = “amazement”,  $e_2$  = “grief”,  $e_3$  = “vigilance”,  $act_1$  =  $show(goal\_oriented\_content)$ ,  $act_2$  =  $show(value\_oriented\_content)$ ,  $act_3$  =  $show(emotion\_oriented\_content)$ ,  $S_1, S_2, S_3$  are observations, considering that  $g_1 \equiv \neg g_2$ , and  $show$  is a propositional action to present content, e.g. “show goal-targeted advise” in Taxonomy 1.

Using Algorithm 1, two non-contradictory sets of hypotheses are generated in line 16:

$$\left\{ \left\{ \begin{array}{l} h_{g1} = \langle \{S_1 \wedge v_1 \wedge e_1 \wedge act_1\}, g_1 \rangle \\ h_{g2} = \langle \{S_2 \wedge v_2 \wedge e_2 \wedge act_2\}, g_2 \rangle \end{array} \right\}, h_{g3} = \langle \{S_3 \wedge v_3 \wedge e_3 \wedge act_3\}, g_3 \rangle \right\} \tag{2}$$

Then, the persuader agent selects from the output lattices (2) one set considering  $\leq^e$ , for example prioritizing emotion  $e_1$  = “amazement” than  $e_2$  = “grief”, which can be seen as an explanation of the persuadee’s current state.

### Gamification Strategies as Agent Dialogues

As we have presented, gamification strategies (Taxonomy 2) have in common the exchange of information between persuader and persuadee. Those interactions follow a *protocol* dictating a turn-taking procedure (e.g first a persuader interaction, then a persuadee response, etc.), the type of exchange under specific circumstances, etc. For example, a reward or praise from a persuader is preceded by a persuadee action; alternatively, challenges, nudges, and parts of simulations and stories are followed by a response from the persuadee. Those exchanges can be formally specified as *dialogue protocols* using formal argumentation. Argument-based dialogues are *strategic games* between two agents (persuader and persuadee) [64], which are formal specifications of

interactions. In this paper, dialogues have the following characteristics: (1) agents’ communications are based on tactical *moves* within a *protocol*; (2) the persuader agent has a well-defined decision-making mechanism and follows strict protocols, and (3) the persuadee agent (e.g. a person) may not follow some postulates of well-defined dialogues [65] and can “brake” protocols. In the following, we introduce our mapping starting with an analysis of protocols and moves, then we present how agents compute a dialogue *outcome*.

### Protocol and Moves

We present general move alternatives corresponding to different strategies and types of software agency (proactive and reactive). This mapping, as a key contribution of this paper, is presented in Table 6, which uses • and ⊙ to represent the starting and ending points of a protocol; we also use  $p, q \in S$  as propositions (e.g.  $q = show(value\_oriented\_content)$ ), and every move is called by one or the other agent using an additional parameter to identify it ( $Ag_c$  or  $Ag_p$ ), for example  $assert(show(value\_oriented\_content), Ag_c)$ .

Protocols 1 to 4 in Table 6, are initiated by the persuader agent ( $Ag_p$ ) directed to the persuadee ( $Ag_c$ ). Conversely, *Protocol*<sub>5</sub> to *Protocol*<sub>7</sub> can be seen as a “reactive” moves that a persuader can take considering that the persuadee initiates the dialogue. This mapping requires formal requirements/constraints of the persuader’s internal decision-making

(Algorithm 1), such as the imposition that a persuader cannot ignore or reject an assert or quest move from the persuadee. We summarize these constraints as follows:

**Proposition 1** (Constraints for gamification persuasive moves) *Let out be the output set from Algorithm 1 or any argument-based decision-making process that considers the next move of a persuader agent in a dialogue. Then, the following formal requirements need to hold:*

- R1: For *Protocol*<sub>2</sub> and *Protocol*<sub>3</sub>,  $Ag_c$  cannot reject or ignore an *asset* move;
- R2: For *Protocol*<sub>5</sub> to *Protocol*<sub>7</sub>,  $out \in SEM(AF)$  and  $out \neq \emptyset$ ; and
- R3: For every *assert*, *challenge* or *quest* move, compatible content w.r.t the strategy should be selected (see Table 5)

### Move Selection and Outcome

The persuader agent requires a fine-grained mechanism for protocol and move selection, then we use a utility function

$Q : 2^{\mathcal{D}} \rightarrow \mathbb{R}$ , which evaluates the attitude uncertainty  $P$  (line 21 in 1) in a dialogues  $\mathcal{D}$ . We compute such utility as an attitude achievement *w.r.t.* goals, values and emotions. For example, a persuadee has as reference  $goal_1$  and  $goal_2$ , then every hypothesis that a persuader obtains from Algorithm 1, provides evidence of  $goal_1$  and/or  $goal_2$  achievement if those goals belong to out, formally: if  $m = \langle sa, ct, Ag_c \rangle$  is a move generated by agent  $Ag_p$  targeting agent  $Ag_c$ , with  $ct \in H \subseteq \text{out} = SEM(AF)$ , and  $G^R, V^R, E^R \subseteq \mathcal{R}$  be the reference attitudes of  $Ag_c$ , then a dialogue outcome quantifier is given by:  $Q = \text{Sim}(\arg \max_{G,V,E}(ct), \mathcal{R})$ , considering a *similarity function*  $\text{Sim} : 2^{G,V,E} \times 2^{G,V,E} \rightarrow \mathbb{R}$ .

## Experimentation

In this section, we exemplify the proposed formalization of gamification strategies using two gamified software platforms, the first one, a behavior change mobile application used in the healthcare area, and the second one, a Web-based application used for financial literacy and financial decisions balancing.

## Materials

In experiment 1 the STAR-C coaching system, we designed and implemented a mobile application using *cards* (see Fig. 6), which follow a user interface design pattern for navigation where available buttons are actions that a user can take *w.r.t.* the information presented in the card [66]. We also implemented a server-side part, such as an implementation of the Algorithm 1, and the move selection mechanism using Java with the *Tweety Project library*.<sup>7</sup> We used Ionic framework<sup>8</sup> to build the cards and the entire user interface of the STAR-C system.

In experiment 2, we upgrade an existing game called *Talous Tandem*,<sup>9</sup> which was adapted to present gamified stories of a simulated student's life. The aim of the game is to support and balance finances, social relationships, happiness, and academic success of a user, assigning points for different situations. A running version of this game can be found in <https://lipas.uwasa.fi/pelit/TalousTandem/>. Talous Tandem stories have a cards-design where a hypothetical situation is presented with two available choices, then, the user has to *flip* the card to the left or right to select an option (see Fig. 5). The Talous Tandem for this experiment was implemented in Unity, with server-side components similarly to experiment 1.

<sup>7</sup> TweetyProject acceded on April 2021 <https://tweetyproject.org/>.

<sup>8</sup> Ionic acceded on April 2021 <https://ionicframework.com>.

<sup>9</sup> TalousTandem Website: <https://sites.uwasa.fi/peek/talouspeli/> Last access 23 Dec 2021.

## Procedure

In our experiments, two designers and a developer tested the STAR-C platform and Talous Tandem to assess the generation of cards. Given the aim of the experiments, which did not involve perceptions or persuasiveness of the cards information, target users of these software platforms were not involved, then only *laboratory* tests are presented.

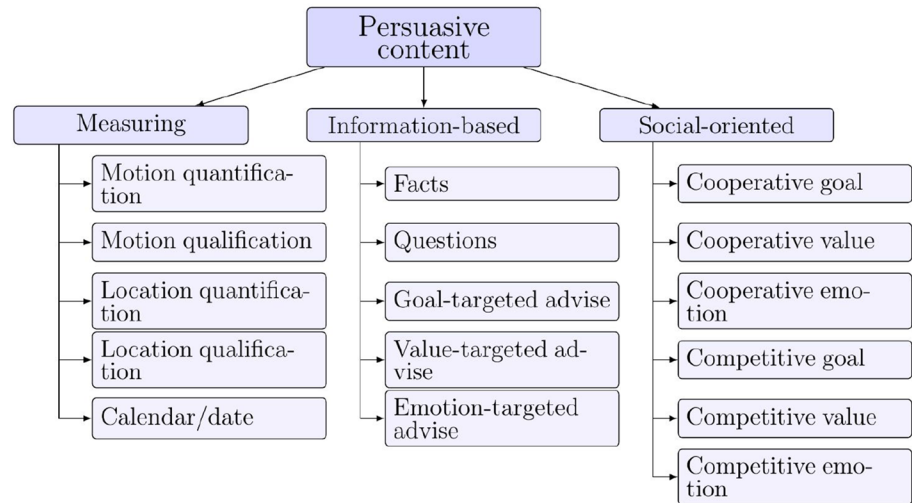
First, we manually elaborated different programs such as  $P$  in 1 considering alternative user parameters, e.g. changing  $G, V, E$  such as  $g_1 = \text{"reduce alcohol consumption"}$ ,  $g_2 = \text{"eat healthy"}$ ,  $g_3 = \text{"improve physical activity"}$ ,  $act_1 = \text{"show measuring"}$ ,  $act_2 = \text{"show facts"}$ , etc (see Fig. 6), recalling that  $g$ 's are goals of the information cards (and the persuasive act), and  $act$ 's are the gamification content type (*w.r.t.* Taxonomy 1 of content). Then, we observed the cards generated by Algorithm 1, and the cards' results were gathered. In the following, we describe details of the two experiments as well as their results.

## Gamified Cards as Dialogues, the STAR-C Platform

Our formal framework and decision-making process presented in "[Formal Framework for Content and Strategy Selection](#)" were instantiated in a practical approach for selecting and re-ordering mobile application cards, which contain information of a persuasive nature (see Fig. 6). In this context, the argument-based hypotheses contained all the information necessary to display in a card, such as the type of content. In order to make the move-based interaction, we coded the persuadee responses or moves *accept*, *ignore*, and *quest* as pre-defined buttons, which are enabled or disabled depending on the followed protocol. For this experiment, we manually manipulated a probability distribution causing different uncertainty levels of the persuadee model. We manipulate a program  $P$  considering the following information:  $g_1 = \text{"improve physical activity"}$ ,  $g_2 = \text{"improve diet"}$ ,  $g_3 = \text{"reduce alcohol consumption"}$ ,  $v_1 = \text{"achievement"}$ ,  $v_2 = \text{"tradition"}$ ,  $v_3 = \text{"hedonism"}$ ,  $e_1 = \text{"amazement"}$ ,  $e_2 = \text{"grief"}$ ,  $e_3 = \text{"vigilance"}$ ,  $act_1 = \text{show(goal\_oriented\_content)}$ ,  $act_2 = \text{show(emotion\_oriented\_content)}$ ,  $act_3 = \text{show(location\_quant\_content)}$ ,  $act_4 = \text{show(calendar\_date\_content)}$ ,  $act_5 = \text{show(question\_content)}$ .

## Results of Experiment 1

Based on the STAR-C scenario, several hypotheses were built using Algorithm 1. In Algorithm 1, we modify  $P = \{0.01, 0.5, 0.99\}$  in the set of created hypotheses, then we limited the set  $\mathcal{H}$  to a size of 10 hypotheses. We found that in general, the persuader agent ( $Agp$  in Fig. 7) "wins"

**Fig. 3** Typology of gamification content

the dialogue when it has more knowledge than the persuadee, i.e. that it will provide more cards connected with proactive strategies.

Conversely, as is expected, the more uncertainty in the persuadee, the more chances that the persuader selects reactive content. For example, when uncertainty was highest (0,99 in Fig. 7), where the persuader has no previous information about  $G$ ,  $V$ ,  $E$  then, only reactive cards were placed on the top of the application, i.e. changing the order from card 1 to card 2 in Fig. 6, where every card is associated with an action, e.g.  $act_2 = \text{show}(\text{emotion\_oriented\_content})$ .

### Gamified Stories as Dialogues, Talous Tandem

We modified the TalousTandem game compelling the user to make a decision, i.e. avoid *ignore*, *reject*, and *accept* moves, only *assert*-ing whit left or right swipes. The rationale for this design decision was based on the idea of making the dialogue-based game short and simple. We aim in our future work to implement other moves types to enrich the game possibilities. Figure 8 presents de protocol used for the cards game used in experiment 1. In this setting, the game generates a *tree*-like structure that has a definite size, the dialogue tree was implemented as a game tree in Unity<sup>10</sup> using Play Maker<sup>11</sup> plugin.

### Outcome of the Talous Tandem

Different ending rules were implemented in the Talous Tandem based on the individual variable score (w.r.t. finance, social, etc.). Such rules were tailored by the designers to generate *always* positive feedback regardless of the reached score. Figure 9 presents screenshots of three different

dialogue outcomes. As part of our future work, we will update those handcrafted rules made for the game with automatic processes, as it is presented in the argumentation state of the art (see [67] as an example).

## Discussion and Future Work

In this section, we contrast in-depth our contributions with the state of the art, considering three points: (1) the taxonomies proposed; (2) the mechanisms for decision-making that we presented, and (3) the use of formal argumentation as a mechanism to formalize stories as a gamified strategy.

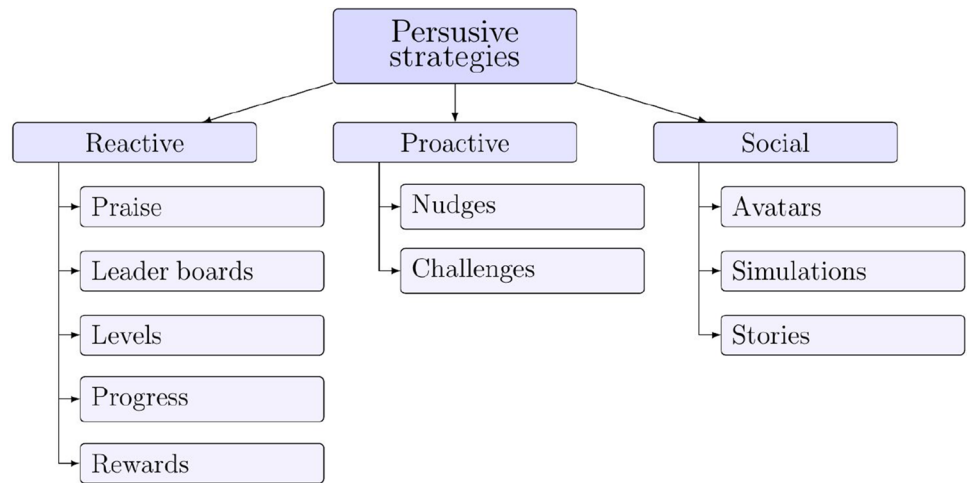
### Taxonomies of Gamified Elements

The type of gamification presented in this work entails the use of software-based visual cues to persuade a user. In the gamification literature, those gamification affordances have been the object of different studies, exploring user orientation and the relationship with game elements [7–9], investigating gamified cues to motivate and induce emotions/feelings [3, 4], and examining if some of these affordances are suitable for social-oriented tasks (e.g. cooperative or competitive) [2, 10]. As it has been highlighted in [11], gamification elements are not consistently defined nor used in consensus, therefore different approaches have classified them considering motivation and effects on user's behavior [12], depending on the type of *artifacts* from a development perspective [13], classifying affordances types depending on the application of different levels of design principles [14], and structuring game elements depending on the engagement experiences in users [11]. All these previous efforts have investigated gamified software as *static* individual artifacts, being common that affordances do not change during the gamified task (see [68] as a review of empirical studies).

<sup>10</sup> <https://unity.com/> Last access December 2020.

<sup>11</sup> Play Maker <https://hutongames.com/> last access December 2020.

**Fig. 4** Typology of gamification strategies



**Table 5** Content-strategies compatibility

		Content															
		Measuring					Information					Social					
		Motion quantification	Motion quantification	Location quantification	Location quantification	Calendar/date	Facts	Questions	Goal-targ. advise	Value-targ. advise	Emotion-targ. advise	Cooper. goal	Cooper. value	Cooper. emotion	Compet. goal	Compet. value	Compet. emotion
Strategies	Social	Avatar	★	★	★	★	★	★	★	★	★	★	★	★	★	★	★
		Simulations	★	★	★	★	★	★	★	★	★	★	★	★	★	★	★
		Stories	★	★	★	★	★	★	★	★	★	★	★	★	★	★	★
	Proactive	Challenges	☆	☆	☆	☆	☆	★	★	★	★	★	★	★	★	★	★
		Nudges	☆	☆	☆	☆	☆	☆	☆	★	★	★	★	★	★	★	★
	Reactive	Praise	★	★	★	★	★	★	☆	★	★	★	★	★	★	★	★
		Leader boards	★	★	★	★	★	☆	☆	★	★	★	★	★	★	★	★
		Levels	★	★	★	★	★	☆	☆	☆	☆	☆	☆	☆	☆	☆	☆
		Progress	★	★	★	★	★	☆	☆	☆	☆	☆	★	★	★	★	★
		Rewards	★	★	★	★	☆	☆	☆	☆	☆	☆	☆	☆	☆	☆	☆

★: complete compatibility.  
 ★: partial compatibility.  
 ☆: incompatibility.

In contrast, in this paper we considered software-based gamification elements *reactive*, i.e. with the aforementioned static visual behavior, but also as the potentially *proactive* and *social* following the well-established perspective of agent-based software (see [54]), which are endowed with cognitive-like procedures that make every agent potentially autonomous for changing its goals, beliefs, and intentions.

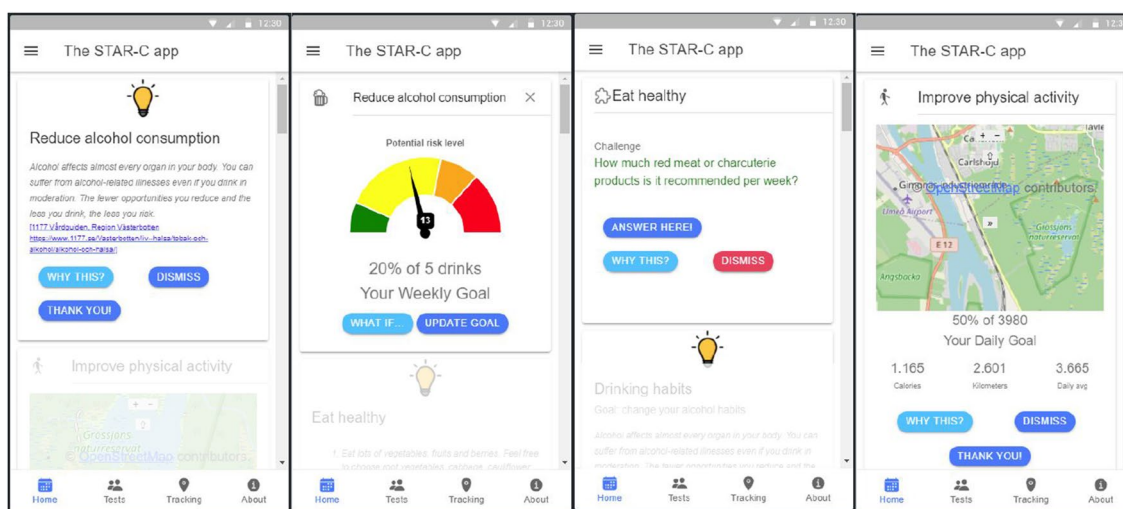
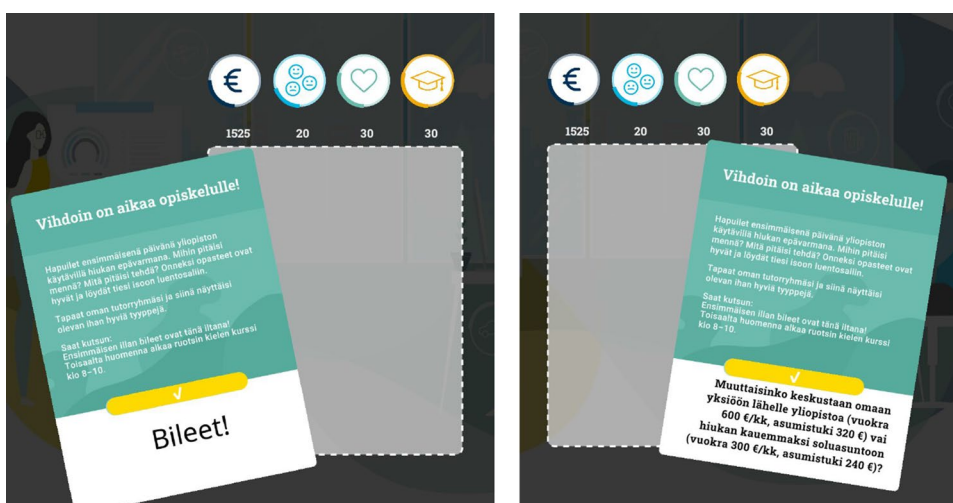
We divided the gamification elements into *content* and *strategies*, which has a similarity with the MDA model presented in [13], seeing affordances as software artifacts

with different information-based nature. On the one side, the content taxonomy (Taxonomy 1 in Fig. 3) is based on the type of data presented with respect to measuring, high-level feedback information, and social-related information, this classification is important when the source, structure, and quality of the information need to be specified to be stored and manipulated. On the other hand, the strategies taxonomy (Taxonomy 2 in Fig. 4) reflects the type of agency that a gamified element is (or might be) able to perform, with respect to information that is generated and transmitted, for

**Table 6** Typology of gamification strategies used in intelligent persuasive/coaching systems

Proactive	Challenges		<i>Protocol</i> <sub>1</sub> : ● <i>assert</i> ( <i>p</i> , <i>Ag</i> <sub><i>c</i></sub> ); <i>ignore</i> ( <i>q</i> , <i>Ag</i> <sub><i>p</i></sub> )⊙ <i>Protocol</i> <sub>2</sub> : ● <i>assert</i> ( <i>p</i> , <i>Ag</i> <sub><i>c</i></sub> ); <i>accept</i> ( <i>q</i> , <i>Ag</i> <sub><i>p</i></sub> )⊙ <i>Protocol</i> <sub>3</sub> : ● <i>assert</i> ( <i>p</i> , <i>Ag</i> <sub><i>c</i></sub> ); <i>challenge</i> ( <i>q</i> , <i>Ag</i> <sub><i>p</i></sub> )⊙ <i>Protocol</i> <sub>4</sub> : ● <i>assert</i> ( <i>p</i> , <i>Ag</i> <sub><i>c</i></sub> ); <i>reject</i> ( <i>q</i> , <i>Ag</i> <sub><i>p</i></sub> )⊙
	Nudges		<i>Protocol</i> <sub>5</sub> : ● <i>assert</i> ( <i>p</i> , <i>Ag</i> <sub><i>p</i></sub> ); <i>assert</i> ( <i>p</i> , <i>Ag</i> <sub><i>c</i></sub> )⊙ <i>Protocol</i> <sub>6</sub> : ● <i>assert</i> ( <i>p</i> , <i>Ag</i> <sub><i>p</i></sub> ); <i>accept</i> ( <i>q</i> , <i>Ag</i> <sub><i>c</i></sub> )⊙  <i>Protocol</i> <sub>7</sub> : ● <i>assert</i> ( <i>p</i> , <i>Ag</i> <sub><i>p</i></sub> ); <i>challenge</i> ( <i>q</i> , <i>Ag</i> <sub><i>c</i></sub> )⊙
Reactive	Praise		<i>Protocol</i> <sub>5</sub> : ● <i>assert</i> ( <i>p</i> , <i>Ag</i> <sub><i>p</i></sub> ); <i>assert</i> ( <i>p</i> , <i>Ag</i> <sub><i>c</i></sub> )⊙ <i>Protocol</i> <sub>6</sub> : ● <i>assert</i> ( <i>p</i> , <i>Ag</i> <sub><i>p</i></sub> ); <i>accept</i> ( <i>q</i> , <i>Ag</i> <sub><i>c</i></sub> )⊙
	Leader boards		<i>Protocol</i> <sub>7</sub> : ● <i>assert</i> ( <i>p</i> , <i>Ag</i> <sub><i>p</i></sub> ); <i>challenge</i> ( <i>q</i> , <i>Ag</i> <sub><i>c</i></sub> )⊙
	Levels		
	Progress Rewards		

**Fig. 5** Card of the Talous Tandem game with the four value-changing variables, finance, social, friendship/love, academic performance. Left image, swipe action to the left displaying a greetings message. Right image, the same card when user made a right swipe displaying a fact-oriented message



**Fig. 6** Experiment 1, the STAR-C platform: mobile application where cards are used as content within persuader moves. Left and left-center (card 1 and card 2) are cards using information and measuring type

content, respectively. Right and center-right figures show cards with information regarding eating and physical activity, using goal-oriented nudges and fact messages

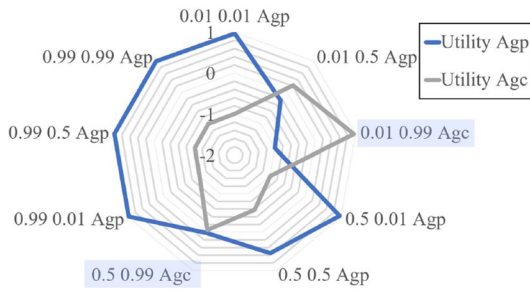


Fig. 7 Uncertainty  $P$  of the agent's model vs protocol winner

example, an affordance such as a level or a reward visual indicator is completely different from an avatar or a story, which are oriented to exchange information with a user.

In the gamification literature, the taxonomy of game elements in the educational domain continuously improved in [69–71] is related to the environment that the gamification is being implemented, and it has a close relationship with other classifications where the psychological effects of those affordances are considered, see for example [3, 4]. Indeed, the work of Toda et al. in [69] is focused on the particular area of education with potential use in other contexts. Similar to

Today's work, in [72] a taxonomy of game elements, with game attributes and their effects on learning is presented. This work has remarkable similarities to Toda's but uses a different methodology, which is analogous to our approach, using a systematic review and using expert opinion. As part of our future work, we want to empirically evaluate our taxonomies in the financial and financial literacy area.

A catalog of gamification patterns presented in [76, 77] is a well-elaborated and empirical collection of gamified approaches, that was established for mobile applications aiming to increase student motivation in a learning context. Inspired by these catalogs, we hope to empirically test what branches of the proposed taxonomies fit better for improving persuasion and motivation. Moreover, we agree with the authors of [76] that the use of gamified applications is not enough to motivate and persuade, it is necessary to complement with other alternatives (e.g. traditional education), since gamification can generate in the student's indices of distraction in the medium and long term [76].

The two taxonomies presented here are the result of expert elicitation and a systematic literature review and lack empirical evaluation and testing, which is part of future work, considering that experiment 2 with the Talous Tandem software is our current ongoing project.

Fig. 8 Left, protocol followed by the modified version of the Talous Tandem game. A user can select one of the two alternative assert moves. Right image, screenshot of the induced tree from the dialogue protocol, implemented in Unity using the Play Maker plugin

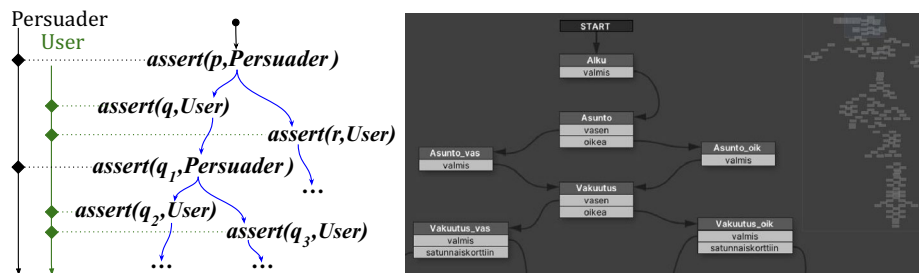
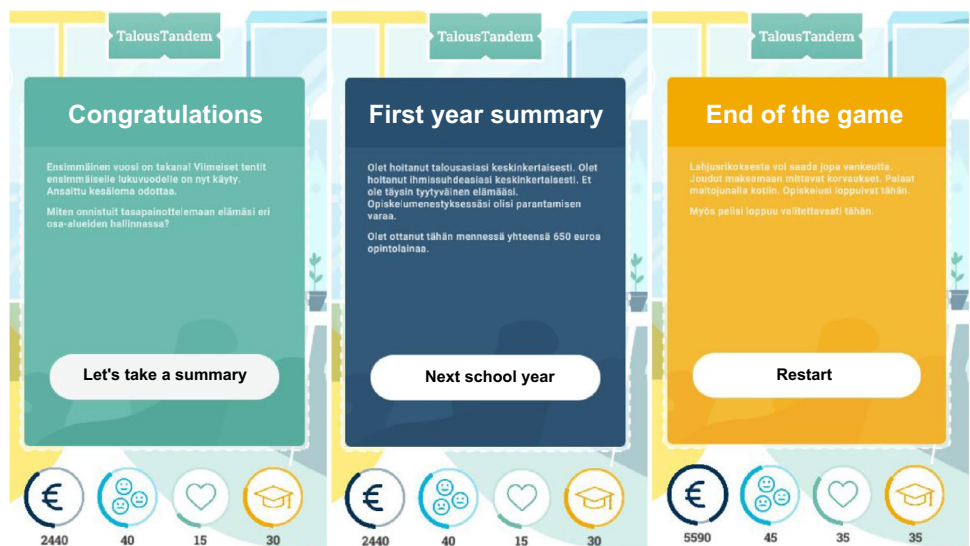


Fig. 9 Screenshots of ending cards of the Talous Tandem, these last moves are handcrafted from outcome rules that depend on the four variables: finance, social, friendship/love, academic performance



## Mechanisms for Automatic Selection/ Decision-Making in Gamification

In this paper, we proposed a general algorithm that generates alternatives for selecting gamified content (*w.r.t.* content taxonomy) considering the user profile. The main characteristic of Algorithm 1 is its *non-monotonicity*, meaning that when input information changes the output also changes, which is different from most of the algorithms in programming languages or mathematical functions. A non-monotonic behavior guarantees a reasoning process closed to human decision-making. Similar to medical doctors that dictate a diagnosis, but under more evidence they may change the final word, the decision-making process in our proposed algorithm generates valid and sound alternatives of what the game should present, but under more information about the user, the algorithm may change its output. Our approach is novel in the gamification literature considering the characterization framework and the methodological direction. Previous work, for example, the model presented in [13], only mentioned the potential use of artificial intelligence with no specific formalization.

Algorithm 1 is an extension of a general reasoning process based on *abstract argumentation* introduced in [62], and a derivation for generating alternative scenarios for human activities presented in [73]. The two main phases of this generic decision-making process: hypotheses generation and hypotheses selection have different computational costs, being the selection of hypotheses computationally intractable, i.e. NP-hard or even harder under some argumentation semantics *SEM* (see [74] for complete complexity analysis of the associated reasoning problem). The computational complexity of the problem for selecting a set of the best” gamification strategies or content depending on parameters of the user profile, varies with the size of the user profile and the number of gamification affordances. However, as we presented in Table 5, not all content types and strategies are compatible (as suggested by other gamification authors, see [7, 69, 72]), then the time for generation of gamification alternatives induced by Algorithm 1 may decrease. Furthermore, in a context where a game is repeatedly played by a user, a learning mechanism can be added to our algorithm to not “run” in every move, but using a machine learning process to generate an output faster. This type of *hybrid* mechanism is part of our future work to be implemented in the new version of Talous Tandem.

## Gamification Strategies as Argument-Based Dialogues

Mathematical characterizations of specific software components are useful to ensure the correct behavior of those modules. Such formalization not only guarantees that the

information-based output follows the intended goal of the software, but also can be used to predict “extreme” use conditions, such as the use of a module under no information, incorrect or incomplete data structures, or large size (even infinite) of information as input. In gamification literature, the use of formal approaches to describe gamification elements and mechanisms is almost nonexistent, as far as we review the literature, which has been one of the strong criticisms and missing research tracks of the gamification literature [4]. Gamified strategies such as stories or avatar interactions require consistent exchanges of information given that the nature of “gamification” implies *behavior change*, for example, to keep a goal-oriented storyline, the use of an agreed language, vocabulary, or visual cues that persuade and persuader understand, the acknowledgment of a start and an ending in the exchanges, etc. All those rules, that for humans are implicit in most regular conversations, for interactive software should be explicitly defined. In that sense, in the formal argumentation literature researchers have devoted themselves to specifying different types of goal-oriented dialogue games such as *persuasive*, *deliberative*, *negotiation-oriented*, and even *eristic* or “fighting” exchanges (see [64]). Then, the use of formal argumentation to describe some gamified strategies such as stories is a useful approach to guarantee the completion of persuasive dialogue goals (see [75] for a description of persuasion dialogues in behavior change contexts).

## Autonomy of Gamification Systems

In this paper, we present theoretical and laboratory-tested experimental approaches for what we called *autonomous gamification*, meaning that gamified software makes decisions based on its own goals, for example running Algorithm 1 without any user input. An autonomous agent is not dependent on the goals of others, it possesses goals that are generated from within rather than adopted [54]. In this context of autonomy, it may necessary to consider persuasive gamification systems that align automatically to the users’ goals (see for example [61]), however, such computational processes are currently under debate given that may imply the need for guidelines or rules for designing artificial intelligence-based systems, such as the joint effort that the European Union and other leading countries to develop *guidelines for trustworthy AI*.<sup>12</sup> In this regard, four principles for autonomous gamification were presented in [78]: traceability of gamified outputs, internal consistency of a gamification attempt, coherent gamified interaction, and rational persuasive gamification. These principles although suitable for the

<sup>12</sup> Ethics guidelines for trustworthy AI see <https://digital-strategy.ec.europa.eu/en/library/ethics-guidelines-trustworthy-ai>, last access April 06 2022.

paper presented here, they are not covering other potential issues that may arise with the use of autonomous software, as has been pointed out by different authors in the artificial intelligence field (e.g. [81]). In our future work, we want to present a set of design principles for autonomous gamification usable for formal computer scientists as well as gamification practitioners.

## Limitations

We acknowledge at least three types of limitations in our contributions: (1) the constraints of our systematic literature review and the expert elicitation process. We are aware that biases during processes of selection and expert judgment could have led to the generation of other types of gamification content and strategies in the proposed taxonomies. (2) The lack of a strict formalization and proof realization of our proposed decision-making algorithm and the dialogue protocols. We understand that characterizations in the argumentation literature require an accurate procedure, however, we decided to leave such formalization for future work in a different venue, we considered that the goals of the paper were not oriented to a rigorous argumentation theory-related context. And (3) we did not make user-oriented empirical experimentation, instead we opted for designing high-level laboratory experiments given that the goal of the paper was introduced novel contributions of what we can call “formal gamification”. Part of our future work, as we have expressed is devoted to solving some of those limitations and continuing our research line in gamification from the perspective of computer science, specifically from artificial intelligence.

## Conclusions

*Persuasive gamification* is a rising research track where empirical theories and models of *behavior change* (e.g. self-determination theory, flow theory, etc.) are used along *game-oriented* (or *gamified*) tools to promote change [80]. *Gamification* as a design process, employs *game elements* (*affordances*) into different types of systems and services with the goal of affording *gameful* experiences [79]. Usually, in persuasive gamification traits (e.g. social-orientation [2], emotion-orientation [3], etc.) are used as a means for tailoring software, which although promising, it presents a problem of highly specialization (lack of generalization of the approaches). Despite an apparent *immaturity* of theoretical foundations and validated methods [4], gamification has increased popularity for designing software that covers enjoyment, immersion and goal-orientation being a conventional approach for *behavior change* [5, 6]. In this context, is clear that gamification literature uses methods and approaches from social sciences, rather from computer

science area. This was our starting point for this research project, a general lack of formal computational models of gamified approaches.

Therefore, in this paper we started with two problems in the gamification research literature: (1) gamification affordances have been considered as static software elements, with no proactive, autonomous, or semi-autonomous behavior, and (2) the current efforts for classifying gamification affordances have been focused on the psychological outcomes that emerge from the user-game interaction, but not from a computer science design perspective where characteristics of the information involved in the gamified content are considered.

In this context, we provide three contributions in the interdisciplinary area that we called “*formal gamification*”, which is the strict characterization of gamification approaches from an artificial intelligence perspective. Our contributions are (1) two taxonomies of gamified affordances, the first one oriented to identify different types of gamification content considering the class of information that communicate, and the second, a taxonomy of gamification mechanisms, that we called strategies, considering the type of agency (w.r.t. proactive and reactive) that the gamified software is oriented. (2) a decision-making algorithm that enables a gamified software with capabilities of personalization and adaptation, generating consistent outputs at the same time that has a non-monotonic behavior. Finally, (3) we present two laboratory empirical experiments showing how the taxonomies and the decision-making algorithm can be used in practical gamified tasks.

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## Declarations

**Conflict of interest** On behalf of all authors, the corresponding author states that there is no conflict of interest.

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