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THE ELEKTRA PROJECT: TOWARDS A NEW LEARNING EXPERIENCE

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Abstract

Digital game-based learning is a hot topic of research and development. Since the advent of computer and video games, educators were inherently interested in utilizing the beneficial aspects of computer games for educational purposes. These factors are primarily the intrinsic motivation of games, immersive environments, engaging stories, and an artful balance between challenges and continuously growing abilities. Proponents of computer games delivered a large number of empirical investigations revealing that games may foster the development of abilities and competencies. Besides the advantageous aspects of computer games, a variety of problems were reported by researchers. Due to the high costs of professional game development, many educational games are technologically poor and cannot compete with entertainment games in terms of visual design, possibilities for interactions, or storytelling. Moreover, many current educational games do not incorporate a sound psychological, pedagogical, or didactic background; instead they are focusing on transmission or rehearsal of isolated facts or skills. Finally, such games lack the ability to adapt to individual competencies failing to balance challenge and abilities regarding knowledge or skills. The ELEKTRA project, introduced in this article, aims for addressing these problems relying on an interdisciplinary approach of cognitive science, neuroscience, pedagogy, game design, and game development. The project will develop an adventure game that can keep up with commercial games and that focuses on primarily curriculum-related educational purposes by incorporating a sound psychological and pedagogical framework. Moreover, the project will prove the outcomes of research and development by a comprehensive game demonstrator.

1. Introduction

The idea of using computer games for educational purposes was already born with the appearance of the first computer games. In each year since the advent of computer games, scientists and developers have published numerous articles and books on the advantages of digital game-based learning [79]. This idea, however, caused considerable debate regarding the power of games for educational purposes, the advantages, disadvantages, costs, and risks. At the same time, computer game industry constantly increased sales up to seven billion US$ in 2005 [30]. Estimations say that more than 100 million people frequently play computer games, alone in the US [56]. A significant number of young people spend many hours a week playing computer games [6][79] and most often these games are the preferred play [78]. Thus, the attempt to utilize gaming activities and benefits

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of games for educational purposes seems to be a promising approach to improve and facilitate learning, especially when fun, motivation, and immersion could be maintained. Most concisely, games can contribute to educational aims in four ways: (a) the time spent for gaming could be utilized -at least partially- for learning, (b) the intrinsic motivation, engagement, and immersion of computer games could be utilized to make learning a more pleasant task and support problem-oriented learning with its challenges driven by game-play, storyline and user interaction, (c) the augmentation of both traditional and interactive storytelling in current adventure games may be also utilized for learning, since storytelling is maybe the most natural teaching and learning method, and (d) the rich visual environment of current games could be utilized to present new and unusual perspectives within meaningful contexts.

Facing the broad range of possibilities, since the nineteen nineties research and development increasingly focused on the effects of playing computer games for entertainment on a variety of abilities, behaviors, or psycho-social issues. Additionally, more and more games have been developed primarily aiming for educational goals. Research and developed covered the whole range of game types, from pure entertainment to so-called edutainment to pure education. The results of research are widely promising; reviews and meta-analyses constantly found that games are able to promote learning [56][79]. Skeptics, however, argued for the difficulty of measuring complex variables or constructs and the need to narrowly define variables and tightly control conditions. Such research most often leads to studies that make correspondingly narrow claims about tightly controlled aspects of games (cf. [79]). Additionally, major weaknesses of games used for educational purposes were reported, especially when aiming to utilize games for teaching in classrooms and related to curricula [32][17][10].

1.1. Games for entertainment

Over the past decades a considerable amount of research has been done on the impact of entertainment games on a variety of psychological and sociological variables and constructs. This research covered the entire spectrum of game types and revealed positive as well as negative effects of (frequent) gaming.

Self-esteem, as one example, was found to be raised by the amount of control and mastery offered by games. However, there is some evidence that these games become a substitute for social interactions and relationships because of the increase of self-esteem imparted by games [15][72][19]. Contrarily, studies revealed that frequent gaming does not significantly influence social behavior and relationships [35][18]. Also more recent studies could not clarify these contradictory results. Subrahmanyam [77] and colleagues suggested that more research has to be done in this direction.

Violence and anti-social behavior, integral parts of many entertainment games, were also subject of research and frequently initiated an ongoing debate about the negative influence on violent behavior of gamers [6][7][9][11]. Generally, violent games are viewed as intensifying factor for violent or anti-social tendencies; games might blur young people’s perceptions of the difference between real life and virtual reality, to the extent that they become desensitized to aggression and violence [77].

Also the effects of computer games for learning and academic performance have been investigated in-depth. Generally, frequent gaming is assumed to foster the ability to adjust to a computer-oriented knowledge and information society [36] and computer skills. Moreover, computer games are able to influence gamers’ strategic and inferential thinking [68] and also the ability to create mental images of information structures [66]. Other beneficial aspects of playing computer games were found, for example, in meta-cognition, spatial abilities, iconic memory, psycho-motor skills, visual attention, peripheral vision, mental rotation abilities, decision making, or even improvements of memory [24][34][44][45][69][78].

However, most often these studies focused on narrowly defined aspects of games (cf. [79]). Symptomatic for this kind of research is that improvements in certain constructs often perfectly matched the demands of specific games (e.g., mental rotation skills when playing hours of Tetris [60][28]). Thus, generalizations to computer games or types of computer games are difficult. Moreover, interpretations of experimental results are often biased towards favoring games. As an example, experiments [42] revealed statistically significant increase in the participants' "multitasking abilities" when playing 3D games. However, this author did not discuss the fact that this result might also be interpreted in terms of a reduction of gamers' abilities to concentrate on one thing at a time.

In summary, even if research results are not perfectly clear, there is some evidence, that playing computer games are able to improve desirable factors like computer skills or different cognitive abilities. The use of games in classrooms, moreover, is fostering motivation and attention [73]. On the other hand, games do have an addictive potential and frequently playing might negatively impact social abilities and relationships. Concerning planned and maybe curriculum-based education, existing games for entertainment have a very limited potential. Games must be aligned with the curriculum, didactic strategy, and content. According to [79], the latter is most difficult because games for entertainment tend to neglect accuracy and completeness of contents.

1.2. Games for education

In consideration of the pervasive influence of computer games on our culture and the amount of time gamers spend on playing computer games, many educators, psychologists, and game developers have increasingly focused on investigating and directly incorporating the beneficial aspects of computer games for educational purposes. This is a great attempt because, even if some educators seriously argue against "making learning fun" [76], playing games is one of the most natural forms of learning. Children start learning to talk by playing with noises, they acquire motor skills by pushing coins into a piggy bank, or they learn collaboration and strategic thinking when playing Cowboy and Indian. Accordingly large is the body of available computer games primarily designed for educational purposes.

Game-based approaches were used, for example, to support children learning specific skills such as reading or math [44][74]. Halttunen and Sormunen [37] developed an information retrieval game or Kusunoki and colleagues [49] designed a game teaching urban planning and environmental issues, supporting factual learning, and, used collaboratively, enhancing cooperation and the ability to discover how others think. Of course also simulation games have found a wide application and are amongst the most effective and successful approaches of using games in education. Besides typical application of simulations in adult training (e.g. in pilot training or in military training in order to reduce risks, costs and in order to realize situation which cannot be realized in reality) such approaches have been also used in classes, e.g. for improving cognitive abilities and factual learning in certain subjects [22][38].

The list of such games could be extended further on [21] (Figure 1): *British Gas* created a game illustrating the importance of customer communication and diagnostic problem solving, *INTEL* created a game illustrating the importance of IT security, *PIXELearning* created a game to foster the development of skills for retail staff, *Games2Train* created a game to teach the use of 3D CAD software, the German association *Schulen ans Netz e.V.* established an online platform for girls including games like job application trainings, The European project *UniGame* (http://www.unigame.net) introduced the game-based learning concept to higher education and lifelong learning.

Generally, games with primarily educational proposes were used to practice certain skills and to improve awareness but less for teaching factual knowledge. Moreover; most existing games have a clearly limited scope, due to the high costs of developing professional games they are often simple and limited in providing intrinsic motivation, immersion, and engagement. Even if the examples shown in Figure 1 are state-of-the-art examples of game-based learning, they cannot compete with commercial games. Finally there is a lack of empirical research investigating the impact of such games on learning performance and comparing the games' success with other methods of teaching and learning.

Figure 1. Examples of current game-based learning. The left images displays a 3D office simulation game by *PIXELearning,* the right a quiz game by *Games2Train*.

1.3. Advantages and disadvantages of computer games in education

The main advantages of using computer games for educational purposes are intrinsic motivation and the technological possibilities of virtual environments. Computer games are intrinsically motivating, pervasive, and gamers voluntarily spend a significant amount of time for playing computer games. Games are played to achieve a certain goal or, in other terms, to win. Thus, motivation is based on "winning while remaining challenged" [10]. Moreover, computer games enable the creation of virtual learning spaces within which new perspectives on a subject (e.g., viewing or manipulating an atom) can be realized and learning content can be presented to the learner in a meaningful context. Digital learning environments can benefit from the wide experience of modern computer games by providing holistic learning experience – since pure information does not become knowledge until it is imparted within a context and can therewith be experienced. However, the mystery of these games is closely related to learning: it is essential to meet a challenge and a task, to solve problems, to improve and of course to be awarded. One plays a game in order to win. This is precisely how the human brain can be motivated to learn: We want to understand ourselves, explore and understand the world around us and rise the challenge – if we succeed, we obtain comprehension and self-confidence. And we want to discover and know even more.

The question is which factors (visual environments, storylines, challenges, interactions with non-player characters) are responsible for these advantages and what are the general rules to incorporate them with future educational computer games.

Malone [53] outlined three factors that “make video games fun”: Challenge, fantasy, and curiosity. He used these concepts to outline several guidelines for creating enjoyable education programs:

- clear goals that students find meaningful,
- multiple goal structures and scoring to give students feedback on their progress,
- multiple difficulty levels to adjust the game difficulty to learner skill,
- random elements of surprise, and
- an emotionally appealing fantasy and metaphor that is related to game skills.

Prensky [71] has outlined similar key factors, which contribute to the immersive capabilities of computer games: clear rules, continuous challenge and competition, clear goals and objectives, direct and instant feedback, and an immersive storyline. Moreover, the rich virtual environments of 3D games might stimulate fantasy and involve the gamer in a virtual world [70] and ambiance information create a rich learning experience [71].

In a pure educational study of factors influencing students motivation Viau [80] emphasizes that the 3 factors (Figure 2) that can be influenced are the learner’s perception regarding (a) the value of the activity, (b) his/her competence to fulfill the activity and (c) the control he/she has on the activity. An obvious relation can be made between Malone’s [53] clear goals that students find meaningful and Viau’s perception regarding the value of the activity. Viau’s factor about the competence is linked to Malone’s and Prensky’s challenge concept especially when the difficulty level is to be adjusted to the learner’s level. The challenge is not to be too easy or too difficult otherwise the player motivation will decrease. Viau’s control factor is clearly linked to the amount of control and mastery offered by games and self-esteem (see paragraph 1.1).

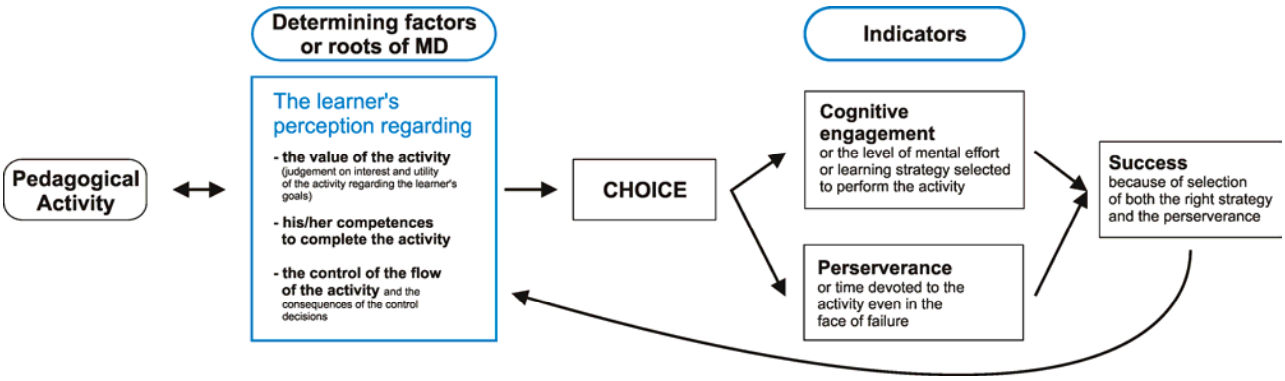

Figure 2. Motivational dynamic of a learner translated and documented from Viau [80].

The main disadvantages are that educational games require a certain balance between learning and gaming action to maintain fun, motivation, or even flow, they require a balance between challenge and ability, and the development of immersive games is expensive.

The balance between actions related to learning and actions related to fun and maintaining motivation is a crucial factor for a cost-benefit trade-off in educational games. It might be difficult to find this balance for all individuals of a target group. In terms of effective and efficient learning it would be inadequate to design an educational game that is highly motivating and engaging and, on the other hand, that is limited to only a small amount of learning content. The risk is high that what can be learned from one textbook page within 10 minutes could take significantly longer to be learned with a computer game which must be enriched with an engaging storyline. In turn, educational software might be disliked by students because of a lack of fun [52].

Furthermore, effective games require a continuous balance between challenge and ability. While game designers have a long tradition and experience in realizing such balance for gaming actions, e.g. battling an opponent, this is not a trivial task for realizing it in terms of knowledge, skills, or competencies. Consequently an adaptive approach is required that accomplishes such balance and that, again, requires an appropriate learner model.

Clark [17] has highlighted a number of additional risk factors that might have negative effects on learning with computer games:

- Games may distract from learning when the gamers primarily concentrates on game actions, e.g. discovering the virtual environment or battling opponents,
- males and females might not be reached by certain types of computer games to the same extent, or
- the risk of "hijacking" the virtual word by educators.

Finally, the creation of professional computer games is very costly [32]. This is true in terms of an appealing design as well as in terms of implementing appropriate didactic methods. Current educational games often confine to a single, traditional learning method, such as reading or listening. In this regard, such games do not differ from other multi-media learning applications. Often the taught as well as the tested knowledge is nothing else but a collection of isolated facts or skills. Learning mainly proceeds in a linear fashion, which means that the learner is confronted with a predefined sequence of learning situations. Moreover, many learning games do not test and profile learners before they enter the game world, and they are generally not able to pay attention to individual performance or learning progress. Additionally, the design of many educational games is not appealing or engaging. They generally do not meet gamers' demands on 3D learning environments and graphics as they are state-of-the-art in commercial computer games. The same is true for gaming possibilities or storylines. Consequently, many current learning games underperform in motivating the learner. They do not use realistic non-player characters that have a convincing appearance and mimic, and maintain eye contact, which is an important factor for motivating the player and is standard in non-learning games. Finally, they do not make use of the motivating power of elaborated story telling.

Summarizing, a large number of today's educational games in contrast to current commercial computer games do not engage learners as they suffer from distractive and incoherent learning and gaming experience, low interactivity, linear learning paths, poor storytelling, poor graphics, weak adaptivity features, and not account for a learner's degree of confidence.

Also [10] reports similar disadvantages of games: It's easy to address the wrong level of interest and challenge for a learner, games might be to easy or too difficult for a learner, it might take a long time to work through a game, due to high costs of professional game development, educational games might easily be poorly designed, games can be addictive, and games might include gender biases and stereotyped characters.

The question is how these disadvantages can be addressed in order to enable a more efficient and effective use of computer games for education. Playing games, as mentioned, is one of the most natural forms of learning. This form is in accordance with constructive approaches to learning. Such cognitive or constructivist approaches to learning claim that information per se is not knowledge; knowledge is constructed by cognitive processing of information and by integrating new information into existing knowledge. The knowledge construction process relates to the learner not as an empty vessel into which pre-formulated knowledge can be poured undigested, but someone with an existing knowledge structure onto which they must fit their new learning. A constructivist approach will therefore begin with what the learner already knows and involve them in active engagement with the new [55]. Computer games offer a wide range of possibilities to "construct" new knowledge in a meaningful context and allow a persistent active engagement which might give games the edge over traditional transmission of information.

2. ELEKTRA: Enhanced learning experience and knowledge transfer

The acronym ELEKTRA (www.elektra-project.org) stands for "enhanced learning experience and knowledge transfer". ELEKTRA is a two-year research and development project funded by the European Commission under the Sixth Framework Programme in the IST research priority. ELEKTRA has the ambitious and visionary goal to fully utilize the advantages of computer games and their design fundamentals for educational purposes and to address and eliminate the disadvantages of game-based learning as far as possible. Nine interdisciplinary European partners contribute to development and research in order to develop a methodology for designing educational games as well as a comprehensive game demonstrator. Furthermore, important research questions shall be addressed by the project both on the level of the involved research domains and on an interdisciplinary level. The consortium members are:

- Laboratory for Mixed Realities (LMR, Germany) is the project coordinator and also responsible for interdisciplinary and overall conception, interactive information design and narration, game design, character design and development
- Testaluna (Italy) is responsible for game design and development
- KLETT Lernen und Wissen GmbH (Germany) is responsible for content development and for game publishing
- Broadview TV (Germany) is responsible for media production and dissemination, as well as production of game assets and animations
- ORT France is responsible for evaluation and validation of the game demonstrator, game components and instructional design
- Trinity College Dublin (Ireland) is responsible for the technological development of adaptive learning and teaching within the game
- University of Liège (Belgium) is responsible for pedagogical implications, didactic design and curriculum development
- Center of Advanced Imaging (CAI) of the University of Bremen (Germany) is responsible for neuroscientific research and media pedagogy
- University of Graz (Austria) is responsible for adaptive user modeling and cognitive research on game-based learning

2.1. The ambitious vision of ELEKTRA

The aim of the ELEKTRA project is to establish a methodology which incorporates the advantages of computer games for educational purposes and to overcome disadvantages and potential risks. Modern computer games let their players enter the virtual worlds by offering a high degree of interactivity and realism. They turn the user into the active protagonist and hero, who can act and interact using more and more complex game features. Furthermore, the "gamer" is embedded in a fascinating universe having its own rules and residents to be discovered. By the player's own actions and his involvement into the framework story the game becomes important and meaningful to him. ELEKTRA will build upon these success principles and apply their design and realization in current computer games in order to develop new forms of didactic design for game-based learning. The aim is to excite and motivate learners equally as leading edge commercial games excite gamers and improve the knowledge transfer at the same time. Learning situations will be presented in a rich and immersive virtual 3D environment offering traditional and new perspectives to learning content and embedded in a meaningful and motivating storyline. This will offer both a consistent world experience that fosters contextual learning and envision knowledge in imaginative and visionary stunning ways. Moreover, ELEKTRA will incorporate sound pedagogical and psychological learner models and didactics. Within this learning game environment ELEKTRA fosters a user-centric approach as regard to both learning and gaming by enabling constructivist and active behavior as well as situation- or story-driven learning and teaching situations. On the basis of an adaptive mechanism in ELEKTRA's game engine, the learner's experience will be personalized and also guided through learning situations by following pedagogical and didactic rules and by adapting to the learners' prior and current knowledge, continuously constructing new knowledge. In this way, learners will be able to face their individual "garden of knowledge" (Figure 3) which can be explored extensively. Moreover, teachers will be supported in including this immersive 3D world as part of their classroom activities by closely relating the learning objectives of ELEKTRA to national curricula and by designing learning scenarios (e.g., experiments or simulations) that will be directly available from outside the game.

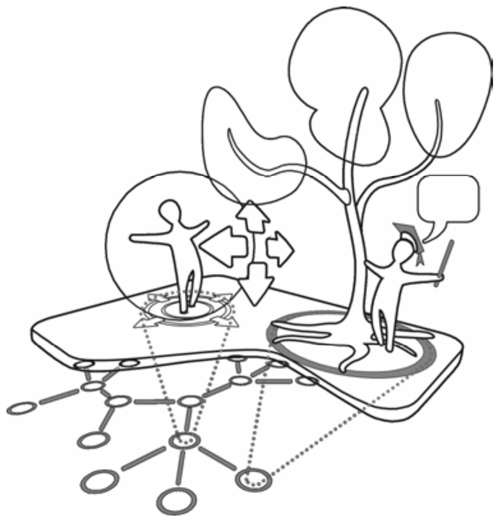

Figure 3. ELEKTRA's garden of knowledge: A metaphor for an immersive 3D environment that enables the learner to explore learning content.

ELEKTRA's 3D world will be the visual representation of the learning environment. It will support the learner in the visualization of the structure of learning content as part of a highly interactive virtual landscape. An appropriate metaphor is a "garden of knowledge" that can be explored and discovered by a learner, which offers new perspectives, and which allows a continuous construction of new knowledge with an ongoing storyline of the game. This virtual landscape of knowledge is the direct visual representation of an underlying consistent network of ontologies and concept maps that represent the learning topic, its context and the several learning objects that belong to the topic. It is also the underlying structure for the progression of the game-play as well as for the background story. Furthermore the visualization by interactive 3D-graphics could render different views of learning objects in real-time layering different perspectives from various subjects in the same spatial environment. This potentially creates the impression of multidimensional realities, which may change according to learning methods and didactical strategies. The concepts for navigation and user interface will support this concept of multi modal perspectives on the same learning content covering a holistic view. The learner model and its connection to the knowledge representation will also contribute to the game play experience by the use of monitoring and assessment of the learner within the environment. This will enable a situated and activity-driven learning experience in ELEKTRA's virtual learning environment that is able to react to the learner's behavior, cognitive state, and learning progress.

Current digital educational games mainly consist of two parts that separates immersive gaming experiences from learning experiences: (a) a game world (often 2 D, sometimes 3 D) with several tasks for the learner and (b) a learning part (2D and similar to traditional non gaming multi media learning products), where the learner mainly has to read text or watch a film to receive information and to gain knowledge. These games use traditional methods to support the knowledge transfer and just imitate traditional learning material and methods such as books and films. They continue the linear content of traditional media display formats in an interactive environment. Thus, the learner often has to jump from the learning part to the gaming part which causes loss of the immersion and the embedding within the context. Summarizing,

- Many existing educational games are, due to high costs of state-of-the-art game development, technologically poor. Learners can not immerse into a consistent learning world and get discouraged due to poor quality standards and concepts for visualization, interaction, and storytelling.
  The ELEKTRA project will not be able to reduce production costs for such games, however, it will encourage companies to invest in high-quality games and will demonstrate that such investments are justified.
- Many existing educational games do not rely on national school curricula or, at best, focus on a very limited part of them.
  ELEKTRA will focus on different national curricula and demonstrate that such learning content can be "hidden" in an immersive game.
- Most existing educational games are not based on sound pedagogical and didactical models. At best, these games support one learning method.
  ELEKTRA will incorporate a sound pedagogical model based on 8LEM [51] and the knowledge taxonomy of Bloom and its revisions [12][48].
- Many educational games focus on isolated facts, skills, or abilities. Moreover, they generally provide a given linear sequence of presenting learning contents.
  ELEKTRA will provide an adaptive approach to knowledge and skills based on *Knowledge Space Theory* [26][27] and the *Competence-Performance Approach* [46][47] enabling individual personalized learning paths. ELEKTRA's learning game offers an edifice of ideas for a complete learning topic that is based on a domain ontology of the corresponding knowledge and learning matter and embedded in a coherent background story.
- Many educational games do not provide an in-depth assessment of prior knowledge or of knowledge and skills acquired during the game play.
  ELEKTRA will provide adaptive assessment algorithms to offer a diagnostic approach that enables adaptivity and, consequently, a balance between challenge and ability.

These aims are of course highly ambitious and optimistic but the interdisciplinary approach to research and development let us believe, that ELEKTRA can make a significant contribution to the future of digital game-based learning.

2.2. ELEKTRA's interdisciplinary approach

To accomplish the optimistic aims of ELEKTRA, an interdisciplinary approach (Figure 4) is required to address all related challenges of designing an educational game; from a psychological perspective, from pedagogical perspective, from content and goal perspectives, from the perspective of game design and programming, and from the perspective of commercial exploitation. Moreover, emerging research questions must be addressed to progress to a future, more effective and desirable game-based learning.

2.2.1. Instructional design and didactic strategies

Current models describing the scope of human learning and teaching methods are crucial for the development of meaningful and engaging game environments and immersive and enthralling storylines. A body research in the fields of instructional theories and personalization theories put emphasis on this point (e.g., [54]). From the work of several authors in the field of learning psychology and pedagogy, a renewed interest for the variety of teaching and learning methods has emerged. On the basis of research in the domain of educational psychology (e.g., [61]), which showed that the deployment of multiple channels reinforces learning, a balance between learning modes can be assumed to maximize learning performance. The diversity of learning experiences by which the learner is encouraged to learn thus emerges as a criterion of educational quality.

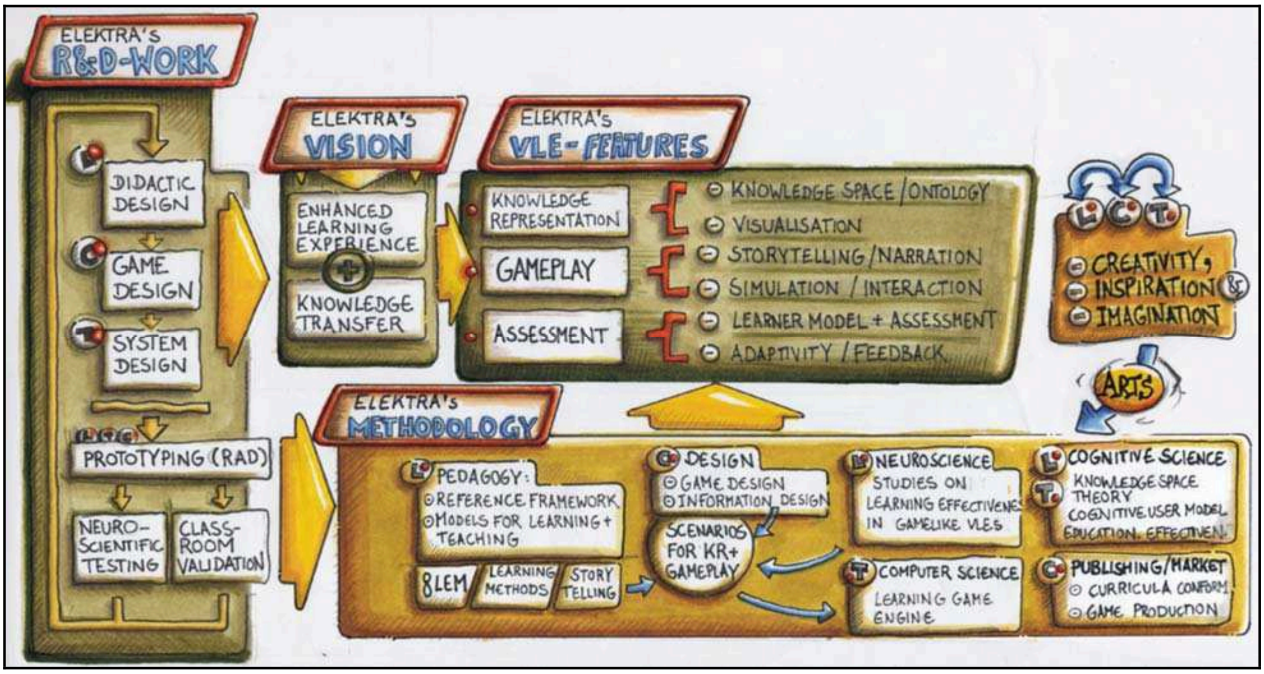

Figure 4. Sketch of ELEKTRA's methodological approach.

ELEKTRA's pedagogical basis will be the *Eight Learning Events Model* (8LEM), which is a pedagogical approach emphasizing that learning events are based on eight basic components. According to [51], on the basis of these eight components any number of training strategies can be deduced or, the other way round, any didactic strategy can be traced on these basic components. An advantage of the 8LEM approach is that, unlike the terms method and strategy, learning events can refer to intentional learning as well as incidental learning. The eight learning events are:

- Imitation / Modeling: Describes incidental or intentional learning through observation and subsequent imitation. The role of a tutor or teacher is being a (role) model.
- Reception / Transmission: Describes learning be receiving information or advice. The tutor’s role is transmitting information.
- Exercising / Guidance: Describes a “proceduralizing” and automation of skills. The tutor’s role is giving learners guidance and corrections.
- Exploration / Documentation: Describes learning by an investigation of information with a certain degree of freedom. The tutor’s role is to provide guidance, sources, or access.
- Experimentation / Reactivity: Describes learning through manipulations of environments and observations of effects. The tutor’s role is to provide an environment which allows experimentation and manipulation of objects, i.e. providing reactivity.
- Creation / Confrontation: Describes learning by creating new content or objects (e.g., texts or music). Creation also includes a reincorporation of known content. The tutor’s role is to foster creation process or confront learners with tasks of creation.
- Self-reflection / Co-reflection: Describes learning by reflecting the own knowledge and skills and the own learning processes. The tutor’s role is to give learners guidance and help in reflection processes.
- Debate / Animation: Describes learning by social interactions such as debates, arguments, and exchange of ideas. The tutor’s role is “animating” and inciting debates and discussions.

The advantages of this model are that it is observable meaning that its components can be identified quantitatively and qualitatively. Moreover, the model is not deterministic; in specific situations more than one learning event can be present. For example, watching TV might include imitation of seen activities combined with perceiving information. From the tutor’s perspective watching TV might include modeling and transmission. The 8LEM allows describing existing learning or teaching strategies or programs. Moreover, from a prescriptive point of view, the model allows to plan and track learning or teaching activities. On this basis, 8LEM allows to assure a diversification of learning or teaching methods.

Diversification of methods is a well-established pedagogical principle. Diversification of methods means to provide learners with a broader range of learning and teaching methods during the learning progress, instead of using continuously the same strategy (e.g., transmission). One of its underpinning principles is that variety benefits not only to current learning activities but also trains students in learning to learn. Should this assumption be confirmed, the diversity of learning experiences by which the learner is encouraged to learn would emerge as a criterion of educational quality. The model substantiates a number of reasons for varying learning events: (a) *Mathetical polyvalence*, meaning that it is in the learner’s interest to gain exposure to a whole range of learning modes in order to become a more competent learner, polyvalent in exploiting the variety of methods, resources, or constraints. This polyvalence becomes an even more urgent necessity in a knowledge society as this experience of diversity prepares the learner to take advantage of any future learning occasion. The learner's mathetics polyvalence corresponds to the teacher's “didactic polyvalence”, i.e. the capacity to organize diverse quality learning experiences. Facilitating the spring of polyvalent learners, the 8LEM provides a tool empowering educators for offering their pupils a rich, i.e. multi-faceted, learning experience. (b) *Epistemology*, meaning the advantage of covering a subject by means of varied events which does not lie purely in the fact that it trains the learner in a variety of learning methods. It also has an impact on the content itself. Varying events also means, over and beyond the question of methods, constructing and enriching the concept and the conceptual network associated to it. A medical student will have a particular idea of the stomach if he reads (reception) documents about that organ. But he will perceive a different facet if he is invited to perform a free dissection of a stomach (exploration). His conceptual network will be enriched further if, as an observer, he attends a stomach operation (imitation). When he himself has practised stomach operations (drilling), his conception of the stomach will have evolved still further. Finally, when he engages in discussion with his peers (debate), his conceptual network will expand even further. As well as experiencing various learning methods, he will in so doing have developed a multimodal approach to the concept in question. (c) *Personalization*, meaning the delivery of learning paths tailored to the personal preferences of the learner. The mathetical polyvalence principle brings back the idea, expressed prosaically, that it is not because a student likes chocolate that she does not have to be served fruits. The practitioner should consider the benefits of accommodating preferences or going against them. Both personalization and polyvalence drive similar attention to diversification. Any learning object can therefore equally serve a polyvalence or a personalization endeavour, both orientations requiring in all cases extra-reflection, extra-work and extra-pedagogical creativity for materializing the educational ideal of a panel of learning experiences offered to students.

The framework of 8LEM allows to plan learning and teaching on a very detailed basis, and from a descriptive perspective it allows to assure a diversification of methods in order to empower learning and to retain motivation.

Based on the question how well people understand or know a subject, Benjamin Bloom and colleagues [12][48] identified three general types of learning:

(a) the cognitive domain which includes skills and knowledge,
(b) the affective domain which includes a development or growth in emotional areas and attitudes, and
(c) the psychomotor domain which includes manual and physical skills.

For each domain Bloom, Krathwohl, and Masia identified categories for the depth of learning. The cognitive domain, which is particularly interesting for ELEKTRA's game-based learning approach, involves knowledge and the development of intellectual skills. This includes the recall or recognition of specific facts, procedural patterns, and concepts that serve in the development of intellectual abilities and skills. There are six major categories, which are listed in order below, starting from the simplest behavior to the most complex. The categories can be thought of as degrees of difficulties [16] which establish a hierarchical order. A more simple level of knowledge or ability must be given in order to reach a deeper one. The categories are

- *Knowledge*: the recall of factual information,
- *Comprehension*: understanding of the meaning, translation, interpolation, and interpretation of instructions and problems,
- *Application*: using of a concept in a new situation or unprompted use of an abstraction,
- *Analysis*: separating material or concepts into sub-components so that its organizational structure may be understood,
- *Synthesis*: building a structure or pattern from diverse elements, joining parts to form a whole, with emphasis on creating a new meaning or structure,
- *Evaluation*: making of judgments about the value of ideas or materials.

Additionally, so-called action verbs are assigned to each category, describing recall methods or abilities more detailed. For the category "knowledge" action verbs are, for example, "define", "describe", or "label"; for the category "analysis" "compare", "quantify", or "measure".

Anderson and Krathwohl [8] revised Bloom's original taxonomy. These authors combined both the cognitive process and knowledge dimensions. This new expanded taxonomy can help instructional designers and teachers to write and revise learning objectives. The knowledge dimension includes factual knowledge, conceptual knowledge, procedural knowledge, and meta-cognitive knowledge, the cognitive process dimension includes the abilities remember, understand, apply, analyze, evaluate, and create. Thus, learning and teaching activities can be related to one of the 24 (4x6) combinations.

Using the categories and the related action verbs, Bloom's taxonomy allows precisely describing and planning learning objectives (e.g., a learner shall be able to apply knowledge about algebra to solve an equation) and the design of knowledge assessments.

ELEKTRA will also build on the most recent pedagogic research about the potential of storytelling, "the original form of teaching" [65][83]. Stories are important cognitive events of particular pedagogical value because, according to [59], they encapsulate four of the crucial elements of human communication in one rhetorical package: information, knowledge, context, and emotion. "Educational media, such as lectures, books, TV programs, are all narrative in form, and for good reason. Narrative provides a macro-structure, which creates global coherence, contributes to local coherence and aids recall through its network of causal links and sign posting. Narrative is fundamentally linked to cognition and so is particularly relevant to the design of multimedia for learning" [50].

2.2.2. A cognitive learner model

Considering current practice in game-based learning from the perspective of cognitive science reveals a major gap. On the one hand, the development of learning games is mostly driven by technology and content. The rationale underlying their design may allude to general learning principles, such as constructivist learning, but it usually does not explicitly build upon elaborated and formalized learning theories. On the other hand, cognitive science does not yet provide the comprehensive and ready-to-be-implemented learning theory, which is capable of capturing the relevant factors and processes in game-based learning. This lack of ties to learning theory as well as that of a coherent theoretical framework and research paradigm has already been acknowledged a decade ago [33]. Since then, gaming technology has improved dramatically, but not much has been done to study how these improvements might be incorporated into learning environments, and there is still very little agreement as to the theoretical underpinnings of this endeavor [75].

A promising approach and starting point for establishing a sound cognitive learner model is Knowledge Space Theory and the Competence Performance Approach.

Knowledge Space Theory (KST; [26][27]) provides a set-theoretic framework for organizing a domain of knowledge and for representing the knowledge of individuals based on prerequisite relations. A knowledge domain is represented by a finite set Q of problems. The *knowledge state* of a learner is described as the subset of problems that s/he is able to master. Due to *prerequisite relations* among the problems of a domain, not all subsets of problems are possible knowledge states. If two problems $a, b \in Q$ are in a prerequisite relation, we can assume from mastering problem b a mastering of problem a. The collection of possible knowledge states corresponding to a prerequisite relation, including the empty set $\varnothing$ and the whole set Q, is called a *knowledge structure* K. In its original formalization, KST is purely behavioral focusing on the observable performance and it does not refer to the skills / competencies that underlie that performance. Several approaches for extending the KST have been published, which incorporate explicit reference to the skills that are required for solving the problems of a domain [2][3][25][29][31]. On of the most successful approaches is the *Competence Performance Approach* (CPA) by Klaus Korossy [46][47]. The basic idea of CPA is to assume a basic set E of abstract cognitive skills that are relevant for mastering the problems of a domain. The *competence state* of an individual is the collection of all available skills, which is not directly observable but can be uncovered on the basis of the observable performance on the problems representing the domain. As in KST, prerequisite relations are described on the set of competencies establishing a *competence structure C*, which contains all possible competence states. Utilizing *skill* and *problem functions*, families of subsets of skills can be mapped to problems, which can be mastered with the given skills and vice versa. By the assignment of skills to the problems of a domain, also a *performance structure* or *problem structure* on the set of problems is induced.

Based on -in detail- specified learning contents and learning goals, the skills must be extracted and defined. This might be lead (a) by the logical structure of learning objects, (b) theoretically, e.g. lead by existing psychological, pedagogical, or didactic theories, (c) empirically, e.g. as the result of empirical investigations of knowledge states of learners at different ages and levels of knowledge, or (d) by querying experts, i.e. referring to the knowledge of experts in a given domain such as teachers.

Once the skills required in a certain domain are defined, in a second step, a *prerequisite relation* in the sense of KST has to be established among the skills. This means, it has to be determined which of the skills are necessarily a prerequisite for acquiring another skill. Again, this might be lead (a) by the logical structure of skills, (b) theoretically, e.g. lead by existing psychological, pedagogical, or didactic theories, (c) empirically, e.g. as the result of empirical investigations of knowledge states of learners at different ages and levels of knowledge, or (d) by querying experts, i.e. referring to the knowledge of experts in a given domain such as teachers.

An example is shown in the upward drawing (or *Hasse* graph) of Figure 5. Table 1 equivalently displays the same prerequisite relation as binary matrix. This matrix can be seen as a computable or computer-understandable representation of the prerequisite relation and thus of the domain's

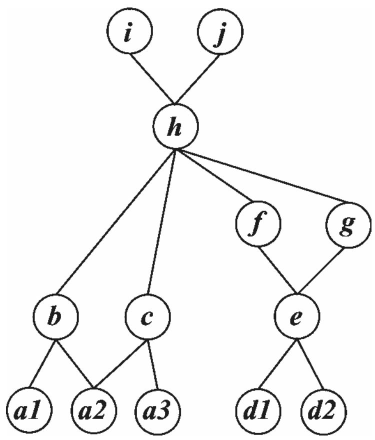

Figure 5. Upward drawing illustrating a prerequisite relations among a set of skills {a1, a2, a3, b, c, d1, d2, e, f, g, h, I, j}. Please note that the lower of two connected skills indicates a prerequisite for the upper one. Thus, as an example, skill a2 is a necessary prerequisite for skill c and, thus, also for h, i, and j.

Table 1. *Prerequisite relation displayed as binary matrix.*

	a1	a2	a3	b	c	d 1	d 2	e	f	g	h	i	j
a1	1	0	0	1	0	0	0	0	0	0	1	1	1
a2	0	1	0	1	1	0	0	0	0	0	1	1	1
a3	0	0	1	0	1	0	0	0	0	0	1	1	1
b	0	0	0	1	0	0	0	0	0	0	1	1	1
c	0	0	0	0	1	0	0	0	0	0	1	1	1
d 1	0	0	0	0	0	1	0	1	1	1	1	1	1

d2	0	0	0	0	0	0	1	1	1	1	1	1	1
e	0	0	0	0	0	0	0	1	1	1	1	1	1
f	0	0	0	0	0	0	0	0	1	0	1	1	1
g	0	0	0	0	0	0	0	0	0	1	1	1	1
h	0	0	0	0	0	0	0	0	0	0	1	1	1
i	0	0	0	0	0	0	0	0	0	0	0	1	0
j	0	0	0	0	0	0	0	0	0	0	0	0	1

Note. The cell value 1 denotes that the competency in a row is a prerequisite for the competency in the related column. Vice versa, a cell value 0 denotes that the competency in a row is not a prerequisite for a competency in the related column. For example, competency b in row 4 is a prerequisite for competency h in column 11.

structure. If the prerequisite relation is established, we can compute the related *competence structure*. The competence structure denotes all competence states, which are possible and meaningful with respect to the prerequisite relation. If we assume that skills a2 and a3 are prerequisites for skill c, competence states, which include skill c but not all of its prerequisites, in this example a2 and a3, are not possible or meaningful; at least from a deterministic perspective.

This procedure allows us to reduce the number of possible competence states. Without prerequisite relation, 13 skills establish a competence structure, which includes 8192 competence states, i.e. the power set of all skills (2^{13}). The proposed prerequisite relation establishes a competence structure, which includes only 108 possible competence states. The resulting competence structure is displayed in Figure 6.

The competence structure defines possible and meaningful competence states and it allows to model possible and meaningful learning paths. A major advantage is that CPA allows multiple, individual, not necessarily linear learning paths. This offers a sound model of learning content which establishes the very basis for game design as well as learning design. On the side of learning design, CPA allows to continuously develop skills and competencies in a structured manner. On the side of game design, branched storylines for interactive, personalized storytelling can be realized, characterized by multiple paths to proceed through the game play and game environment (Figure 5). The competence structure (at least in this example) also establishes certain bottlenecks, each learner / gamer has to pass. In the terms of game play, such competence states might be realized, for instance, as starting points of new game levels. Thus, the nature of competence structures as a formal representation of human skills or competencies in a given domain is quite similar to the storytelling and action design of typical computer games. Thus, CPA offers a method to meaningfully join learning and gaming design.

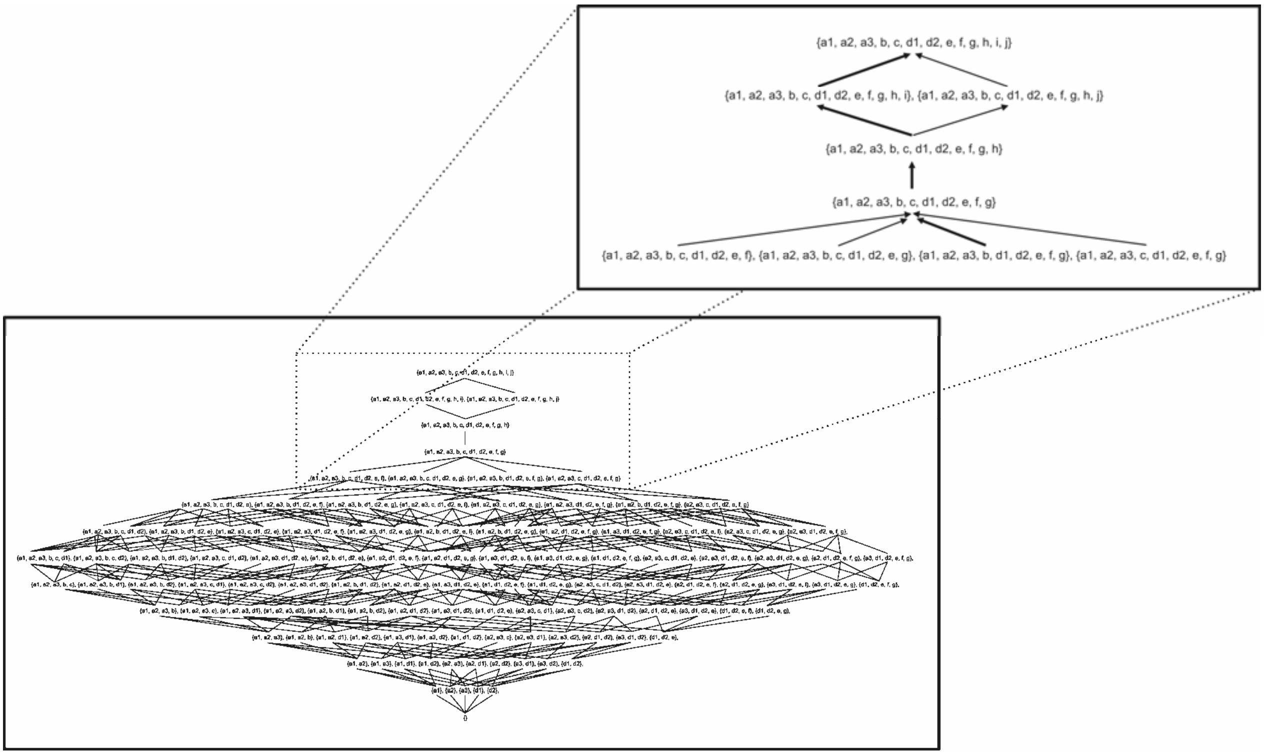

Figure 6. Competence structure established by the prerequisite relation (shown in Figure 5) among a set of skills. Each of arrows in the magnified image denote a valid learning step, consequently, learning progress is modeled by valid learning paths.

Besides the cognitive components of competence development, for the aims of ELEKTRA restrictions by the curricula and pedagogical theories must be considered. Pedagogical theories might restrict the prerequisite relation in a way that it might be pedagogically important to teach specific skills prior to others. These restrictions provoke an altered prerequisite relation (displayed in Figure 7, left panel) and consequently an altered competence structure (displayed in Figure 7, right panel). Alteration, however, can only be implemented, as far as they do not violate the assumptions of the initial prerequisite relation. For instance, an alteration cannot lead to a constellation within which skill c is taught prior to skill a2. In this example, the number of possible competence states is reduced to 21 out of 8192.

So far, we focused on latent unobservable skills; these must be mapped to observable performance. CPA therefore provides representation and interpretation functions or in the terminology of [29] skill and problem functions.

The problem function assigns the problems (e.g. test items) of each learning situation to each competence state, within which they can be mastered. Vice versa, the problem function assigns the competence states to the problems of each learning situation, within which they can be mastered. These functions strongly depend on the game's storytelling and the realization of learning situations and its assessments. These functions do not require a one-to-one mapping, hence, in the game scenario, there might be learning situations that include more than one skill.

The skill and problem functions can be seen as an interface between the competence structure and the game design. A major advantage of these functions is that a change in the game design (i.e., the design of learning or assessment activities) does not require to change the underlying competence structure but only to edit the problem and skill functions.

To give a simple example, ELEKTRA's scenario might include four learning units (A1 to A4) including related learning situations and problems (e.g. assessment tasks or test items. Possibly resulting problem and skill Functions are shown in Table 2.

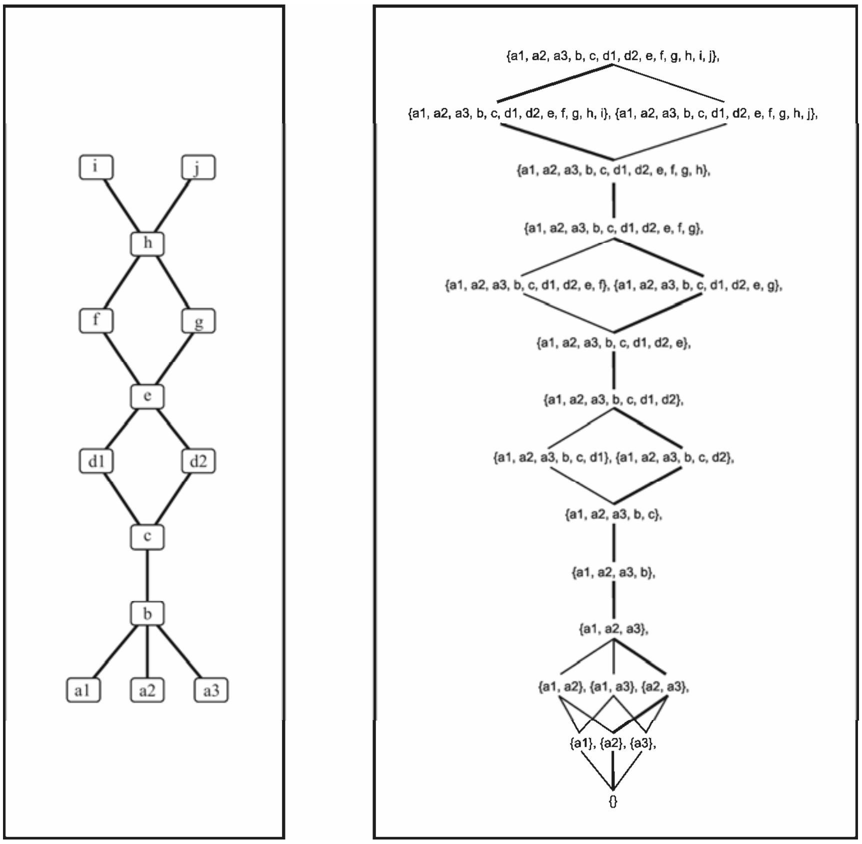

Figure 7. Altered prerequisite relation (left panel) and the resulting competence structure (right panel).

Table 2. *Problem and skill functions.*

Problem Function

competence state	Problem
{a1,a2,a3,b,c}	A1
{a1,a2,a3,b,c,d1,d2,e,f,g}	A1, A2
{a1,a2,a3,b,c,d1,d2,e,f,g,h,i,j}	A1, A2, A3, A4

Skill Function

Problem	competence state
A1	{a1,a2,a3,b,c}
A2	{a1,a2,a3,b,c,d1,d2,e,f,g}
A3	{a1,a2,a3,b,c,d1,d2,e,f,g,h,i,j}
A4	{a1,a2,a3,b,c,d1,d2,e,f,g,h,i,j}

Note. Please note that for the problem function only these competence states are listed, within which a further problem can be accomplished. For the skill function only these competence states are listed which are the states that include the smallest number possible to accomplish a learning situation.

2.2.3. Game design

ELEKTRA’s 3D world will be the visual representation of the learning environment. It will support the learner in the visualization of the knowledge space of a learning topic as part of a highly interactive virtual landscape. For the ELEKTRA demonstrator a single-user adventure game will be realized covering an immersive storyline. This game demonstrator, as commercial games, will include

- Storytelling situations that are realized as cut-scenes or in game storytelling explaining the main goal of the game, as well as tasks and challenges alongside the course of the game, the background story and the progress of the story,
- tutorials to make learners familiar with game concepts and to convey game literacy
- gaming situations which primarily aim for impelling the storyline and retaining motivation and interest,
- learning situations which primarily focus on providing educational content and impartation of knowledge, and
- assessment situations within which the current knowledge of a learner will be measured.

The educational contents of the demonstrator will cover the domain of optics, and as part of this domain, particularly the topic “eclipse”. Information about eclipses will be packed into an immersive and naturalistic 3D environment (Figure 8) and, more importantly, into a meaningful and exciting story. Also assessments will be an integral part of the game. As an example, learning success will be measured by observing the learner’s ability to solve certain riddles and tasks. Learning and assessment situations are equivalently to the different stations in the campaign of a typical adventure game and can represent both challenge (in form of problems that have to be solved) and knowledge (that is necessary to solve the problems). The target group of the game demonstrator will be student at the age of 14 to 15 years.

From a technical perspective, the ELEKTRA demonstrator will be based on the Nebula2 game engine (www.radonlabs.de/nebula.html) which includes a rendering engine, a game logic engine, a physics engine, and a scripting engine. Furthermore, interfaces between game engine and adaptive and learning engines will be established. The latter are responsible for implementing the rules and mechanisms of CPA to the game.

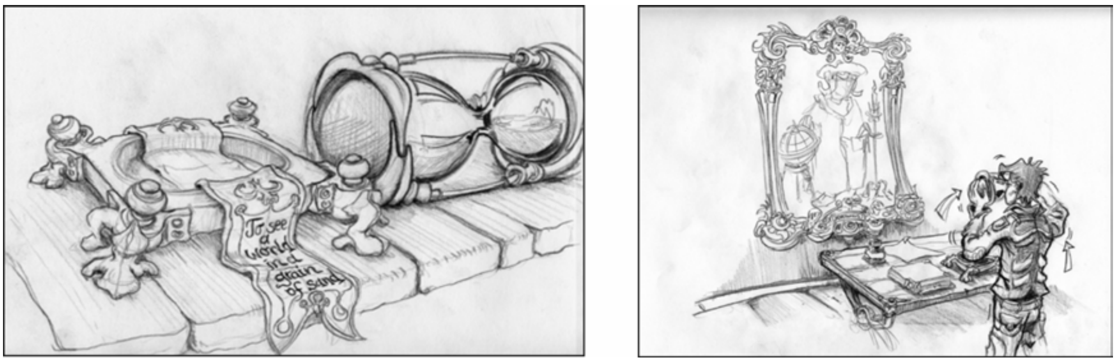

Figure 8. Example sketches of ELEKTRA’s storyboard.

Computer games are quite complex pieces of software including a vast amount of menus, functionalities, objects, maps, and so on. Many commercial and educational games lack of usable interfaces, interaction methods, and game functionality, failing in providing pleasant and relaxed gaming experiences. For some reasons usability engineering has not gained the extent of popularity yet it has gained in software and web development. *Gamasutra*, for example, found a number of serious usability problems in a prototypical study (http://www.gamasutra.com/features/20050623/laitinen_01.shtml, retrieved August 24, 2006). Usability, however, is crucially important for games [61][62]: (a) Interactive experiences are the focal point of games and users are very sensitive to obstructions in this interaction. Because playing generally is purely voluntary, usability problems are a serious risk for a game's success. (b) The market of computer games is extremely competitive; if one game fails in providing fluent and pleasant interactions, e.g. handling the inventory of an adventure game, gamers can instantly choose another, equivalent game from the rich offers. Thus, usability engineering is obviously more important for the game genre than for other software categories; there are for example not too many operating systems to choose from.

When aiming for a "voluntary learning" with a game, usability and user-experience are even more important factors. Consequently, ELEKTRA will rely on well established principles and guidelines for usability engineering (see [38][40]) and will apply usability engineering during the development process and in the framework of comprehensive evaluations of the game demonstrator. Because ELEKTRA aims to be used also in classrooms or related to classroom activities, usability engineering will also address requirements of learners with special needs (cf. [39]).

2.3. ELEKTRA's architecture

The very basis of the ELEKTRA methodology as well as the game demonstrator is to establish learning objectives for the game. For the ELEKRTA demonstrator we selected the domain of "eclipse". This topic primarily covers physics education at the age of 14+. The learning objectives are extracted from the national curricula of Belgium, France, and Germany; ELEKTRA thereby covers the union set of these three curricula. In order to realize a game intelligence, as described above, this static information have to be stored. Furthermore, dynamic information about the learner, its preferences and knowledge must be stored and continuously updated.

2.3.1. The ontology

The "database" for relevant information used by the game demonstrator will be based on an ontology. An ontology in computer science is a data model to represent entities of a domain and relations among them. An ontology includes concepts or classes which are generic terms, e.g. learning objects or test items, and it includes instances or individuals related to a set of concepts, e.g. a specific test item. The entities of an ontology can be described with attributes. Each attribute has a name, a certain data type, and one or more values, e.g. attribute "language" and value "English". Attributes, moreover, serve to establish relations among entities. For example, a relation might be "A is part of B". The prerequisite relation introduced in this article can be modelled in this way. Thus, a skill (on the latent level) or a learning object / test item (on the performance level) may have an attribute "is prerequisite of". Ontologies establish a formalized and computable representation of a domain and the related entities. Generally, this is accomplished with XML metadata. A typical standard is OWL (ontology web language) which is used in ELEKTRA.

The preliminary structure of ELEKTRA's ontology is shown in Figure 9. Its major concept is the "learner", emphasizing the learner-centric approach of ELEKTRA. The domain of knowledge is

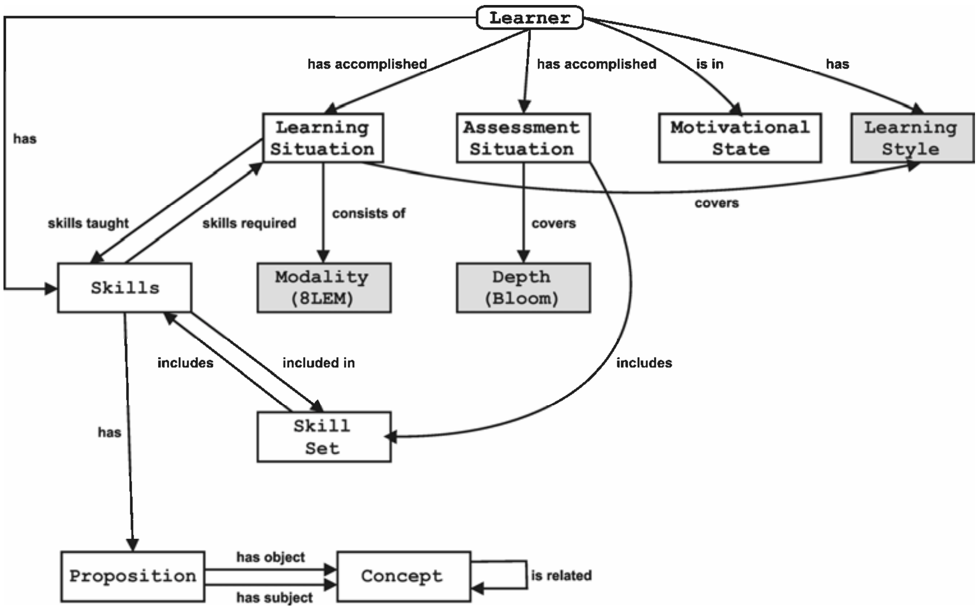

Figure 9. The preliminary structure of the ontology used as "database" for static and dynamic information.

modeled in form of propositions. Equal to concept maps, propositions are established by to concepts, an object and a subject which are connected to each other by any kind of relation. As an example, a proposition might be [Sun – is a – star]. On the basis of a complete set of propositions of the domain, skills can be deduced and refined in combination with depth information (this refers to the taxonomy of Bloom [12]and related action verbs). Thus, not only detailed skills can be deduced but also learning objectives can be defined in detail, e.g. "to define a star".

As demonstrated in Figure 5, within the ontology prerequisite relation among the skills can be established and combined with pedagogical implications (e.g., defined by the learning modality). This might refer to the 8LEM but also to didactical strategies such as problem-based learning or factual learning approaches. As described above, so far, skills are on a latent, unobservable level. According to CPA, the ontology allows us to relate a set of learning situations of the game and also a set of assessment situations to skills and specific sets of skills. Thus, we can model problem and skill functions (cf. Table 2). Finally, the ontology allows us to model and store further learner information, e.g., motivational states or learning styles, in order to provide a suitable database for making the game adaptively and adequately react to certain learner requirements.

As mentioned, in contrast to traditional CPA approaches, the ontology-based approach allows to model pedagogical implications, for example implications by 8LEM or didactic strategies. The lines in Figures 5 and 6 indicate learning by accomplishing specific learning situations. These "transitions" are based on purely cognitive modeling of the domain. However, this cognitive theory does not make any advice of how the learning activity must be designed or presented in the game. The selection of an appropriate learning activity for the transitions (represented by the upwards directed lines in the diagram) has to be grounded on pedagogical principles. Figure 10 demonstrates the performance structure derived from the sample interpretation and representation functions of Table 2. One or more learning situations may lead from one performance state (meaning a learner / gamer is able to master a specific task or assessment; indicated by symbols A1 to A4) to another, superior one. This is indicated in Figure 10 by eight lines connecting the performance states. Bold lines indicate that not necessarily all of the eight learning events must be realized as a learning situation in the game. Additionally, the ontology allows us to adaptively refer to certain learning paths according to the needs of learners or instructional designers and educators.

Besides selecting appropriate learning or teaching methods (i.e., learning situations) pedagogical implications might also influence the selection of appropriate learning paths. The magnified area in Figure 6, for example, displays eight possible learning paths; for pedagogical implications in interaction with individual preferences only some of these learning paths might be appropriate. The ontology allows referring to a data basis to adaptively react to such implications on a larger scale.

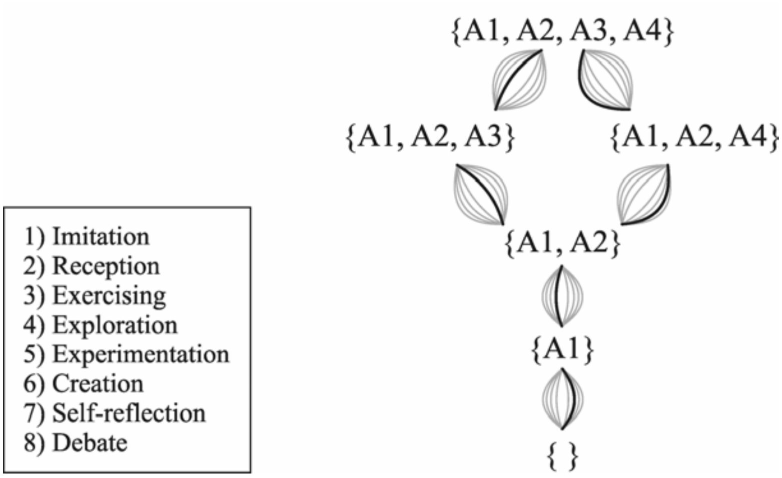

Figure 10. Performance structure established by the problem and skill functions of Table 2. The progress from one performance state to another is realized by one or more learning situations which are determined by 8LEM.

2.3.2. Adaptivity

Games generally react on user actions; for example, when a gamer fails in a certain task s/he might lose energy or power. An educational game must react on user actions related to learning in the same manner. This, however, is not a trivial task.

Systems that attempt to adapt to a learner's competence or performance state are well-established in traditional forms of eLearning. Generally, these systems are used to tailor learners' views of learning objects to their personal requirements. Such technologies are often incorporated to guide through a large body of learning objects assisting learners in their comprehension of that material. For example, an adaptive system may only provide learning objects which are suitable for the learner. Too difficult and also too easy learning objects might not be displayed in order to avoid visual and cognitive load and to suggest an appropriate learning path through the learning content.

Existing adaptive eLearning systems such as ALEKS (www.aleks.com) or ELM-ART [82] demonstrated benefits for learners in terms of navigating through contents [14] and in terms of classroom and platform independence [13]. Generally, these adaptive approaches attempt to compete the one-fits-all approach of traditional eLearning accounting for certain requirements and preferences of a learner. Primarily, such approaches provide adaptive navigation and adaptive presentation of contents [4][5][20]. Adaptive navigation, as already mentioned, refers to guidance through learning objects by, for example, a customized hyperlink structure or format. The degree of freedom granted within a system is determined by a specific underlying learner model. Adaptive presentation refers to a customized presentation of learning objects. On the one hand this might concern the visual or auditory design; on the other hand this might concern the amount or grade of details of presented learning contents.

In ELEKTRA, adaptivity regarding the learner's knowledge will be realized by providing appropriate learning situations for a learner's current competence state. This means, a learner will be provided with learning situations and learning paths within the game environment that are not too easy or too difficult. This assures that meaningful and efficient learning is possible and, on the other hand, this assures an appropriate balance between challenge and skill in order to retain motivation and engagement. Thus, the game requires adequate assessment situations.

In the scope of the game, there are three types of assessment: (a) An initial assessment of a learner's competence state before starting the game, (b) a continuous assessment of learning progress, and (c) a final assessment measuring the overall learning success, for game levels and for the entire game.

For the initial assessment we will provide adaptive assessment algorithms, which are able to reduce the number of test items to determine a learners / gamers competence state. Generally, the exact assessment of a competence state requires as much test items as competencies. Referring to the competence structure, CPA allows concluding from mastering or failing in a certain test item, which test items can be skipped. In the game, the initial assessment might be realized as a tutorial level, which is common in many games.

Crucially important for the game process is a continuous assessment of learning success, because learning success (meaning the acquisition of competencies) determines the way in which learning situations can be realized for the learner. According to CPA, no learning objects shall be presented to the learner, which require skills this person does not already have. In the game this might be realized by certain tasks, which must be accomplished to make headway in the game's story.

The final assessment might be covered by the same tasks; since the CPA-based storytelling will be designed that new levels or the end of the game can only be reached when all necessary competencies are learned. Additionally, we have to consider forgetting, especially when factual learning is involved or the prerequisite relation is altered by pedagogical and storytelling constraints, which might lead to relations which are not based on logical cognitive prerequisites. Thus, at the end of levels or the entire game, it might be useful to realize comprehensive assessments. As for the initial assessment such procedures might be based on adaptive assessment algorithms.

To realize the assessment, the game engine will be connected to a so-called adaptive engine and a learning engine, which implement the rules of CPA and make suggestions for the progress in the game. Thus, adaptive and learning engines can be viewed as interface between the game itself and the information stored in the ontology.

Because ELETRA will not only be adaptive regarding knowledge but also regarding motivational states, learning styles, or didactical strategies, the same approach can be used to provide adaptivity in this regard (cf. [43]). Thus, assessment will involve meta-cognitive judgment on the answer the learner provides. We will provide then reflection tools based on the meta-cognitive information they give with their judgments, to improve their cognitive and meta-cognitive performances. But we will also link the feedback to the learning strategies they have used through the game in resolving the problems and challenges. Progress in learning will be more precise for it and will be more detailed in terms of granularity. For instance, an answer can still be wrong in a following test but if the answer is associated with a lower confidence degree we have quantitative data proving the progress. The same is true for a correct answer with a low confidence degree in which progress still can be made by increasing the confidence degree in that correct answer. As De Finetti [22] stated: ”Partial information exists. To detect it is necessary and feasible (p. 109). It is only subjective probability that can give an objective meaning to every response and scoring method (p. 111)”.

3. Research questions and evaluation

As mentioned, currently there are a number of open research questions. Van Eck [79] pointed out that research must clarify why educational games are effective and give practical guidelines how game-based learning can be implemented successfully in or to maximize learning potential. Moreover, he emphasizes the importance to investigate not only how educational games work, but also how different types of games work and how game taxonomies relate to learning taxonomies. It’s clear that not all types of games work equally well for each learning objective. For example, simple card games might be adequate for pattern recognition or the matching of concepts, adventure games, on the other hand, likely be adequate for promoting hypothesis testing or problem solving.

Moreover, ELEKTRA’s achievement of the general objectives - the production of the demonstrator and methodology - will be measured in empirical evaluations carried out with learners as they are actively engaged in using the ELEKTRA demonstrator in classrooms, single user tests and laboratory studies, ensuring an empirical evaluation of the effectiveness of this demonstrator. The formal cognitive modeling requires deriving parameters that explicitly characterize the educational efficiency and effectiveness not only at a global level (e.g. for evaluating the employed teaching method), but also at a highly specific level (charactering, for example, single learning objects, or learning activities).

These aims for research and evaluation / validation are realized as an interdisciplinary process, combining research of cognitive science, neuroscience, pedagogy, and game research. From a cognitive perspective, major research questions concern the validation of the domain structure or the implications of instructional design on learning and performance. Neuroscience will contribute sophisticated methods such as event-related fMRI (functional magnetic resonance imaging), which allows identifying brain activity related to the recognition and encoding of events, such as words, faces, or objects and the retrieval of brain representations of these events from memory. Research paradigms enabling a reliable neuroimaging of “insight” during learning are still lacking. This is why the ELEKTRA-evaluation scenarios will concentrate on facts, not on “insight”. From the perspective of pedagogy, important research questions concern the impact of method diversification on learning or meta-cognition. Finally from the perspective of game research and game design, important questions are how to merge adequate game design and didactical design (cf. [79]) or what are the mechanisms to achieve immersive visuals and storytelling by retain pedagogical demands.

4. Conclusion

The ELEKTRA project has highly ambitious and visionary aims to make a significant contribution to the evolution of digital game-based learning. In consideration of the vast amount of gaming in all cultures, the enormous intrinsic motivation of games, and the fact the gaming is one of the most natural and effective forms of learning, this is a estimable and important aim, especially for an information and knowledge society which assets are primarily based on knowledge, competence, and know-how.

The problems with most current game-based learning reported in the literature are manifold. The costs of developing high quality games are very high, games which tend to be educational and engaging often tend to privilege engaging game elements over pedagogical demands, or vice versa. Generally educational games fail to be related to school curricula or to provide appropriate assessment. Cynically, Seymour Papert [64] termed the problems in merging state-of-the-art game design with educational demands "Shavian reversal", meaning that the offspring inherits the worst of both parents (educational design and game design).

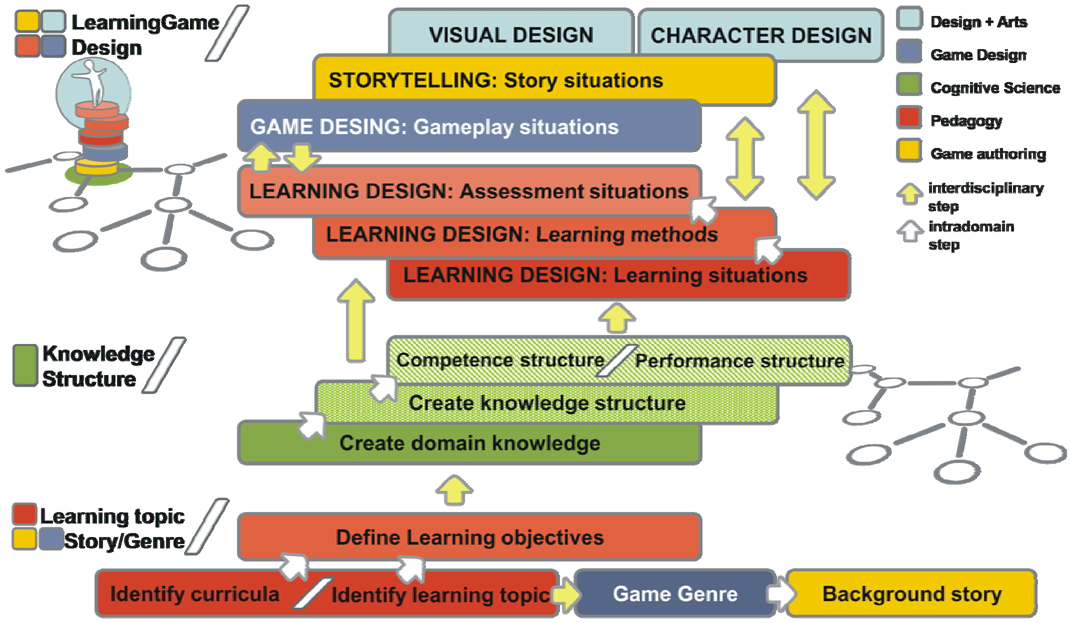

Figure 11. A proposal for the design process for educational games.

The ELEKTRA project aims for addressing these problems and to establish a methodology for state-of-the-art educational game design and to provide the related technology. Figure 11 summarizes ELEKTRA's methodological approach to design educational games. To align an educational game with curricula and contents, in a first step existing national curricula for a given learning topic must be identified and analyzed. On this basis learning objects can be defined in detailed referring to pedagogical models and taxonomies (e.g., 8LEM or Bloom's taxonomy). Moreover, learning topic and curriculum determine the game genre and, subsequently, the background story which covers the educational aim. As Van Eck [79] pointed out, not all types of games are suitable for each educational aim and it is an important question to clarify which game types are suitable for which learning topic. In a next step an ontology of the knowledge domain must be established, including skills in a sufficiently fine granularity and prerequisite relations among these skills. Third, learning and assessment situations must be developed according to the learning objectives and the game genre. This task might be the most difficult one since it requires creativity and fantasy. Finally, story telling and game design must meld these components into a immersive and motivating game.

Relying on the body of research on digital game-based learning, computer games have the potential to foster learning and to offer new and rich perspectives and experiences. Despite the disadvantages and problems of existing educational games, we believe that games hold out the prospect of melding gaming for learning and gaming for fun to a much broader and successful extent. We are optimistic that ELEKTRA can make a significant contribution to the enthralling future of game-based learning.

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8. References

[1] ALAVA, S., & CLANET, J. (2000). Éléments pour une meilleure connaissance des pratiques tutorales: regards croisés sur la fonction de tuteur. Revue des sciences de l'éducation, 26 (3), 545-570.

[2] ALBERT, D., & HELD, T. (1994). Establishing knowledge spaces by systematical problem construction. In D. Albert (Ed.), *Knowledge Structures (*pp. 78–112). New York: Springer-Verlag.

[3] ALBERT, D., & HELD, T. (1999). Component Based Knowledge Spaces in Problem Solving and Inductive Reasoning. In D. Albert & J. Lukas (Eds.), *Knowledge Spaces: Theories, Empirical Research Applications* (pp. 15–40). Mahwah, NJ: Lawrence Erlbaum Associates.

[4] ALBERT, D., HOCKEMEYER, C., & WESIAK, G. (2002). Current Trends in eLearning based on Knowledge Space Theory and Cognitive Psychology. *Psychologische Beiträge*, 44(4), 478–494

[5] ALBERT, D., & MORI, T. (2001). Contributions of Cognitive Psychology to the Future of e-Learning. *Bulletin of the Graduate School of Education Hiroshima University, Part I (Learning and Curriculum Development)*, 50, 25–34.

[6] ANDERSON, C.A., & BUSHMAN, B.J. (2001). Effects of violent video games on aggressive behavior, aggressive cognition, aggressive affect, physiological arousal and prosocial behavior: a meta-analytic review of the scientific literature. *Psychological Science*, 12(5), 353–359.

[7] ANDERSON, C.A., & DILL, K.E. (2000). Video games and aggressive thoughts, feelings and behavior in the laboratory and in life. *Journal of Personality and Social Psychology*, 78(4), 772–790.

[8] ANDERSON, L.W., & KRATHWOHL, D.R. (Eds.). (2001). *A Taxonomy for Learning,Teaching, and Assessing: A Revision of Bloom's Taxonomy of Educational Objectives*. New York: Longman.

[9] BARTHOLOW, B.D, SESTIR, M.A., & DAVIS, E.B. (2005). Correlates and Consequences of Exposure to Video Game Violence: Hostile Personality, Empathy, and Aggressive Behavior. *Personality & Social Psychology Bulletin*, 31, 1573-1586.

[10] BECTA (2001). *Computer Games in Education project*. Retrieved May 2, 2004 from www.becta.org.uk/research/research.cfm?section=1&id=2826.

[11] BENSLEY, L., & VAN EENWYK, J. (2001). Video games and real-life aggression: review of the literature. *Journal of Adolescent Health*, 29, 244–257.

[12] BLOOM, B.S. (1956). *Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain*. New York: David McKay.

[13] BRUSILOVSKY, P. (1999). Adaptive and Intelligent Technologies for Web-based Education. *Künstliche Intelligenz,* 4, 19-25.

[14] BRUSILOVSKY, P., SOSNOVSKY, S., & YUDELSON, M. (2004). Adaptive Hypermedia Services for E-Learning. In Proceedings of W*orkshop on Applying Adaptive Hypermedia Techniques to Service Oriented Environments at the Third International Conference on Adaptive Hypermedia and Adaptive Web-Based Systems* (AH'2004), Eindhoven, the Netherlands, August 23, 2004, 470-479.

[15] CESARONE, B. (1998). Video games: research, ratings, recommendations. *ERIC Digest*, Report No. EDO-PS-98-11.

[16] CLARK, D. (1999). *Learning Domains or Bloom's Taxonomy*. Retrieved November 8, 2005 from www.nwlink.com/~donclark/hrd/bloom.html

[17] CLARK, D. (2003). *Learning by playing: can computer games and simulations support teaching and learning for post-16 learners in formal, workplace and informal learning contexts?* Retrieved June 10, 2005 from http://www.bbk.ac.uk/ccs/elearn/events.html

[18] COLWELL, J., GRADY, C., & RHAITI, S. (1995). Computer games, self-esteem and gratification of needs in adolescents. *Journal of Community and Applied Social Psychology*, 5, 195–206.

[19] COLWELL, J., & PAYNE, J. (2000). Negative correlates of computer game play in adolescents. *British Journal of Psychology*, 91(3), 295–310.

[20] CONLAN, O., HOCKEMEYER, C., WADE, V., & ALBERT, D. (2002). Metadata Driven Approaches to Facilitate Adaptivity in Personalized eLearning systems. *Journal of Information and Systems in Education*, 1, 38–44.

[21] CORTI, K. (2005). Game-based learning: A serious business applications. Retrieved August 22, 2006 from http://www.pixellearning.com/serious_games-white_papers.htm

[22] DE FINETTI, B. (1965). Methods for discriminating levels of partial knowledge concerning a test item. *British Journal of Mathematical and Statistical Psychology*, 18, 87-123.

[23] DE LISI, R., & CAMMARANO, D.M. (1996). Computer experience and gender differences in undergraduate mental rotation performance. *Computers in Human Behavior*, 12, 351-361

[24] DE LISI, R., & WOLFORD, J.L. (2002). Improving children's mental rotation accuracy with computer game playing. *Journal of Genetic Psychology*, 163(3), 272–282.

[25] DOIGNON, J.-P. (1994). Knowledge spaces and skill assignments. In G. H. Fischer & D. Laming (Eds.), *Contributions to Mathematical Psychology, Psychometrics and Methodology* (pp. 111– 121). New York: Springer-Verlag.

[26] DOIGNON J.-P., & FALMAGNE, J.-C. (1985). Spaces for the assessment of knowledge. *International Journal of Man-Machine Studies*, 23, 175-196.

[27] DOIGNON J.-P., & FALMAGNE, J.-C. (1999). *Knowledge spaces*. Berlin; Heidelberg; New York: Springer-Verlag.

[28] DORVAL, M., & PEPIN, M. (1986). Effect of playing a video game on a measure of spatial visualization. *Perceptual Motor Skills*, 62, 159-162.

[29] DÜNTSCH, I., & GEDIGA, G. (1995). Skills and Knowledge Structures. *British Journal of Mathematical and Statistical Psychology*, 48, 9–27.

[30] ENTERTAINMENT SOFTWARE ASSOCIATION (2006). *Essential facts about the computer and video game industry.* Retrieved August 1, 2006 from http://www.theesa.com/archives/files/Essential%20Facts%202006.pdf

[31] FALMANGE, J.-C., KOPPEN, M., VILLANO, M., DOIGNON, J.-P. & JOHANNESEN, L. (1990). Introduction to Knowledge Spaces: How to Build, Test, and Search Them. *Psychological Review*, 97, 201-224.

[32] GIKAS, J., & VAN ECK, R. (2004). Integrating Video Games in the Classroom: Where to Begin? Paper presented for the annual meeting of the *National Learning Infrastructure Initiative*, January 25-27, San Diego, CA.

[33] GREDLER, M. E. (1996). Educational games and simulations: A technology in search of a (research) pradigm. In D. H. Jonassen (Ed.), *Handbook of research for educational communications and technology* (pp. 521–540). New York: McMillan.

[34] GREEN, C., & BAVELIER, D. (2003). Action video game modifies visual selective attention. *Nature*, 423, 534–537.

[35] GLISSOV, P., SIANN, G., & DURNDELL, A. (1994). Chips with everything: personal attributes of heavy computer users. *Educational Studies*, 20(3), 367–377.

[36] GREENFIELD, P.M., CAMIONI, L., ERCOLANI, P., WEISS, L., LAUBER, B.A., PEUCCHINI, P. (1994). Cognitive socialization by computer games in two cultures: inductive discovery or mastery of an iconic code? *Journal of Applied Developmental Psychology*, 15(1), 59–85.

[37] HALTTUNEN, K., & SORMUNEN, E. (2000). Learning information retrieval through an educational game. Is gaming sufficient for learning? *Education for Information*, 18(4), 289–311.

[38] HOLZINGER, A. (2004): Application of Rapid Prototyping to the User Interface Development for a Virtual Medical Campus. *IEEE Software*, 21(1), 92-99.

[39] HOLZINGER, A. (2004): How can Human-Computer Interaction & Usability Engineering contribute to to the design and development of IT for people with special needs. In: Miesenberger K.; Klaus J.; Burger D.; Zagler W. (Eds.), *Lecture Notes of Computer Science*, LNCS 3118.

[40] HOLZINGER, A. (2005): Usability Engineering for Software Developers. *Communications of the ACM*, 48 (1), 71-74.

[41] JAYAKANTHAN, R. (2002). Application of computer games in the field of education. *The Electronic Library*, 20(2), 98–102.

[42] KEARNEY, P. (2005). Cognitive Callisthenics: Do FPS computer games enhance the player's cognitive abilities? In Proceedings of *Changing Views: Worlds in Play, 20005 International Conference*.

[43] KICKMEIER-RUST, M.D., ALBERT, D., & ROTH, R. (in press). *A Methodological Approach to Address Individual Factors and Gender Differences in Adaptive eLearning.*

[44] KIRRIEMUIR, J. (2002). *The relevance of video games and gaming consoles to the higher and further education learning experience*. April 2002. Techwatch ReportTSW 02.01. Retrieved May, 2, 2004 from http://www.jisc.ac.uk/index.cfm?name=techwatch_report_0201

[45] KO, S. (2002). An empirical analysis of children's thinking and learning using a computer game context. *Educational Psychology*, 22(2), 219–233.

[46] KOROSSY, K. (1997). Extending the theory of knowledge spaces: a competence-performance approach. *Zeitschrift für Psychologie*, 205, 53-82.

[47] KOROSSY K., (1999). Modelling Knowledge as Competence and Performance. In D. Albert & J. Lukas (Eds.), *Knowledge Spaces: Theories, Empirical Research, and Applications* (pp. 103–132). Mahwah, NJ: Lawrence Erlbaum Associates.

[48] KRATHWOHL, D.R., BLOOM, B.S., & BERTRAM, B.M. (1973). *Taxonomy of Educational Objectives, the Classification of Educational Goals. Handbook II: Affective Domain*. New York: David McKay.

[49] KUSUNOKI, F., SUGIMOTO, M., & HASHIZUME, H. (2000). Discovering how other pupils think by collaborative learning in a classroom. In proceedings of the *Fourth International Conference on Knowledge-based Intelligent Engineering Systems and Allied Technologies*, 30 August–1 September 2000, Brighton, UK.

[50] LAURILLARD, D., STRATFOLD, M., LUCKIN, R., PLOWMAN, L., & TAYLOR, J. (2002). Affordances for Learning in a Non-Linear Narrative Medium. *Journal of Interactive Media in Education*, 2, 1-17.

[51] LECLERCQ, D., & POUMAY, M. (2005). *The 8 Learning events model and its principles*. Retrieved August 20, 2006 from http://www.labset.net/media/prod/8LEM.pdf

[52] LEDDO, J. (1996). An intelligent tutoring game to teach scientific reasoning. *Journal of Instruction Delivery Systems*, 10(4), 22–25.

[53] MALONE, T.W. (1981). Toward a theory of intrinsically motivating instruction. *Cognitive Science*, 4, 333–369.

[54] MARTINEZ, M., & BUNDERSON, C. (2000). Building Interactive Web Learning Environments to Match and Support Individual Learning Differences. *Journal of Interactive Learning Research*, 11(2).

[55] MAYES, J.T. (1992). Mindtools: A suitable case for learning. In P.A.M. Kommer, D. Jonassen, & Mayes, T. (Eds.), *Cognitive tools for learning*. Heidelberg: Springer-Verlag.

[56] MITCHELL, A., & SAVILL-SMITH, C. (2004). *The use of computer and video games for learning: A review of the literature.* London: Learning and Skills Development Agency.

[57] MOSS, C. (2002). Finding balance: The vices of our "Versus", *First Monday*, 7(1).

[58] MULLIGAN, J., & PATROVSKY, B. (2003). *Developing Online Games: An Insider's Guide* (1st ed.). Indianapolis: New Riders.

[59] NORMAN, D. A. (1993). *Things that make us smart - Defending human attributes in the age of the machine*. Reading, MA: Addison-Wesley.

[60] OKAGAKI, L., & FRENSCH, P.A. (1994). Effects of video game playing on measures of spatial performance: Gender Effects in Late adolescence. *Journal of Applied Developmental Psychology,* 15, 33-58.

[61] PAGULAYAN, R.J., & STEURY, K. (2004). Beyond usability in games. *Interactions*, 11(5), 70-71.

[62] PAGULAYAN, R.J., KEEKER, K., WIXON, D., & ROMERO, R.L., & FULLER, T. (2002). User-centered game design. In J. Jacko, & A. Sears (Eds.), *Handbook for Human-Computer Interaction in Interactive* Systems (pp. 883-906). Mahwah, NJ: Lawrence Erlbaum Associates.

[63] PAIVIO, A. (1979): *Imagery and verbal processes*. Hillsdale, NJ: Erlbaum.

[64] PAPERT, S. (1998). Does easy do it? Children, games, and learning. *Game Developer Magazine*, 6, 88.

[65] PEDERSON, E. (1995). Language as context, language as means: Spatial cognition and habitual language use. *Cognitive Linguistics*, 6, 3–62.

[66] PETERS, O. (2004). *Visions of autonomous learning. In Distance education in transition - New trends and challenges* (4th ed.). Oldenburg: Bibliotheks und Informationssystem der Universität Oldenburg.

[67] PHILLIPS, C.A., ROLLS, S., ROUSE, A., & GIFFITHS, M.D. (1995). Home video game playing in schoolchildren: a study of incidence and patterns of play. *Journal of Adolescence*, 18(6), 687–691.

[68] PILLAY, H. (2003). An investigation of cognitive processes engaged in by recreational computer games players: implications for skills of the future. *Journal of Research on Technology in Education*, 34(3), 336–350.

[69] PILLAY, H., BROWNLEE,J., & WILSS, L. (1999). Cognition and recreational computer games: implications for educational technology. *Journal of Research on Computing in Education*, 32(1), 203–216.

[70] POOLE, S. (2000). *Trigger happy, video games and the entertainment revolution*. New York: Arcade Publishing.

[71] PRENSKY, M. (2001). *Digital game-based learning.* New York: McGraw-Hill.

[72] ROE, K., & MUJIS, D. (1998). Children and computer games – a profile of the heavy user. *European Journal of Communication*, 13(2), 181–200.

[73] ROSAS, R., NUSSBAUM, M., CUMSILE, P., MARIANOV, V., CORREA, M., FLORES, P., GRAU, V., LAGOS, F., LÓPEZ, X., LÓPEZ, V., RODRIGUEZ, P., & SALINAS, M. (2003). Beyond Nintendo: design and assessment of educational video games for first and second grade students. *Computers and Education*, 40, 71–94.

[74] SCHWARTZ, S. (1988). A comparison of componential and traditional approaches to training reading skills. *Applied Cognitive Psychology*, 2(3), 189–201.

[75] SQUIRE, K. (2003). *Gameplay in context: Learning through participation in communities of Civilization III players.* Unpublished PhD thesis. Instructional Systems Technology Department, Indiana University.

[76] STOLL, C. (1999). *High tech heretic – reflections of a computer contrarian*. New York: First Anchor Books.

[77] SUBRAHMANYAM, K., GREENFIELD, P., KRAUT, R., & GROSS, E. (2001). The impact of computer use on children's and adolescents' development. *Journal of Applied Developmental Psychology*, 22(1), 7–30.

[78] VAN DEVENTER, S.S., & WHITE, J.A. (2002). Expert behavior in children's video game play. *Simulation and Gaming*, 33(1), 28–48.

[79] VAN ECK, R. (2006). Digital Game-Based Learning: It's Not Just the Digital Natives Who Are Restless. *EDUCAUSE Review*, 41 (2), 16-30.

[80] VIAU, R. (1998). *La motivation en contexte scolaire* (2nd ed.). Bruxelles: Èditions de Deboeck.

[81] WALSH, D. (2002). Kids don't read because they CAN'T read. *Education Digest*, 67(5), 29–30.

[82] WEBER, G., & BRUSILOVSKY, P. (2001). ELM-ART: An adaptive versatile system for Web-based instruction. *International Journal of Artificial Intelligence in Education*, 12, 351-384.

[83] WELLER, M.J. (2002). The Use of Narrative to Provide a Cohesive Structure for a Web Based Computing Course. *Journal of Interactive Media in Education*, 1, 1-18.