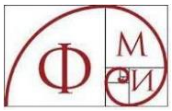
SOFIA UNIVERSITY "ST. KLIMENT OHRIDSKI"
FACULTY OF MATHEMATICS AND INFORMATICS



Yavor Ivanov Dankov

INSTRUMENTS FOR MANAGEMENT AND EVALUATION APPLYING A USER-CENTERED APPROACH FOR THE DESIGN OF VIDEO GAMES FOR EDUCATION

ABSTRACT

of a PhD Thesis
for awarding the PhD Degree
in the Professional field 4.6 Informatics and Computer Sciences,
(Doctoral program "Computer Sciences")

Scientific supervisors:

Prof. PhD Boyan Paskalev Bontchev

Assoc. Prof. PhD Dimitur Yordanov Birov

Sofia
2022

The PhD Thesis was discussed and directed for defense on 17.03.2022, at an extended meeting of the Department of Computing Systems (Temporary joined to Mechatronics, Robotics and Mechanics), Faculty of Mathematics and Informatics (FMI) of the Sofia University "St. Kliment Ohridski" with an extension consisting of Prof. PhD Boyan Paskalev Bontchev, Prof. PhD Ivan Kolev Koichev, Assoc. Prof. Dessislava Georgieva Petrova-Antonova, Assoc. Prof. Milen Yordanov Petrov, Assoc. Prof. Aleksandar Dimov Dimov. The extension of the Department of Computing Systems (Temporary joined to Mechatronics, Robotics and Mechanics), FMI, has been made with the order RD-38-142 / 04.03.2022 of the Rector of Sofia University "St. Kliment Ohridski".

The public defence of the PhD Thesis will take place in an open meeting of scientific jury:

Prof. Boyan Paskalev Bontchev, PhD – Department of Software technologies, FMI, Sofia University

Prof. Angel Atanasov Golev, PhD – Department of Software technologies, FMI University of Plovdiv, Plovdiv

Assoc. Prof. Dessislava Georgieva Petrova-Antonova, PhD – Department of Software technologies, FMI, Sofia University, Sofia

Assoc. Prof. Desislava Antonova Ivanova, PhD – Department of Informatics, FPMI, Technical University of Sofia, Sofia

Assoc. Prof. Boris Blagovestov Shishkov, PhD – Department of Information systems and technologies, FIS, University of Library Studies and Information Technologies, Sofia

The PhD Thesis consists of an introduction, four chapters, a conclusion, a list of the author's scientific publications on the topic of the PhD Thesis, a bibliography, one appendix, and is in a volume of 134 pages. It includes a section of the main contributions of the PhD Thesis, a statement of originality and guidelines for future development. The list of the bibliography used consists of 130 quoted sources. The PhD Thesis contains 24 figures and 17 tables. The numbers in the figures and tables in the abstract correspond to those in the PhD Thesis.

The list of the author's scientific publications on the topic of the PhD Thesis consists of six titles. From these papers, one is published in an international scientific journal (*SJR SCOPUS*) and five are published in international scientific conferences (*SJR SCOPUS*).

The author is a full-time PhD Student at the Department of Computing Systems (Temporary joined to Mechatronics, Robotics and Mechanics) of the Department of Computing Systems (Temporary joined to Mechatronics, Robotics and Mechanics), Faculty of Mathematics and Informatics (FMI) of the Sofia University "St. Kliment Ohridski".

Author: **Yavor Ivanov Dankov**

Title: **"Instruments for Management and Evaluation Applying a User-Centered Approach for The Design of Video Games for Education"**

Sofia, 2022

Table of Contents

GENERAL CHARACTERISTICS OF THE PHD THESIS

Relevance of the Problem

Video games are becoming an integral part of the everyday life of modern man, due to constantly evolving technologies and innovations that enable games to reach the user as quickly as possible. The video game industry is one of the world's leading industries which generates multimillion-dollar revenues each year. Video games affect both the individual and society. This leads to the conclusion that games must contain good messages and values. Modern education is looking for new learning practices and this is where video games for education "come to the rescue" as part of serious games. Video learning games are engaging and attractive, allowing the embedding of learning content from different fields.

Learning strategies can be adapted and customized to the needs of each individual user (learner). The production of educational video games is a process that requires a wide range of diverse resources and this process involves many professionals from different fields. There is a need for instruments (tools) and platforms for the automated construction of educational video games. This leads to the development and emergence of specialized software instruments to support these processes. The instruments are used to create video games (in particular maze video games for education) and support the development of a variety of educational content (including content such as quizzes, puzzles, etc.) to integrate into the video games.

PhD Thesis research is dedicated to the instruments for the design, analysis and evaluation of maze video games for education. The issue of the design of video games for education is raised and in the theoretical part definitions are given for different types of video games, instruments for the management of the design of video games for education, classification and comparative analysis of analytical tools for analysis and evaluation of the design of video games for education.

The practical aspect of the PhD Thesis is to create a specialized taxonomy of software instruments for managing and evaluating the design of video games with a user-centered approach and application of this taxonomy to design these instruments. The PhD Thesis raises the issue of facilitating the process management processes and the appropriate evaluation of these designed video games through instruments that integrate into educational platforms and support and enable people who are not IT specialists, to create and design with ease of educational video games and have the opportunity to analyze and assess the design of the game designed.

Object and Subject of the PhD Thesis

The Object of the PhD Thesis is the study of software instruments for the management of the design and evaluation of video games for education.

The Subject of the PhD Thesis is the study of the analysis, design, integration into software architecture and the practical validation of specific software instruments for the management of the design and evaluation of maze video games for education.

Aim and Tasks of the PhD Thesis

The aim of the PhD Thesis is on the design and validation of instruments for management and evaluation applying a user-centered approach for the design of maze video games for education using a specially designed and created a taxonomy for this purpose.

Tasks of the PhD Thesis

- Research and analysis of video games for education.
- Research and analysis of software instruments for the management of the design and evaluation of video games for education.
- Research and analysis of analytical instruments and definitions related to them.
- Creating a common taxonomy of instruments managing the design and evaluating the design of **educational video games**.
- Creating a specific taxonomy of instruments to manage and evaluate the design of **maze video games for education**.
- Design of instruments functionalities according to the specific taxonomy of instruments for management and evaluation of the design **of maze video games for education.**
- Analysis and description of the business processes of using the designed instruments for the management and evaluation applying a user-centered approach for the design of maze video games for education
- Design of a software architecture of a system for creating maze video games that include the designed tools
- Validation of designed instruments through practical experiments with experimental educational video games developed with these tools.
- Analysing the results of practical experiments.

PhD Thesis Structure

The PhD Thesis consists of an introduction, four chapters, a conclusion, a list of the author's scientific publications on the topic of the PhD Thesis, a bibliography, one appendix, and is in a volume of 134 pages. It includes a section of the main contributions of the PhD Thesis, a statement of originality and guidelines for future development. The list of the bibliography used consists of 130 quoted sources. The PhD Thesis contains 24 figures and 17 tables. The numbers in the figures and tables in the abstract correspond to those in the PhD Thesis.

The list of the author's scientific publications on the topic of the PhD Thesis consists of six titles. From these papers, one is published in an international scientific journal (*SJR SCOPUS*) and five are published in international scientific conferences (*SJR SCOPUS*).

BRIEF CONTENT OF THE PHD THESIS

CHAPTER 1. CONTEMPORARY STATE OF THE STUDY AREA

Chapter 1. “Contemporary State of the Study Area” presents video games and their role in the modern world. The design of video games for education, instruments for the management of the design and analytical instruments and the corresponding definitions related to them are also analyzed.

The following conclusions can be drawn from the studies carried out in Chapter 1:

- Important factors that contribute to the continual development of video games are the digitization of human households, as well as the entry of new technologies and methods of interaction with people. Video games are becoming more and **more popular** and become an integral part of the everyday life of modern man and have a great impact on consumers. The video game industry shows that they **reach a broad audience from users** with a variety of features such as gender, age, skills, preferences, interests, and so on. Therefore, it is necessary to create **more educational video games** that **contain pedagogical messages**.
- To achieve the desired **educational goals**, users who design and create video games for education (who are not information technology specialists) need to have appropriate instruments to support the design and management and to provide opportunities for analysis and evaluation of the design of educational video games.
- To achieve the desired **educational purpose**, it is possible to include instruments that enable **personalization of the content** of educational games to the characteristics of learners who are designed as well as the **ability to adapt the gameplay**.
- In the process of designing educational games, as well as a result of game sessions, a large amount of data is generated that has to be processed. This requires designing instruments for **effective analysis and evaluation of the design** of video games. Therefore, the use of analytical instruments for analyzing and evaluating video games for education contributes to improving the design of the projected educational games.
- From the studies made on the management, analysis and evaluation instruments of educational video games, it is concluded that most of them do not provide the opportunity to use by users who are not information technology specialists.

CHAPTER 2. TAXONOMY OF INSTRUMENTS FOR MANAGEMENT AND EVALUATION OF DESIGN OF VIDEO GAMES FOR EDUCATION

Chapter 2. “Taxonomy of Instruments for Management and Evaluation of Design of Video Games for Education” presents the challenges and principles in taxonomy development. A common taxonomy of software instruments for managing and evaluating the design of video games for education is designed. Based on that taxonomy, a specialized TIMED-VGE taxonomy of software tools for managing and evaluating the design of video games for education has been developed which can be used for all kinds of educational maze video games.

2.1. Taxonomy of Instruments for Management and Evaluation Applying a User-Centered Approach for The Design of Video Games for Education

Chapter 1 of the PhD Thesis presents and analyses the taxonomies of video games and serious video games, but no easily accessible taxonomies of instruments for management and evaluation of video games have been found. The presence of such taxonomy would support designers of educational platforms to carefully plan all processes and include the instruments required to support the management and evaluation processes of designed educational games (Dankov and Bontchev, 2020).

In the current PhD Thesis, the **user-centered design approach** for designing educational video games is closely related to the **User Experience**, as well as the **main factors of the user experience** in the games. The factors of user experience are (Dankov et al., 2022a): **Playability, Usability and Learnability.**

The approach is among the most suitable for use in the design of educational video games and the satisfaction of the specific educational needs of learners, achieving the desired results and is mainly focused on: **user behaviour**; **user satisfaction** and **general feedback** from game users.

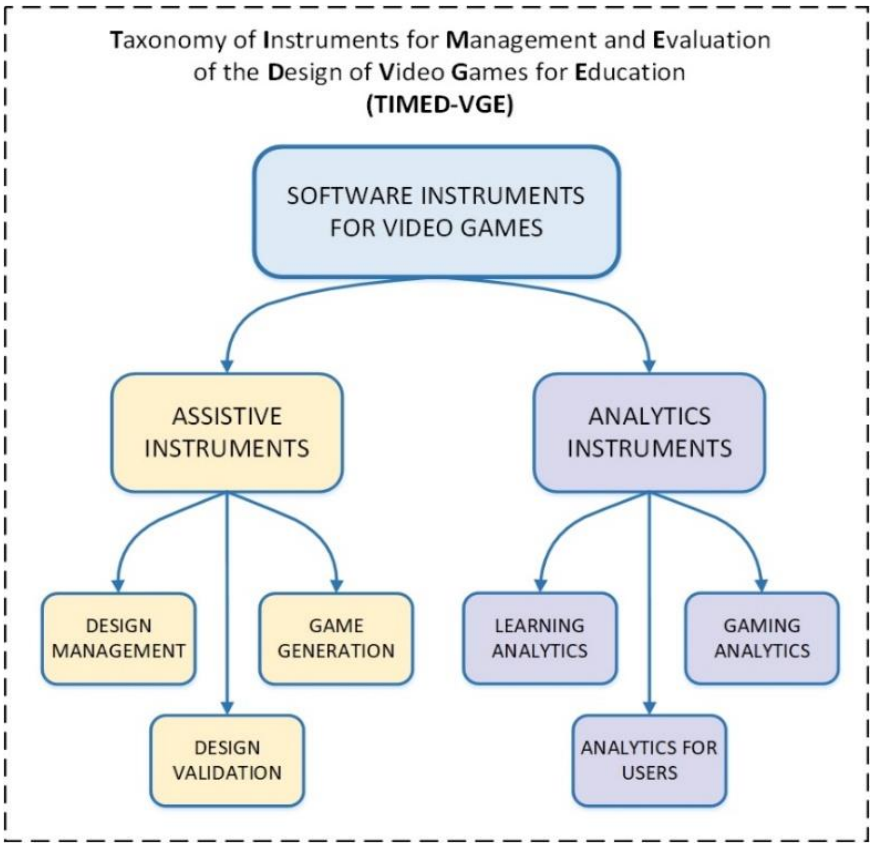


Figure 6. Taxonomy of Instruments for Management and Evaluation of the Design of Video Games for Education (TIMED-VGE)
(Dankov and Bontchev, 2020)

This PhD Thesis proposes the following taxonomy depicted in Figure 6 with the name **"Taxonomy of Instruments for Management and Evaluation of Design of Video Games for Education (TIMED-VGE)"** (Dankov and Bontchev, 2020). In order to facilitate the use of the name, the taxonomy will be used in the text as **TIMED-VGE taxonomy.**

The TIMED-VGE taxonomy presents the hierarchical classification of management tools and evaluation of the design of educational video games (Dankov and Bontchev, 2020). Figure 6 illustrates the presentation of the taxonomy. Using generalization and specialization

approaches, the taxonomy presents the main tools for managing and evaluating video games for education as well as the main relationship between the categories in taxonomy. The choice of the taxonomy name is targeted on these functionalities and semantics of these tools.

The main category in the TIMED-VGE taxonomy is the "**Software Instruments for Video Games**". This is the top class of the taxonomy. It contains all other subcategories of instruments. In designing and creating educational video games, many challenges are available for their successful realization (Dankov and Bontchev, 2020). Among the major challenges can be:

- Design and development of the game in an effective way as a tool for education and entertainment;
- Analyzing and evaluating the learner and player results from the game sessions.

Therefore, taxonomy offers two basic subcategories on the second level of taxonomy:

- **"Assistive Instruments**";
- **"Analytics Instruments**".

The "Assistive instruments" category classifies the main instruments for managing design processes in the initial development of video games. This category contains three basic subcategories of the third level of the taxonomy. These are:

- **"Design Management";**
- **"Design Validation";**
- **"Game Generation".**

The "Analytics Instruments" category provides the inclusion of multiple analytics software instruments that provide opportunities and monitoring functionalities (Vanthienen et al., 2017; Somani and Deka, 2017; Dankov and Birov, 2018), processing, analyzing all available data and their visualization (Peña-Ayala, 2017; Thomas and Cook, 2005; Keim et al., 2008), through a variety of data visualization techniques (Keim et al., 2010; Dill et al., 2012; Suh and Anthony, 2017). This category contains three basic subcategories of the third level of taxonomy, namely:

- **"Learning Analytics";**
- **"Gaming Analytics";**
- **"Analytics for Users".**

The taxonomy TIMED-VGE and the instruments for the management of the design and evaluation of educational video games are beneficial to designers, consumers and stakeholders. The instruments contribute to a better understanding of the system, the rapid learning of educational content from learners and improving their gaming experience, which in turn leads to significant benefits for game-based learning (Dankov and Bontchev, 2020).

For these reasons, dealing with the challenges of taxonomy development and problems related to educational video games, the current PhD Thesis offers precisely the TIMED-VGE taxonomy, which brings together the instruments, distributing them in two directions:

- **Instruments that support the design and management of the design;**
- **Analytics instruments for analyzing and evaluating the design of educational video games.**

The TIMED-VGE taxonomy could be used as the starting point for designing, creating and integrating the most suitable instruments in platforms (for video games for education) to support and improve processes of analysis and evaluation, design and development of improved educational video games (including educational video games with personalized and high-quality educational content combined with the adaptability of the gameplay process and improved user experience). This also enables those skilled in the field of information technology to use these tools and platforms. This also allows people who are not information technology specialists to use these tools and platforms.

2.2. Specialised TIMED-VGE Taxonomy for Maze Video Games for Education

This PhD Thesis proposes a specialized taxonomy depicted in Figure 7, named **"Specialized Taxonomy of Instruments for Management and Evaluation of the Design of Maze Video Games for Education (Specialized TIMED-VGE)" (**Dankov and Bontchev, 2020). In order to facilitate the use of the name, the taxonomy will be used in the text as **specialized TIMED-VGE taxonomy.**

The **specialized TIMED-VGE taxonomy** presents software instruments for the management and evaluation of the design of maze video games for education.

Taxonomy presents software tools for managing and evaluating the design of labyrinth educational video games. For this reason, the classified instruments for managing and evaluating these games are presented in the main categories of the taxonomy. There are the main categories of instruments as described in the previous part of this chapter. The two main directions of the TIMED-VGE taxonomy are preserved, but in the **specialized TIMED-VGE taxonomy**, **they are specifically targeted at maze video games for education**. These directions include:

1) **Instruments that support the design and management of maze video games for education and;**
2) **Analytics instruments for analysing and evaluating the design of maze video games for education.**

In the **specialized TIMED-VGE taxonomy** the instruments for management and evaluation of the design of maze video games for education are distributed in each of the listed subcategories. The taxonomy presents the classification of these instruments allocated in the categories "**Assistive Instruments"** and "**Analytics Instruments**".

In the **specialized TIMED-VGE taxonomy,** the category "**Assistive Instruments"** includes two subcategories:

- **"Design Management";**
- **"Game Design Validation and Generation".**

The "**Design Management**" category classifies the instruments for supporting and managing the design of educational video games, applying user-centered approach. The following tools are classified in this category

1. **"Maze Game Designer";**
2. **"Learning Content Manager";**
3. **"Gaming Content Manager)";**
4. **"(Additional Features";**
   - 4.1. **"Adaptation/Personalization Configurator";**
   - 4.2. **"NPC Configurator".**

The "**Game Design Validation and Generation**" category is the second subcategory of "Assistive Instruments" of specialized TIMED-VGE taxonomy. These instruments support the management and validation of the design of maze video games for education. In the "**Game Design Validation and Generation**" category, the following software instruments are classified:

1. **"Design Validator";**
2. **"Generator Valid Game of Descriptions";**
3. **"Maze Builder Plugin";**
4. **"Game Builder";**
5. **"Game Deployer".**

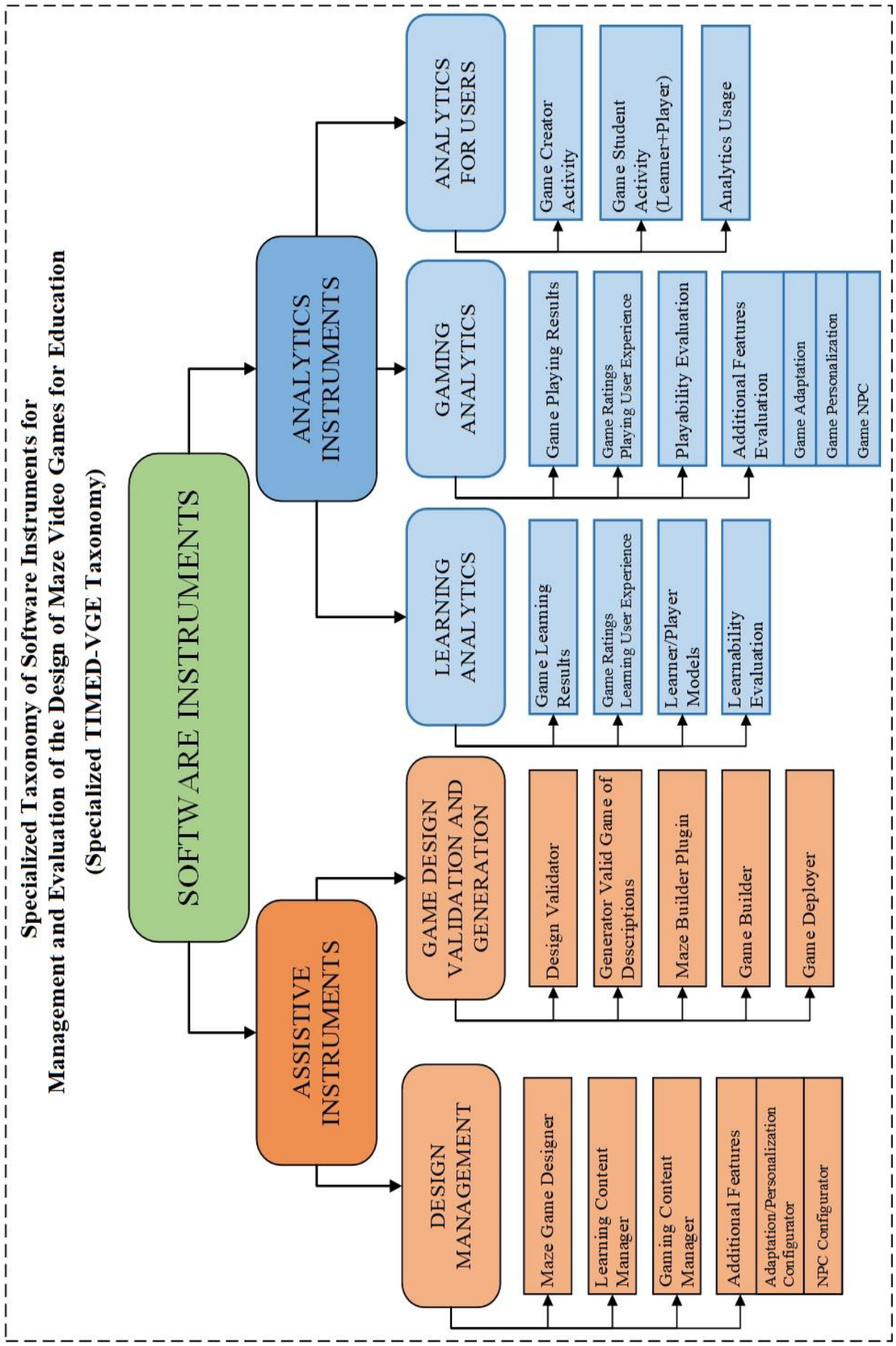


Figure 7. Specialized Taxonomy of Instruments for Management and Evaluation of the Design of Video Maze Games for Education (Specialized TIMED-VGE) (Dankov and Bontchev, 2020)

In the **specialized TIMED-VGE taxonomy,** the "Analytics Instruments" category classifies the instruments for analysis and evaluation of the design of maze video games for education, applying user-centered design approach. The category classifies the following software instruments:

- **"Learning Analytics";**
- **"Gaming Analytics";**
- **"Analytics for Users".**

The **"Learning Analytics**" category classifies the analytics instruments that focus on data about learning, learners, training and optimization and improvement opportunities, etc. The category classifies the following software instruments:

1. **"Game Learning Results";**
2. **"Game Ratings Learning User Experience";**
3. **"Learner/Player Models";**
4. **"Learnability Evaluation".**

The **"Gaming Analytics**" category classifies the analytics instruments that focus on data about the game and players, gameplay and user experience, and also on the application of different game metrics on data. The analytics instruments enable the analysis of data about the game and the assessment of the design of maze video games for education. The category classifies the following software instruments:

1. **"Game Playing Results";**
2. **"Game Ratings Playing User Experience";**
3. **"Playability Evaluation";**
4. **"Additional Features Evaluation":**
   - **4.1. "Game Adaptation";**
   - **4.2. "Game Personalization";**
   - **4.3. "Game NPC.**

The **"Analytics for Users**" category provides an additional opportunity for the integration of analytics instruments to analyze and evaluate the design of educational video games by applying user-centered approach. Depending on the specific requirements and goals of the users (in the role of gaming designers), as well as users in the role of stakeholders in the design process, there is the possibility of using and integrating the tools from the **"Analytics for Users**" category. The category classifies the following software instruments:

1. **"Game Creator Activity";**
2. **"Game Student Activity (Learner + Player)";**
3. **"Analytics Usage".**

2.3. Conclusions

Chapter 2 presented a taxonomy of software instruments for the evaluation and management of the design of video games for education, applying user-centered approach. The conclusions of the development of this taxonomy as well as its version, which specializes in maze video games for education, can be summarized as follows:

- The **common taxonomy** allows being used for supporting the design of video games from various genres – not only for **serious games** (such as video games for education) but also for **entertaining video games**.
- The possibilities of the **specialized taxonomy** can be tailored to **any kind of maze video game for education**.
- The **specialized taxonomy** also enables to be applied for the development of **entertainment video games** without including the "Learning Content Manager".
- Essential for the assessment of taxonomy usability it is to be **applied in a specific software platform** for the development of educational video games.

CHAPTER 3. APPLICATION OF THE SPECIALIZED TIMED-VGE TAXONOMY IN THE APOGEE PLATFORM

Chapter 3 “Application of the Specialized TIMED-VGE Taxonomy in the APOGEE Platform” presents the use of the specialized TIMED-VGE taxonomy for the design of software instruments for management and evaluation of maze video games for education in the APOGEE platform. The platform is presented and the designed functionalities of the software instruments are described in detail. An analysis and description have been made of the business processes of using the designed software instruments for management and evaluation, applying user-centered approach for the design of maze video games for education in the APOGEE platform. The software architecture of the APOGEE platform has been designed, which includes the designed software instruments and the architecture is used for the practical creation of the platform within the APOGEE project.

3.1. APOGEE Online Software Platform for Creating and Using Maze Video Games for Education

The scientific research and applied project APOGEE (smArt adaPtive videO GamEs for Education), (http://apogee.online/index-en.html). The project started in 2017 and lasts until July 2022. Among the main goals of the project is the creation of an innovative open-access software platform that will enable professionals such as teachers and educators (including those who do not are specialists in information technology) to design, create and automatically generate maze video games for education, as well as to customize the educational content of video games. These games are created on the basis of a formal descriptive model of the game, presenting the semantics of the structure of the game and the didactic content (Bontchev, Vassileva and Dankov, 2019).

The online platform APOGEE allows the automated creation of maze video games for education. This type of game is a three-dimensional maze game, consisting of many halls connected by doors. In the halls of the maze can be presented rich multimedia educational content with didactic orientation, through (Bontchev, Vassileva and Dankov, 2019): boards on the walls of the maze, with educational content; various types of mini-games with integrated educational content, implementing specific educational tasks; integration of audio and visual educational content in the halls of the maze; additional opportunities such as the integration of virtual players to help players/learners, such as answering their educational questions (Bontchev, Vassileva and Dankov, 2019).

The game has a **defined goal and predefined rules** defined by the designer (creator of the game). The maze can include many different mini-games with educational content, implemented in separate halls of the maze. Mini-games can be **two-dimensional** or **three-dimensional**. The learner/player receives a certain number of points for each successfully completed activity in the game, such as: answering the questions for opening the door to the next room; playing mini-games in the halls; finding all the hidden objects in the halls of the maze; the successful passage of the whole maze and others.

In the initial stages of the development of the APOGEE software platform, the creation of educational maze video games for education in the platform, in general, goes through the processes of **design**, **generation** and **validation** (Bontchev, Vassileva and Dankov, 2019).

Therefore, in the process of development and development of the APOGEE platform, there is a need to develop specialized instruments to integrate into the platform and **provide the ability to manage, analyze and evaluate the design** of maze video games for education and by **users, who are not specialists in the field of information technology**. These software instruments should provide a more accessible way to design games, be user-oriented and

provide an opportunity to analyze and evaluate the designed maze video games for education in the platform.

3.2. Features of the Analysis and Design of Software Instruments for Management and Evaluation of the Design of Educational Video Games in The APOGEE Platform

3.2.1. Use of Specialized TIMED-VGE taxonomy

To test the usability of the **specialized TIMED-VGE taxonomy**, this taxonomy is used for the design of software instruments for management and evaluation of the design of maze video games for education in the APOGEE platform.

The specialized TIMED-VGE taxonomy and the software instruments included in it are designed for **management, analysis and evaluation of the design of maze video games for education, applying user-centered approach**. It provides an opportunity for both professionals and non-IT specialists to use the tools included in it. Therefore, this taxonomy is suitable for the APOGEE platform, as certain instruments of the taxonomy support the processes of designing maze video games for education. They enable the third category of users (game designers) in the APOGEE platform, and in particular, those users who have no experience in the field of markup languages, to design video games in a more accessible way. On the other hand, the tools provide opportunities to analyze and evaluate the designed video games on the platform. This enables the three main categories of user-designers (described in Section 3.1 of the PhD Thesis) of video games in the APOGEE platform, based on the results of the game sessions, to analyze and evaluate the design of their designed games and, if necessary, improve game design.

Therefore, using the **specialized TIMED-VGE taxonomy** in the APOGEE platform, all the software instruments included in it are designed. When integrating the instruments of the **specialized TIMED-VGE taxonomy**, the platform is enriched with all the functionalities and capabilities provided by these tools. These are the software instruments in the categories: "Assistive Instruments" and "Analytics Instruments ". The specialized taxonomy is described in detail and presented in Chapter 2, and the designed functionalities of these tools are presented in Section 3.3 of this Chapter.

3.2.2. Using User-Centered Approach

The use and integration of all instruments from the **specialized TIMED-VGE taxonomy** in the APOGEE platform support the overall process of creating, analyzing and evaluating the design of video games for education in the platform. In particular, these software instruments support the creators (game designers) in the design processes, with a user-centered (learner/player) approach and design management, as well as the processes of analysis and evaluation of the design of maze video games for education. As a result, the integrated software instruments in the platform support the overall process of creating a video game using the user-centered approach in the APOGEE platform, illustrated in Figure 10 (Bontchev, Antonova, Terzieva and Dankov, 2022).

The integration of all software instruments in the platform supports the entire process of creating a video game, using a user-centered approach in the APOGEE platform. This process is enriched with all the features and functionalities that the software instruments provide. The diagram illustrates the life cycle of development and evaluation of a maze video game for education, applying a user-centered approach using the software instruments from the specialized TIMED-VGE taxonomy in the APOGEE platform The diagram consists of two parts that represent this cyclical process in varying degrees of abstraction.

At the top of the diagram is an overview of the process of creating, analyzing and evaluating the design of an educational video game, using a user-centered approach (User-Centered Design Overview). This part of the diagram shows, in the most abstract form, the main modules of the life cycle of video game development and evaluation, using this approach, presented as interconnected yellow ovals and their corresponding names.

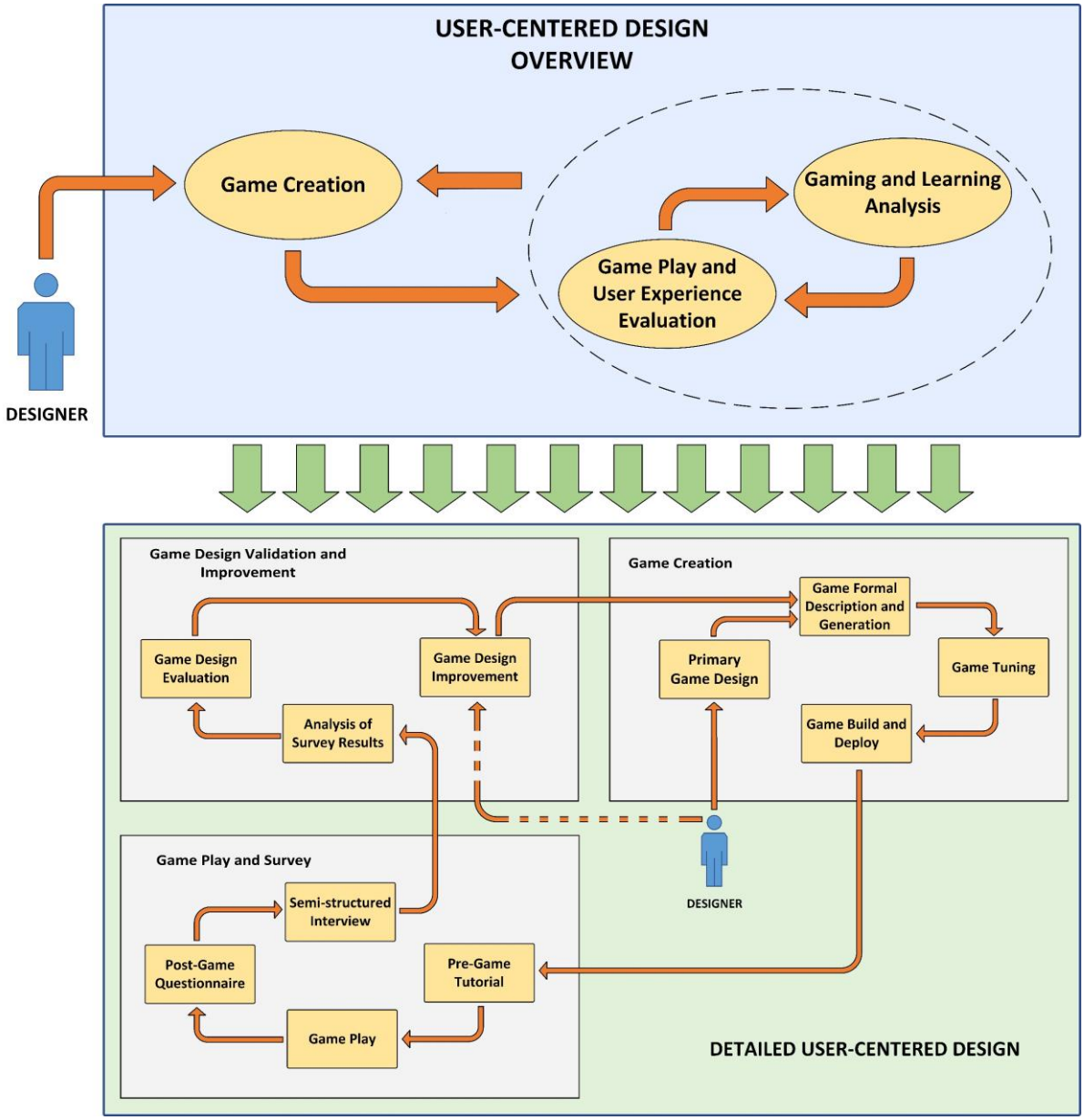


Figure 10. The life cycle of development and evaluation of a maze video game for education, applying a user-centered approach using the software instruments from the specialized TIMED-VGE taxonomy in the APOGEE platform (Bontchev, Antonova, Terzieva and Dankov, 2022)

At the bottom of the diagram (Figure 10), a detailed view of the process of creating, analyzing and evaluating the design of an educational video game applying user-centered approach (Detailed User-Centered Design) is presented. This part of the diagram depicts the main stages of the life cycle of development and evaluation of video games in the APOGEE platform using this approach:

- **Stage 1: Game Creation,** consisting of four modules:
  - **Module 1.1. Primary Game Design;**
  - **Module 1.2. Game Formal Description and Generation;**

- **Module 1.3. Game Tuning;**
- **Module 1.4. Game Build and Deploy.**

- **Stage 2: Game Play and Survey,** consisting of four modules:
  - **Module 2.1. Pre-Game Tutorial;**
  - **Module 2.2. Game Play;**
  - **Module 2.3. Post-Game Questionnaire;**
  - **Module 2.4. Semi-Structured Interview.**
- **Stage 3: Game Design Validation and Improvement,** consisting of three modules:
  - **Module 3.1. Analysis of Survey Results;**
  - **Module 3.2. Game Design Evaluation;**
  - **Module 3.3. Game Design Improvement.**

The difference between the two views is expressed in the degree of abstraction of the representation of this cyclical process. The three abstract modules are presented in more detail as three main stages of the life cycle of video game development and evaluation in the APOGEE platform, using a user-centered approach and integrated software instruments from the specialized TIMED-VGE taxonomy. The software instruments support all stages, thanks to the functionalities and capabilities they provide to the platform.

3.3. Software Instruments for Management and Evaluation of The Design of Video Games for Education in The APOGEE Platform

In this section, the PhD Thesis aims to present the designed functional requirements for the software instruments for management and evaluation of the design of maze video games for education, **using the specialized TIMED-VGE taxonomy** in the APOGEE platform. Based on the presented features of the analysis, discussed in Section 3.2. of this Chapter 3, and using the **specialized TIMED-VGE taxonomy** in the APOGEE platform, the functionalities of all instruments included in it are designed. These are the tools in the categories "Assistive Instruments" and "Analytics Instruments".

3.3.1. Functional Requirements

The software instruments in the “Assistive Instruments” category consist of two sub-categories. These are the software instruments from the subcategories: “**Design Management**” and “**Game Design Validation and Generation**”. Using **specialized TIMED-VGE taxonomy** in the APOGEE platform, the main functionalities of these software instruments are designed.

Table 4 presents the designed functionalities of the software instruments from the category “**Design Management**” of the **specialized TIMED-VGE taxonomy** in the platform APOGEE, based on (Dankov and Bontchev, 2021a). Five software instruments with the respectively designed functionalities are presented.

Table 4. Functionalities of the software instruments from the category "Design Management" of the specialized TIMED-VGE taxonomy in the APOGEE platform
(Dankov and Bontchev, 2021a)

INSTRUMENTS FROM THE "DESIGN MANAGEMENT" CATEGORY	FUNCTIONALITIES OF THE SOFTWARE INSTRUMENTS
MAZE GAME DESIGNER	Choice of the number of maze halls
	Choice of maze connectivity
	Choice of the overall visual arrangement of each maze hall
	Choice of the overall audio arrangement in each maze hall and each mini-game
	Selection of existing learning boards and their distribution in the halls of the maze
	Selection of existing mini-games, their properties and their distribution in the halls of the maze
LEARNING CONTENT MANAGER	Creation of learning content
	Reading and selection of learning content
	Update of learning content
	Deletion of learning content
GAMING CONTENT MANAGER	Creation of gaming content
	Reading of gaming content
	Update of gaming content
	Deletion of gaming content
ADAPTATION/ PERSONALIZATION CONFIGURATOR	Choice of adaptive gameplay
	Tuning of dynamic adaptive game features
	Choice of personalized learning content
	Tuning/Recommendation of personalized gaming/learning content
NPC CONFIGURATOR	Selection of NPC for each maze hall
	Choice of distribution and settings for Non-Player Characters (NPC) in the halls of the maze

Table 5 presents the designed functionalities of the software instruments from the category "**Game Design Validation and Generation**" of the **specialized TIMED-VGE taxonomy** in the platform APOGEE, based on (Dankov and Bontchev, 2021a). Five software instruments with the respectively designed functionalities are presented.

Table 5. Functionalities of the software instruments from the category "Game Design Validation and Generation" of the specialized TIMED-VGE taxonomy in the APOGEE platform (Dankov and Bontchev, 2021a)

INSTRUMENTS FROM THE "GAME DESIGN VALIDATION AND GENERATION" CATEGORY	FUNCTIONALITIES OF THE SOFTWARE INSTRUMENTS
DESIGN VALIDATOR	Validation of the game design according to the rules of the formal description of the game
	Validate the structure of the maze
	Validate the overall content availability arrangement of each maze hall
	Validate overall spatial arrangement in each maze hall
	Read and validate an external mini-game description
	Validate mini-games and their properties
	Validate adaptation/personalization and their properties
	Validate NPC and their settings
GENERATOR OF VALID GAME DESCRIPTIONS	Generate document of the valid game description
	Generate archive, containing all game assets for further game generation
	Download valid game description
	Read valid game description
	Delete valid game description
MAZE BUILDER PLUGIN - UNITY 3D	Insert of game visual assets
	Insert of game audio assets
	Insert and Read XML game description and verify it
	Generate maze game modules from valid game description
	View and tuning of maze game modules
GAME BUILDER – UNITY 3D	Generate/build an executable file to view the game
GAME DEPLOYER – UNITY 3D	Deploy the game - Generate/build a game executable file for a particular platform.

Table 6 presents the designed functionalities of the software instruments from the category "**Learning Analytics**" of the **specialized TIMED-VGE taxonomy** in the platform APOGEE,

based on (Dankov and Bontchev, 2021). Four software instruments with the respectively designed functionalities are presented.

Table 6. Functionalities of the software instruments from the category "Learning Analytics" of the specialized TIMED-VGE taxonomy in the APOGEE platform (Dankov and Bontchev, 2021)

INSTRUMENTS FROM THE "LEARNING ANALYTICS" CATEGORY	FUNCTIONALITIES OF THE SOFTWARE INSTRUMENTS
INSTRUMENT FOR GAME LEARNING RESULTS	Selection of data metrics for game learning results
	View individual learning results of the game
	View the overall learning results of the game
	View dependencies (correlations)
INSTRUMENT FOR GAME RATINGS AND LEARNING USER EXPERIENCE	Selection of data metrics for game ratings about **learning user experience**
	View game ratings for learning user experience
	Selection of questionnaire for game ratings about learning user experience
	View dependencies (correlations)
INSTRUMENT FOR LEARNER / PLAYER MODELS	Selection and read of learner/player models
	Creation of learner/player models
	Update of learner/player models
	Deletion of learner/player models
	View dependencies (correlations)
INSTRUMENT FOR LEARNABILITY EVALUATION	Evaluation of overall game personalization, about the learnability
	View dependencies (correlations) between a personalized game and the same game without personalization, about the **learning user experience**
	View dependencies (correlations)

Table 7 presents the designed functionalities of the software instruments from the category "**Gaming Analytics**" of the **specialized TIMED-VGE taxonomy** in the platform APOGEE, based on (Dankov and Bontchev, 2021). Six software instruments with the respectively designed functionalities are presented.

Table 8 presents the designed functionalities of the software instruments from the category "**Analytics for Users**" of the **specialized TIMED-VGE taxonomy** in the platform APOGEE, based on (Dankov and Bontchev, 2021). Three software instruments with the respectively designed functionalities are presented.

Table 7. Functionalities of the software instruments from the category "Gaming Analytics" of the specialized TIMED-VGE taxonomy in the APOGEE platform
(Dankov and Bontchev, 2021)

INSTRUMENTS FROM THE "GAMING ANALYTICS" CATEGORY	FUNCTIONALITIES OF THE SOFTWARE INSTRUMENTS
INSTRUMENT FOR GAME PLAYING RESULTS	Selection of data metrics for game playing results for games without learning content.
	View individual game playing results of games without learning content.
	View the overall game playing results of games without learning content.
	View dependencies (correlations)
INSTRUMENT FOR GAME RATINGS AND PLAYING USER EXPERIENCE	Selection of data metrics for game ratings about **playing user experience** of games without learning content.
	View game ratings for playing user experience of games without learning content
	Selection of questionnaire for game ratings about playing user experience of games without learning content.
	View dependencies (correlations)
INSTRUMENT FOR PLAYABILITY EVALUATION	View dependencies (correlations) between pre-defined game objectives and the results of the data of the individual achievements of the users regarding the **playability**
	View dependencies (correlations)
INSTRUMENT FOR GAME ADAPTATION EVALUATION	Evaluation of the overall adaptation of the game
	View dependencies (correlations) between an adapted game and the same game without adaptation, regarding the **gaming experience**
	View dependencies (correlations)
INSTRUMENT FOR GAME PERSONALIZATION EVALUATION	Evaluation of the overall personalization of the game
	View dependencies (correlations) between a personalized game and the same game without personalization, regarding the gaming experience
	View dependencies (correlations)
INSTRUMENT FOR GAME NPC EVALUATION	Evaluation of NPC in game
	View dependencies (correlations) between the game with NPC and a similar game without one, regarding the gaming experience
	View dependencies (correlations)

Table 8. Functionalities of the software instruments from the category "Analytics for Users" of the specialized TIMED-VGE taxonomy in the APOGEE platform
(Dankov and Bontchev, 2021)

INSTRUMENTS FROM THE "ANALYTICS FOR USERS" CATEGORY	FUNCTIONALITIES OF THE SOFTWARE INSTRUMENTS
INSTRUMENT FOR GAME CREATOR ACTIVITY	View data for other usage activities of creator
	Save data about the activities of creator
INSTRUMENT FOR GAME STUDENT ACTIVITY - LEARNER + PLAYER	View data about the activities of users (learners / players) in the game
	Save data about the activities of users (learners / players) in the game
INSTRUMENT FOR ANALYTICS USAGE	View data for other usage activities
	Save data for other usage activities

All software instruments in this category provide users with the ability to monitor, analyze and visualize data for the respective defined activities. Depending on the defined user profiles in the platform, the respective user can use a software instrument from the category "Analytics for users" and their functionalities. There are three main categories of users in the APOGEE platform with their respective profiles:

- Users as Game designers;
- Users as learners and players;
- Administrator responsible for the software support of the platform.

Along with the functional requirements of the designed software instrument, the quality requirements are analyzed, which include performance, scalability, reliability, portability, usability, which, however, are not the subject of this PhD Thesis.

3.3.2. Business Modelling of Processes for Managing and Evaluating the Design of Video Games for Education Using a User-Centered Approach

Based on the presented software instruments and their functionalities, the current section of the abstract of the PhD Thesis presents the business modelling of the processes for management and evaluation of the design of educational video games for education using a user-oriented approach in the APOGEE platform.

The diagram illustrated in Figure 11 presents the software instruments and the main processes in the APOGEE platform for the management and evaluation of the design of educational video games using a user-centered approach. The diagram is authored and developed on the basis of (Bontchev, Antonova and Dankov, 2020). A detailed description of the instruments and their functionalities is presented in the previous parts of the PhD Thesis.

As presented in the previous parts of the PhD Thesis, there are three main categories of users of the APOGEE platform who can use the functionalities and software instruments of the platform through predefined profiles. Therefore, these are the defined profiles (represented in

the diagram as light blue rectangles) and the corresponding users in the platform who use these profiles:

- **"Game Creator Profile"**. This profile is intended for users defined as **game designers;**
- **"Student Profile".** This profile is intended for users defined as **players and learners** on the platform;
- **"Admin Profile".** Used by **users-administrators** on the platform responsible for software support.

Depending on their profile, each user can use a limited set of features provided by the platform. Defining a user profile is done with pre-registration.

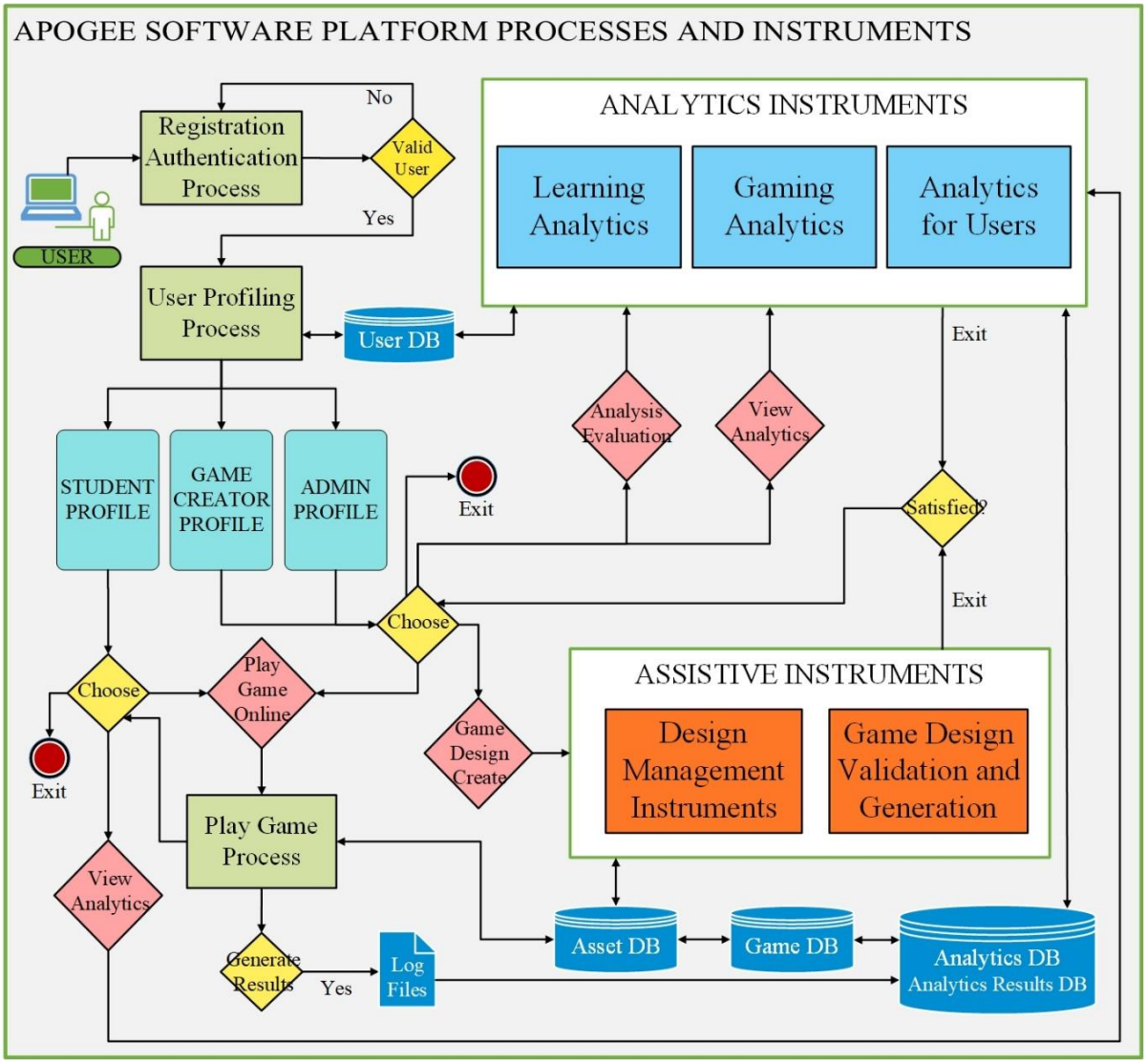


Figure 11. Business processes and software tools in the APOGEE platform, based on (Bontchev, Antonova and Dankov, 2020)

The following diagrams provide a detailed view of the use of software instruments of the "Design Management" and "Analytics Instruments" categories. The functionalities of these tools are described in detail and presented in the previous parts of the PhD Thesis.

Figure 12 presents a **detailed view of the business process of using** the design management software instruments, and Figure 13 presents a **detailed view of the business process of using the software instruments for analysis and evaluation** of maze video games for education with a **user-centered approach** in the APOGEE platform.

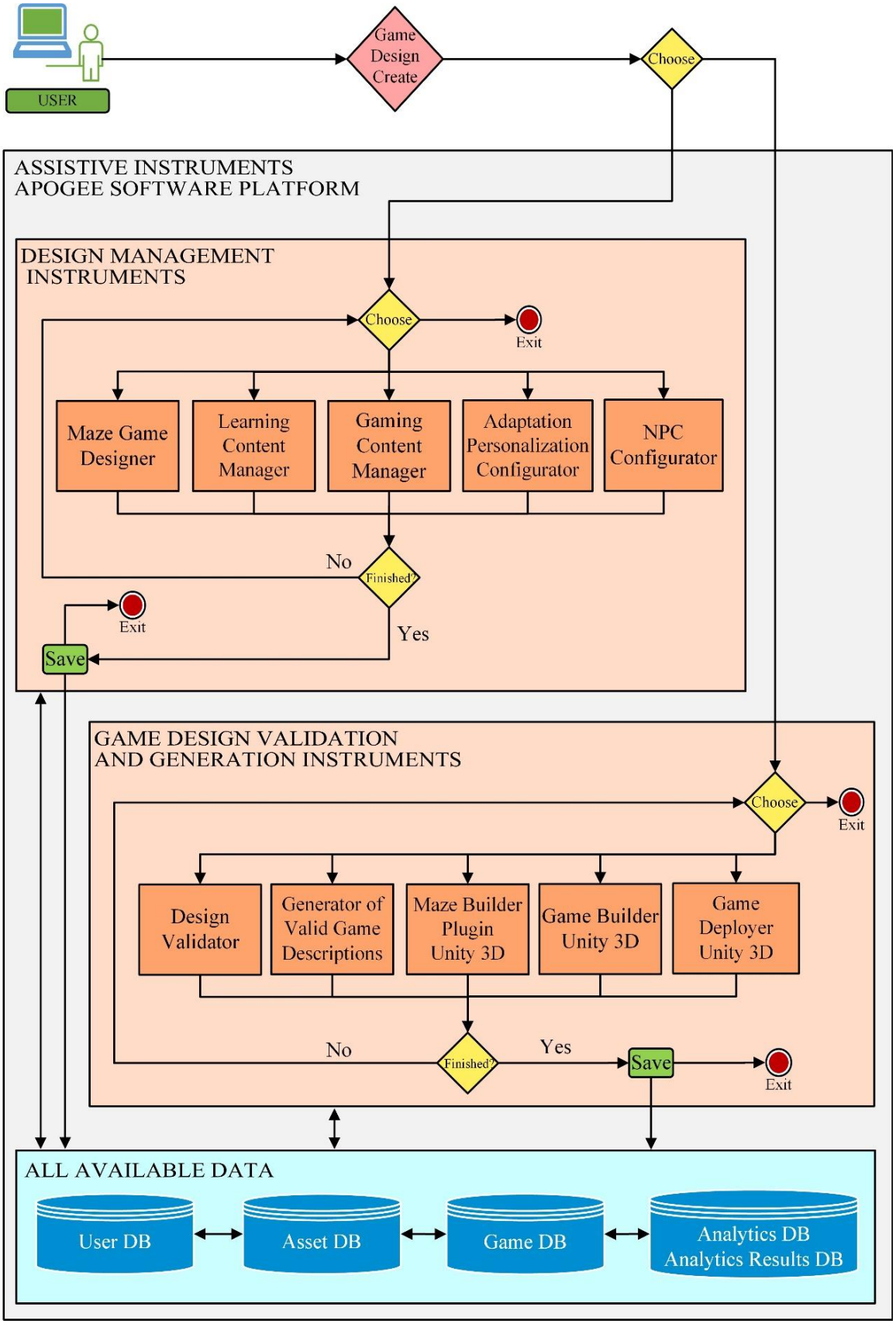


Figure 12. "Assistive Instruments" in the APOGEE platform for managing the processes of designing educational video games, with a user-centered approach

Figure 14 presents a **detailed view of the business process** in the APOGEE platform, focused on the **analysis and evaluation of the design of educational video games, with a user-centered approach**. The diagram provides a detailed description of this process.

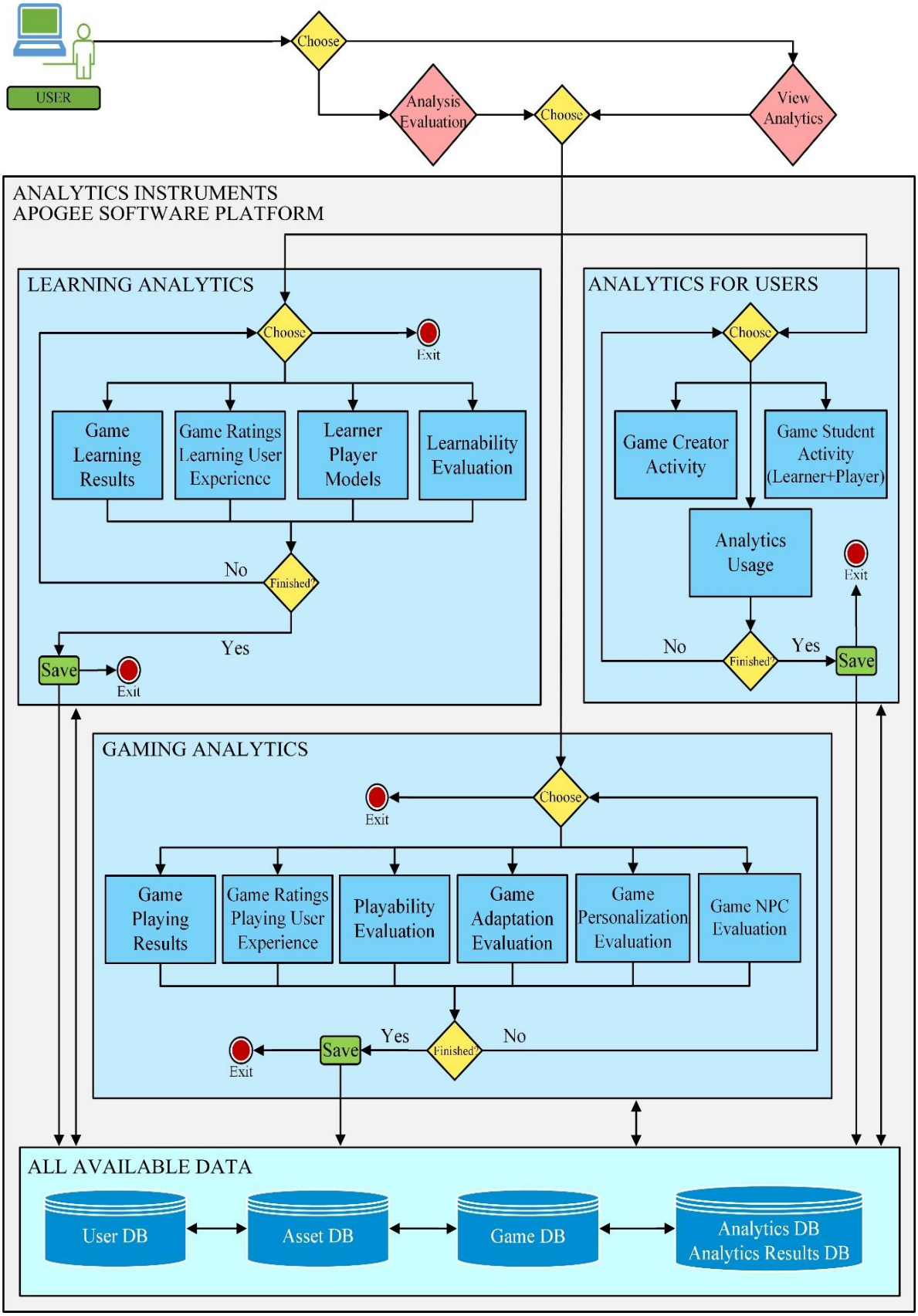


Figure 13. "Analytics tools" in the APOGEE platform for analysis and evaluation of the processes of designing educational video games, with a user-centered approach

The emphasis is placed on the use of analytics instruments and their functionalities from the instruments from "Learning Analytics" and "Game Analytics" categories. Figure 14 shows the summarized processes presented in Figure 11, Figure 12 and Figure 13.

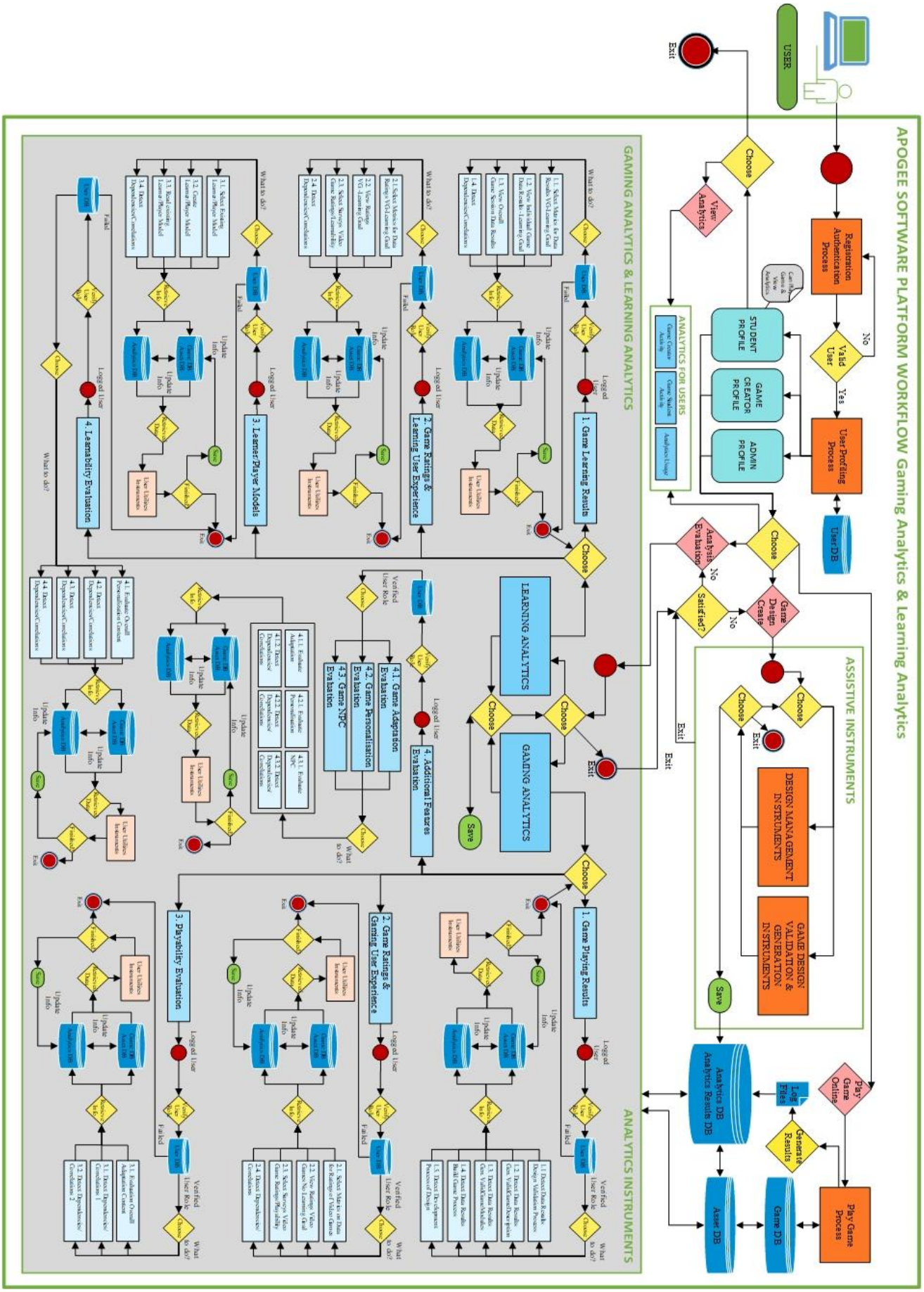


Figure 14. Detailed view of the business process in the APOGEE platform focused on the analysis and evaluation of the design of educational video games, with user-centered approach

3.3.3. The Software Architecture of The APOGEE Platform

As a result of the application of the specialized TIMED-VGE taxonomy in the platform, in order to develop software instruments and their functionalities, the software architecture of the APOGEE platform was designed. The software architecture of the APOGEE platform, with its integrated software instruments for managing and evaluating the design of maze video games for education, is presented in Figure 15.

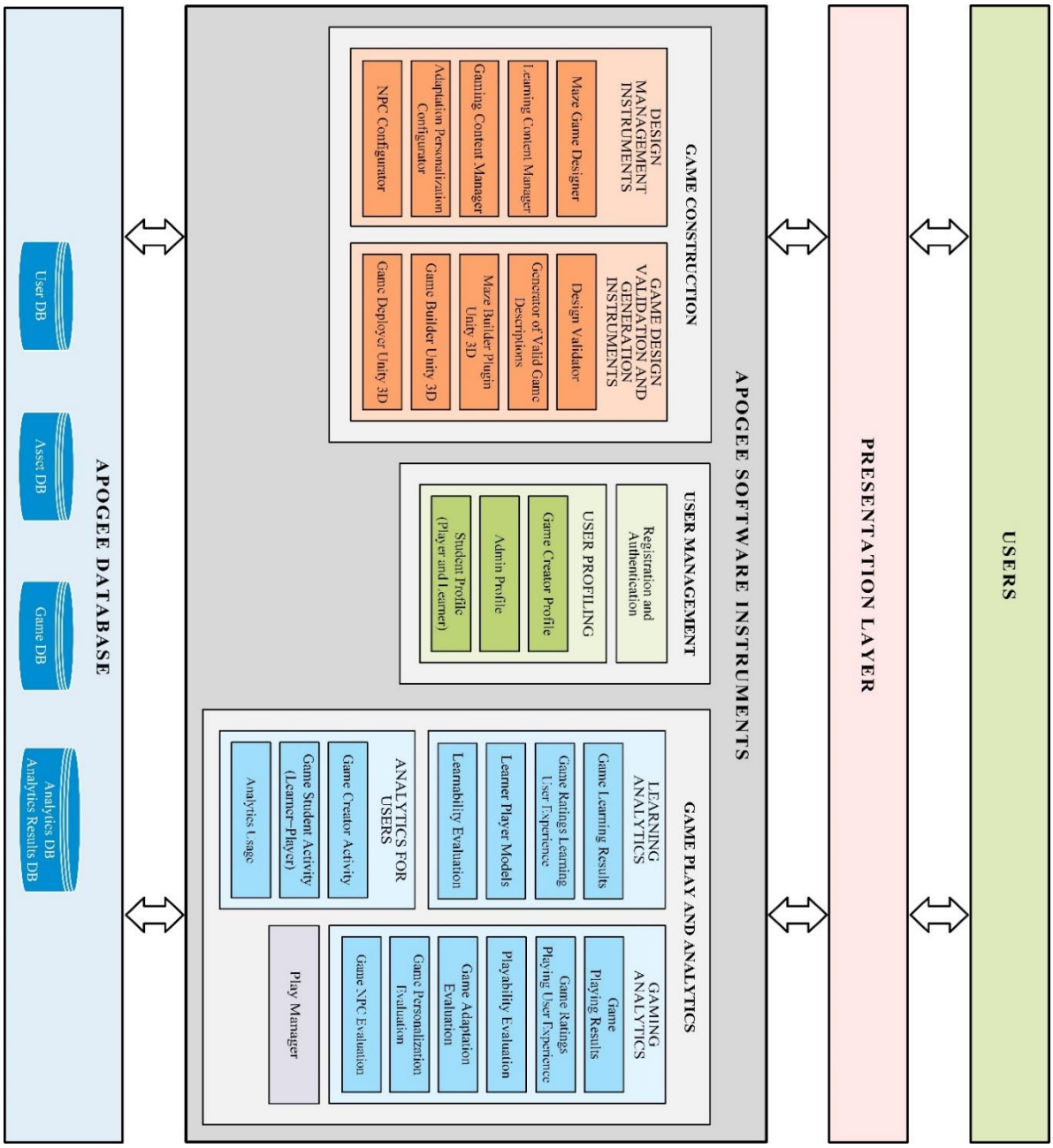


Figure 15. The software architecture of the APOGEE platform

The software architecture of the APOGEE platform has the following layers:

- **"User Layer"**
- **"Presentation Layer";**
- **"APOGEE Software Instruments Layer";**
- **"APOGEE Database".**

Users communicate with the platform through the **"Presentation Layer"**. They access the platform using the User Management module included in the "**APOGEE Software**

Instruments Layer". This module contains two sub-modules responsible for the **registration, validation and authentication of users in the platform** (Registration and Authentication), as well as for their profiling in the relevant user profiles (User Profiling), namely:

- **"Game Creator Profile";**
- **"Student Profile";**
- **"Admin Profile".**

The **"APOGEE Software Instruments Layer"** layer includes both the **"Game Construction" and "Game Play and Analytics"** modules. These modules include the software instruments of specialized TIMED-VGE taxonomy, distributed by the respective modules. These software instruments are described in detail in the previous sections of the abstract of the PhD Thesis. Users can play the games created on the platform using the **Play Manager** module located in the **Gameplay and Analytics** module. The Platform Data Layer stores all platform data that is generated during its use.

3.3.4. Conclusions

Chapter 3 presents the application of the specialized TIMED-VGE taxonomy, on the basis of which the functionalities of the software instruments are designed, a description of the business processes and software architecture of the APOGEE platform is also presented. The conclusions from this chapter can be summarized as follows:

- The taxonomy **has been successfully applied** in the APOGEE platform for the design of the instruments for management and evaluation of educational video games.
- The **functionalities of the software instruments** for the management and evaluation of the design of video games for education in the APOGEE platform have been designed
- An analysis and description of the **business processes** of using the designed software instruments for management and evaluation of the design of maze video games for education, applying user-centered approach in the APOGEE platform.
- The **software architecture** of the APOGEE platform has been designed, which includes the designed software instruments and based on that software architecture, the platform itself has been created within the APOGEE project.
- The software instruments are designed to work **successfully** to create maze video games for education.
- **The validation of the software instruments** can be done directly, by using the tools for management and evaluation by stakeholders, who use them to create, analyze and evaluate the design of educational video games and survey these people; or indirectly by using experimental video games by users and surveying users to assess the user experience, showing the degree of usability and usefulness of the designed software instruments.

CHAPTER 4. VALIDATION OF THE DESIGNED INSTRUMENTS

Chapter 4 "Validation of Designed Tools" presents a methodology for validation of designed software instruments in the APOGEE platform, based on their practical use. The experimental video games for education are described - "Assenevtsi", "Valchan Voyvoda" and "Let's save Venice" (presented in detail in the PhD Thesis), which were created using the designed software instruments for management and evaluation of the design of video games for education in the APOGEE platform.

The author of the PhD Thesis is involved in all stages of the development and evaluation of the experimental maze video games using the designed instruments for management and evaluation in the platform.

The analysis of the results of the practical use of video games for education is presented. The software instruments are validated based on the assessment of the user experience of the users in the experimental games.

4.1.Methodology for Validation of Designed Software Instruments

The **Methodology for Validation of the Designed Software Instruments** in the APOGEE platform is **based on their practical use**. The main goal of the methodology is to design and create maze video games for education with the help of the **software instruments** in the platform and to make **practical experiments** to evaluate their characteristics (Bontchev, Terzieva and Dankov, 2021). For these reasons, the methodology includes a **study of the usability** of the platform in the following stages (Bontchev, Terzieva and Dankov, 2021):

- *"**Stage 1**: Creating game scenarios and a model of an educational 3D maze video game"* with the relevant thematic content:
  - "*Collection, selection and processing of text and multimedia content in order to incorporate it into an educational 3D maze video game*";
  - "*Creating game scenarios for educational the 3D maze video game, enriched with mini-games of different types of puzzles (riddles) and quizzes, including the collected content*";
  - *"Create a model of a 3D maze video game with mini-games from different types of puzzles using the game scenarios".*
- *"**Stage 2**: Design, programming and testing of the initial version of an educational 3D maze video game"* using the designed software instruments and with the built-in educational and game content (including mini-games of various kinds) in the halls of the maze:
  - "*Design of the gameplay in the maze halls and the audio-visual layout of the halls of the maze and the built-in mini-games*";
  - "*Creating an XML description of the maze enriched with mini-games*", validating and generating the video game in the Unity3D video game development environment;
  - "*Testing the game and generating desktop and online versions*".
- *„**Stage 3**: Practical experiment with the final version of an educational 3D maze video game":*
  - *"Creating a methodology for conducting the online video game experiment"* (Incl. User surveys);
  - *"Organization and conduct of the experiment".*
- **Stage4:** Analysis of the obtained results.

4.1.1. Evaluation of the user experience

The analysis of the obtained results (Stage 4 of the methodology for validation of the designed software instruments) is directly related to the users of the platform and aims to assess the following **factors of the user experience** (Dankov et al., 2022a):

- **Playability.** Related to the indicators for "**Gaming Experience - Challenge** (the player's perceptions of the difficulty of the game), **Immersion**, **Game Flow**, **Affect** (confidence, efficiency and attitudes), and **Motivation to engage***" (*Sánchez et al., 2009).
- **Learnability** is associated with learning experience dependent on defining clear objectives, the effectiveness of the educational game and the availability of feedback.

The content that integrates into video games needs to meet the set educational goals and needs of the users. This directly affects consumers as well as the knowledge and skills they can acquire during the process of playing the educational video game. This directly affects users as well as the knowledge and skills that they can acquire during the process of playing the educational video game.

- **Usability.** It consists of a variety of quality indicators of usability such as "ease of use of the interface, user control in the gaming environment, error avoidance and satisfaction with the interactive features of the game" (Poels et al., 2007). Usability explains how the user can effectively and efficiently achieve certain goals in the game and be satisfied with the result of use. The three quality indicators for usability are:
    - **Effectiveness** - refers to the degree of success of users (achieved result), measured by the degree of achievement of the defined goal.
    - **Efficiency** - refers to the degree of completion of the achieved goals, in terms of effort, time and resources on the part of the player (for example, time spent to complete a task, the number of attempts by players to achieve the defined goal, etc.).
    - **Satisfaction** - is expressed in the positive attitude and experience of the player regarding the use of the game.

Therefore, the evaluation of the user experience in the APOGEE platform and the evaluation of the software instruments for management and evaluation of the design of educational video games, with a user-centered approach in the platform, is carried out using the practical use of games and answering three questions presented in Table 9 (Dankov et al., 2022a)

Evaluation of learnability in the APOGEE platform is carried out using the **attributes of learning ability** (Senapathi, 2005) and **user surveys**, through a specially designed questionnaire, after playing the games, directly related to the **learning user experience**. It is completed by learners and players and contains 16 questions on the formation of the assessment of the **learnability** (based on the measurement of attributes) of maze video games for education in the APOGEE platform.

Table 9. Factors for assessing the user experience in educational video games in the APOGEE platform (Dankov et al., 2022a)

Factors of the user experience	**Learnability**	**Playability**
User	Learner	Player
What should be evaluated?	Learning experience	Gaming experience
Why this assessment is needed?	Efficiency, effectiveness, motivation and satisfaction from the **learning process**	Efficiency, effectiveness, motivation and satisfaction from the **game playing process**
How the assessment is carried out?	Questionnaires before the start and after the end of the game, interviews and data from analytics tools	Questionnaires before the start and after the end of the game, interviews and data from analytics tools

Based on the **attributes of the learnability**, the evaluation of the learnability in the APOGEE platform is formed. These are the attributes (Senapathi, 2005): **Ease of Learning, Familiarity, Consistency, Predictability, Informative Feedback** and **Error Handling.**

The 6 attributes of learnability described are assessed by applying a five-point Likert scale and in the context of four factors. These are the application of **educational tasks based on games**; **the environment in which the learning takes place** (including teaching methodologies, teaching methods, content sources, etc.); **the individual characteristics** of

learners and players (gender, age, prior knowledge, etc.) and **educational video games** in the APOGEE platform as a learning tool (Bontchev, Antonova, Terzieva and Dankov, 2022).

The evaluation of **playability** in the APOGEE platform is realized with the help of a survey of users, through a specially created questionnaire after playing the games directly related to the **gaming experience of the users**.

The gaming experience is defined as "the unity of feelings, thoughts, senses, actions and significance of the player in the game environment (Ermi and Mäyrä, 2005). In order to implement the assessment of the gaming experience, it is necessary to create questionnaires that are filled out by users after playing the game. There are many different questionnaires that are used to evaluate the gaming experience with different criteria (Brockmyer et al., 2009; IJsselsteijn et al., 2013; Högberg et al., 2019).

Based on the **evaluation of the gaming experience of the users**, the evaluation of the **playability** in the APOGEE platform is formed. This is done with the help of the **Game Experience Questionnaire** (GEQ) (IJsselsteijn et al., 2013), which is filled in by users after the game sessions. This questionnaire forms the evaluation of the gaming experience of users, based on seven (sensory and imaginary) **components of the gaming experience** (Poels et al., 2007; IJsselsteijn et al., 2013): **Flow, Challenge, Competence, Positive Affect, Negative Affect, Immersion, Tension.**

In summary, the process of collecting data on users and the user experience in the APOGEE platform consists of (Bontchev et al., 2018; Dankov et al., 2022a; Dankov et al., 2021b; Bontchev, Antonova, Terzieva and Dankov, 2022):

Questionnaires before starting the game. Refer to collecting information about the individual characteristics of the user (age, gender, preferences, etc., **learning style**, **playing style**. To be filled in by the learners and players before the start of the game.

Questionnaire after playing the game. Questionnaire after playing the game. After the end of the game session, users fill out a specially created questionnaire on the **evaluation of the user experience** through the **factors of the user experience** - **playability**, **learnability** and **usability**.

Semi-structured user interview after playing the game. Semi-structured interview of users after playing the game. Refers to the collection of additional information on quality research and **evaluation of the user experience**. Conducted by the teacher by asking open-ended questions to gather information about the subjective opinion of players and learners, their experiences and impressions. Implemented if necessary and provided that a questionnaire is completed after playing the game

Therefore, following the life cycle of the APOGEE platform (illustrated in Figure 10 and described in detail in Chapter 3 of the PhD Thesis), a mechanism for collecting user data and generated data from game sessions, as well as using software instruments for management and evaluation, applying user-centered approach for the design of video games for education, game designers have the opportunity to realize:

- Overall evaluation of the user experience;
- Overall evaluation of the designed video game for education;
- Overall evaluation of the APOGEE platform.

Based on these results, game designers have the opportunity to make the necessary adjustments and settings to improve the design of the designed maze video games for education, to improve the user experience, as well as to improve and develop the APOGEE software platform.

4.2. Analysis of the Results of The Practical Use of Video Games for Education

Due to the large volume of results, the present PhD Thesis presents the results of the use of the maze video game for education "Let's save Venice". Based on the practical use of the game and following the methodology for validation of the designed software instruments, the validation of the designed software instruments for the management and evaluation, applying user-centered approach for the design of video games for education in the APOGEE platform, is performed through the **evaluation of the user experience**.

For this purpose, the educational video game of the maze video game for education "Let's save Venice" is practically used by the participants in the first workshop of the European international project e-Creha (Climate Xtremes and Resilient Heritage) - (https://www.ecreha .org/). The workshop was held from August 31 to September 8, 2021, at the Technical University of Eindhoven, the Netherlands. Participants include students, professors and researchers from various universities. The workshop was dedicated to climate resilience and the protection of immovable cultural heritage (Bontchev, Antonova, Terzieva and Dankov, 2022).

The **evaluation of the user experience** is carried out with the help of the **factors for user experience**, which are described in detail in the previous sections of this chapter of the PhD Thesis. Therefore, for this study, the learnability and playability in the maze video game for education "Let's save Venice" are evaluated. This is done by surveying users through questionnaires that are filled out by users after the game sessions.

The **evaluation of learnability** is formed based on the **attributes of learnability** (Ease of Learning, Familiarity, Consistency, Predictability, Informative Feedback and Error Handling). The **evaluation of playability** is formed based on the evaluation of the **gaming experience of users** by measuring the **components of the gaming experience** (Flow, Challenge, Competence, Positive Affect, Negative Affect; Immersion, Tension.). Assessments are made using a five-point Likert scale and are described in detail in section 4.1 of the current chapter of PhD Thesis.

As a result, abbreviated versions of the questionnaires were created, because of the time constraint of the workshop and the realization of the objectives of the research of the user experience in the maze video game for education "Let's save Venice". In addition to the questionnaire, there is an opportunity to conduct a semi-structured interview of the participants after playing the game. The whole process of assessing the consumer experience includes (Bontchev, Antonova, Terzieva and Dankov, 2022):

- **Questionnaire 1 after playing the game.** Contains seven questions about the individual characteristics of a player and a learner.
- **Questionnaire 2 after playing the game.** Contains six general questions for the evaluation of **learnability**, based on each of the **six attributes of learnability**;
- **Questionnaire 3 after playing the game.** Contains seven general questions about the evaluation of the **playability**, based on the evaluation of the gaming experience of users, through each of the **components of the gaming experience**;
- **Semi-structured user interview after playing the game.** Conducted by the teacher during the workshop on collecting information about the subjective opinion of users (participants in the workshop), their impressions and opinions about the game.

The full description of the questionnaires for evaluation of the **user experience** in the maze video game for education "Let's save Venice" is presented in detail in the PhD Thesis.

All the results of the use of the video game for education "Let's save Venice" and the survey of the user experience are published and presented in (Bontchev, Antonova, Terzieva and

Dankov, 2022). The results presented in the chapter of the PhD Thesis are based entirely on this publication (Bontchev, Antonova, Terzieva and Dankov, 2022). In the pilot study and the evaluation of the maze video game for education "Let's save Venice" took part 24 people (12 men and 12 women), played the game during the workshop. The participants are 21 students and three doctoral students from different universities and countries. The mean age is 25.20 with a standard deviation of 6.48.

The **evaluation of the user experience** is realized with the help of the **evaluation of the learnability** and **the evaluation of the playability** of the mini-games.

The results of the assessment of the **learnability** and the assessment of the **playability** are presented in detail in the PhD Thesis. From the analysis of the results, presented in detail in the PhD Thesis, it is evident that they satisfy the **factors of the user experience**. **The results of the evaluation confirmed that the usability of the tools is high.**

4.3. Conclusions

Chapter 4 present the validation of the designed software instruments for management and evaluation of the design of video games for education. The conclusions of this chapter can be summarized as follows:

- The developed **methodology for validation of the designed software instruments** has been **successfully used** for **practical validation** of the designed software **instruments** in the APOGEE platform
- The created **experimental video games for education** - "Asenevtsi", "Valchan Voyvoda" and "Let's save Venice", with the help of the designed software instruments for management and evaluation of the design of video games for education in the APOGEE platform, provided the ability to validate the instruments through the practical use of games.
- **The software instruments have been successfully validated** based on the evaluation of the user experience of the users in the experimental games.
- From the analysis of the results of the practical use of the created experimental maze video game for education, with the help of designed software instruments for management and evaluation, applying user-centered approach for the design of video games for education in the APOGEE platform, it is evident that **they satisfy the factors of user experience.**
- A strong relationship has been established between all **attributes of the learnability**, as well as between all **components of the gaming experience**.
- From the results of the survey related to the evaluation of learnability, based on the attributes of learnability, it is evident that most participants gave a positive grade on the Likert scale for each of the **attributes of learnability**.
- The results of the survey related to the evaluation of the playability, which is realized by the **evaluation of gaming experience of users in mini-games**, based on the **components of the gaming experience**, shows high values of four of the components - Immersion, Positive Affect, Competence, Flow, which in turn proves that the game provides a rich gaming experience to users.
- The result proves the **positive connection between the acquisition of learning content and the good design of the game**, as a result of the work of the designed software instruments for management and evaluation, applying user-centered approach for the design of video games for education in the APOGEE platform.
- The results of the evaluation confirmed that the **usability of the software instruments is high**.

CONCLUSION

Summary of the PhD Thesis research

The PhD Thesis is studied and analyzed the design of video games for education, the software instruments for the management the design of video games for education and the analytics instruments and the definitions related to them. Special attention is paid to the need for appropriate instruments to support the design and management, as well as to provide opportunities for analysis and evaluation of the design of educational video games. A large amount of data is generated in the process of designing educational games, as well as a result of game sessions that need to be processed, which requires the design of software instruments for **effective analysis and evaluation of the design**.

A **common taxonomy** of software instruments for management and evaluation of the design of video games for education is designed. It allows being used to help design video games from a variety of genres - both for serious games (in particular educational) and for entertainment video games. Based on the **common taxonomy** it has developed a **specialized TIMED-VGE taxonomy** of software instruments for management and evaluation of the design of video games for education that can be used for all kinds of video games from an educational maze. The specialized TIMED-VGE taxonomy has **been successfully applied** in the APOGEE platform to design the software instruments for the management and evaluation of the design of video games for education.

The **functionalities of the software instruments for management and evaluation of the design of video games for education in the APOGEE platform are designed**. An analysis and description of the **business processes** of using the designed software instruments for management and evaluation of the design of maze video games for education, applying user-centered approach in the APOGEE platform. The **software architecture** of the APOGEE platform has been designed, which includes the designed software instruments and based on that software architecture, the platform has been created within the APOGEE project. The software instruments are designed to work **successfully** to create maze video games for education.

Accordingly, the **methodology for validation of the designed software instruments** has been **successfully used** for **practical validation** of the designed software **instruments** in the APOGEE platform. The created **experimental video games for education** - "Asenevtsi", "Valchan Voyvoda" and "Let's save Venice", with the help of the designed software instruments for management and evaluation of the design of video games for education in the APOGEE platform, provided the ability to validate the instruments through the practical use of games. **The software instruments have been successfully validated** based on the evaluation of the user experience of the users in the experimental games. From the analysis of the results of the practical use of the created experimental maze video game for education, with the help of designed software instruments for management and evaluation, applying user-centered approach for the design of video games for education in the APOGEE platform, it is evident that **they satisfy the factors of user experience.** A strong relationship has been established between all **attributes of the learnability**, as well as between all **components of the gaming experience**. From the results of the survey related to the **evaluation of learnability**, based on the attributes of learnability, it is evident that **most participants gave a positive grade** on the Likert scale for each of the attributes of learnability. The results of the survey related to the evaluation of the playability, which is realized by the **evaluation of gaming experience** of users in mini-games, based on the components of the gaming experience, shows high values of four of the components - Immersion, Positive Affect, Competence, Flow, which in turn **proves that the game provides a rich gaming experience to users.** The result proves the **positive connection between the acquisition of learning**

content and the good design of the game, as a result of the work of the designed software instruments for management and evaluation, applying user-centered approach for the design of video games for education in the APOGEE platform. **The results of the evaluation confirmed that the usability of the software instruments is high.**

Through the implementation of all the set tasks, **the aim of the PhD Thesis has been achieved** - design and validation of instruments for management and evaluation applying a user-centered approach for the design of maze video games for education using a specially designed and created a taxonomy for this purpose

Guidelines for Future Development

As a future development, it is planned to implement all software instruments in the APOGEE platform as well as their improvement through the evaluation of their use based on the evaluation of the user experience. This will provide the designers of video games with the entire set of capabilities and functionalities of the instruments from the TIMED-VGE taxonomy. The specialized TIMED-VGE taxonomy can also be used to develop entertainment video games without including certain software instruments from it - such as the " Learning Content Manager". The TIMED-VGE taxonomy can, also be used to develop software instruments for management and evaluation, applying user-centered approach for the design of video games in other platforms for creation of video games.

PHD THESIS CONTRIBUTIONS

The PhD Thesis contributions are scientific, scientific-applied and applied contributions and can be summarized as follows:

1. A systematic analysis of the instruments for analysis and evaluation of the design of video games for education was performed.
2. A common taxonomy of software instruments for management and evaluation of the design of video games is designed, as well as specialized taxonomy of software instruments for management and evaluation, applying user-centered approach for the design of maze video games for education.
3. Design of software instruments for management and evaluation of the design of maze video game for education describing the functional requirements and business processes was performed. The software architecture of the APOGEE platform for creating video games has been designed, where the designed software instruments are integrated into the platform and based on that architecture within the APOGEE project, the platform itself is created.
4. Practical validation of the designed software instruments for management and evaluation of the design of maze video game for education was performed by:
    - **4.1.** Creating methodology for validation of the designed software instruments.
    - **4.2.** Creating maze video games for education.
    - **4.3.** Conducting practical experiments with the created video games for education.
    - **4.4.** Analyze the results of the practical experiments that were performed and make and evaluate the designed software instruments.

The author of the PhD Thesis assumes that a contribution (2) is scientific, contributions (1), (3), (4.1) and (4.4) are scientific-applied and contributions (4.2) and (4.3) have an applied nature.

LIST OF THE AUTHOR'S SCIENTIFIC PUBLICATIONS ON THE TOPIC OF PHD THESIS

1. **Yavor Dankov** and Boyan Bontchev. (2020). Towards a Taxonomy of Instruments for Facilitated Design and Evaluation of Video Games for Education. Proceedings of the 21st International Conference on Computer Systems and Technologies (CompSysTech'20), ISBN: 9781450377683, pp 285-292, Association for Computing Machinery (ACM), New York, NY, USA. https://doi.org/10.1145/3407982.3408010 (**BEST PAPER AWARD**)
2. **Yavor Dankov** and Boyan Bontchev. (2021). Software Instruments for Management of the Design of Educational Video Games. In book Human Interaction, Emerging Technologies and Future Applications IV. Proceedings of 4th International Conference on Human Interaction and Emerging Technologies (IHIET-AI 2021), Strasbourg, France, 2021. Advances in Intelligent Systems and Computing, vol 1378, ISBN:978-303073270-7, ISSN 2194-5357, pp 414-421, Springer, Cham. https://doi.org/10.1007/978-3-030-74009-2_53
3. **Yavor Dankov** and Boyan Bontchev. (2021). Designing Software Instruments for Analysis and Visualization of Data relevant to Playing Educational Video Games. In book Human Interaction, Emerging Technologies and Future Applications IV. Proceedings of 4th International Conference on Human Interaction and Emerging Technologies (IHIET-AI 2021), Strasbourg, France, 2021. Advances in Intelligent Systems and Computing, vol 1378, ISBN:978-303073270-7, ISSN:2194-5357, pp 422-429, Springer, Cham. https://doi.org/10.1007/978-3-030-74009-2_54
4. **Yavor Dankov**, Albena Antonova and Boyan Bontchev. (2022). Adopting User-Centered Design to Identify Assessment Metrics for Adaptive Video Games for Education. In book Human Interaction, Emerging Technologies and Future Systems V. Proceedings of the 5th International Conference on Human Interaction and Emerging Technologies (IHIET 2021), Paris, France, 2021. Lecture Notes in Networks and Systems, vol 319, ISBN:978-303085539-0, ISSN: 2367-3370, pp 289-297, Springer, Cham. https://doi.org/10.1007/978-3-030-85540-6_37
5. **Yavor Dankov,** Albena Antonova, Valentina Terzieva and Boyan Bontchev (2021). Applying User-Centered Design for A Climate Resilience Video Game. International Journal of Differential Equations and Applications, vol 20, issue 2, ISSN:1314-6084, pp 147-156, Academic Publications Ltd. https://doi.org/10.12732/ijdea.v20i2.1 https://www.ijpam.eu/en/index.php/ijdea/article/view/5956 (**INVITED PAPER**)
6. Boyan Bontchev, Dessislava Vassileva, and **Yavor Dankov**. (2019). The APOGEE Software Platform for Construction of Rich Maze Video Games for Education. In Proceedings of the 14th International Conference on Software Technologies (ICSOFT 2019), Prague, Czech Republic,2019, ISBN:978-989758379-7, ISSN 2184-2833, pp 491-498, SciTePress. https://doi.org/10.5220/0007930404910498

DECLARATION OF ORIGINALITY

I declare that the PhD Thesis for awarding the PhD Degree in the Professional field 4.6 Informatics and Computer Sciences (Doctoral program "Computer Sciences"), on "Instruments for Management and Evaluation Applying a User-Centered Approach for The Design of Video Games for Education" is my own work and it does not use directly or indirectly foreign texts, illustrations, figures and tables without being properly cited. No part of the PhD Thesis is in violation of the copyright of an institution or individual. The results and contributions obtained are original and are not borrowed from research and publications in which I do not participate.

BIBLIOGRAPHY OF THE ABSTRACT

1. **(Bontchev, Antonova and Dankov, 2020)** Bontchev, B., Antonova, A. and Dankov, Y. (2022). Educational Video Game Design Using Personalized Learning Scenarios. In: Gervasi O. et al. (eds) Computational Science and Its Applications – ICCSA 2020, ICCSA 2020, Lecture Notes in Computer Science, Springer, Cham, vol 12254, pp 829–845. https://doi.org/10.1007/978-3-030-58817-5-59
2. **(Bontchev, Antonova, Terzieva and Dankov, 2022)** Bontchev, B., Antonova, A., Terzieva, V. and Dankov, Y. (2022). "Let Us Save Venice"—An Educational Online Maze Game for Climate Resilience. In International Scientific Journal: Sustainability, 2022, vol 14, Issue 7, ISSN 2071-1050, MDPI, Switzerland. https://doi.org/10.3390/su14010007
3. **(Bontchev, Terzieva and Dankov, 2021)** Bontchev, B., Terzieva, V. and Dankov, Y. (2021). Educational Video Maze Games. In Journal NAUKA (SCIENCE), vol: XXXI, Issue 1, 2021, pp 25-33, Bulgarian Edition, ISSN:0861-3362, ISSN:2603-3623. http://spisanie-nauka.bg/arhiv/1-2021.pdf
4. **(Bontchev, Vassileva and Dankov, 2019)** Bontchev, B. Vassileva, D. and Dankov, Y. (2019). The APOGEE Software Platform for Construction of Rich Maze Video Games for Education. In Proceedings of the 14th International Conference on Software Technologies (ICSOFT 2019), Prague, Czech Republic,2019, ISBN:978-989758379-7, ISSN 2184-2833, pp 491-498, SciTePress. https://doi.org/10.5220/0007930404910498
5. **(Brockmyer et al., 2009)** Brockmyer, J.H., Fox, C.M., Curtiss, K.A., McBroom, E., Burkhart, K.M., and Pidruzny, J.N. (2009). The Development of the Game Engagement Questionnaire: A Measure of Engagement in Video Game-Playing. In Journal of Experimental Social Psychology, vol 45, Issue 4, Elsevier, pp 624–634. https://doi.org/10.1016/j.jesp.2009.02.016
6. **(Dankov and Birov, 2018)** Dankov, Y. and Birov, D. (2018). General Architectural Framework for Business Visual Analytics. In: Shishkov B. (eds) Business Modeling and Software Design. BMSD 2018. Vienna, Austria, Lecture Notes in Business Information Processing, vol 319, Springer, Cham, ISBN:9783319942131, ISSN:18651348. https://doi.org/10.1007/978-3-319-94214-8_19
7. **(Dankov and Bontchev, 2020)** Dankov, Y. and Bontchev, B. (2020). Towards a Taxonomy of Instruments for Facilitated Design and Evaluation of Video Games for Education. Proceedings of the 21st International Conference on Computer Systems and Technologies (CompSysTech'20), ISBN: 9781450377683, pp 285-292, Association for Computing Machinery (ACM), New York, NY, USA. https://doi.org/10.1145/3407982.3408010
8. **(Dankov and Bontchev, 2021)** Dankov, Y. and Bontchev, B. (2021). Designing Software Instruments for Analysis and Visualization of Data Relevant to Playing Educational Video Games. In book Human Interaction, Emerging Technologies and Future Applications IV. Proceedings of 4th International Conference on Human Interaction and Emerging Technologies (IHIET-AI 2021), Strasbourg, France, 2021. Advances in Intelligent Systems and Computing, vol 1378, ISBN:978-303073270-7, ISSN:2194-5357, pp 422-429, Springer, Cham. https://doi.org/10.1007/978-3-030-74009-2_54
9. **(Dankov and Bontchev, 2021a)** Dankov, Y. and Bontchev, B. (2021). Software Instruments for Management of the Design of Educational Video Games. In book Human Interaction, Emerging Technologies and Future Applications IV. Proceedings of 4th International Conference on Human Interaction and Emerging Technologies (IHIET-AI 2021), Strasbourg, France, 2021. Advances in Intelligent Systems and Computing, vol 1378, ISBN:978-303073270-7, ISSN 2194-5357, pp 414-421, Springer, Cham. https://doi.org/10.1007/978-3-030-74009-2_53
10. **(Dankov et al., 2021b)** Dankov, Y., Antonova, A., Terzieva, V. and Bontchev, B. Applying User-Centered Design for A Climate Resilience Video Game. International Journal of Differential Equations and Applications, vol 20, issue 2, ISSN:1314-6084, pp 147-156, Academic Publications Ltd. https://doi.org/10.12732/ijdea.v20i2.1,https://www.ijpam.eu/en/index.php/ijdea/article/view/5956
11. **(Dankov et al., 2022a)** Dankov Y., Antonova A. and Bontchev B. (2022). Adopting User-Centered Design to Identify Assessment Metrics for Adaptive Video Games for Education. In

book Human Interaction, Emerging Technologies and Future Systems V. Proceedings of the 5th International Conference on Human Interaction and Emerging Technologies (IHIET 2021), Paris, France, 2021. Lecture Notes in Networks and Systems, vol 319, ISBN:978-303085539-0, ISSN: 2367-3370, pp 289-297, Springer, Cham. https://doi.org/10.1007/978-3-030-85540-6_37

12. **(Dill et al., 2012)** Dill, J., Earnshaw, R., Kasik, D., Vince, J. and Chung Wong, P. (2012). Expanding the Frontiers of Visual Analytics and Visualization. Springer London Dordrecht Heidelberg New York, ISBN 9781447128038. https://doi.org/10.1007/978-1-4471-2804-5
13. **(Ermi and Mäyrä, 2005)** Ermi, L. and Mäyrä, F. (2005). Fundamental Components of The Gameplay Experience: Analysing Immersion. In Proceedings of the 2005 DiGRA International Conference: Changing Views: Worlds in Play, Vancouver, BC, Canada.
14. **(Högberg et al., 2019**) Högberg, J., Hamari, J. and Wästlund, E. (2019). Gameful Experience Questionnaire (GAMEFULQUEST): an Instrument for Measuring the Perceived Gamefulness of System Use. In Journal of User Modeling and User-Adapted Interaction, 29, pp 619–660. https://doi.org/10.1007/s11257-019-09223-w
15. **(IJsselsteijn et al., 2013)** IJsselsteijn, W.A., de Kort, Y.A. and Poels, K. (2013). The Game Experience Questionnaire. Technische Universiteit Eindhoven, The Netherlands.
16. **(Keim et al., 2008)** Keim D., Andrienko G., Fekete JD., Görg C., Kohlhammer J. and Melançon G. (2008). Visual Analytics: Definition, Process, and Challenges. In Kerren A., Stasko J.T., Fekete JD., North C. (eds) Information Visualization. Lecture Notes in Computer Science, vol 4950. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-70956-5_7
17. **(Keim et al., 2010)** Keim, D., Kohlhammer, J., Ellis, G. and Mansmann, F. (2010). Mastering The Information Age – Solving Problems with Visual Analytics. Eurographics Association, Goslar, Germany, ISBN 9783905673777.
18. **(Peña-Ayala, 2017)** Peña-Ayala, A. (2017). Learning Analytics: Fundaments, Applications, and Trends: A View of the Current State of the Art to Enhance E-Learning. In Series Studies in Systems, Decision and Control No 94, Springer International Publishing, Switzerland. https://doi.org/10.1007/978-3-319-52977-6
19. **(Poels et al., 2007)** Poels, K., de Kort, Y. and IJsselsteijn, W. (2009). D3.3: Game Experience Questionnaire: Development of a Self-Report Measure to Assess the Psychological Impact of Digital Games. Technische Universiteit Eindhoven, The Netherlands.
20. **(Sánchez et al., 2009)** Sánchez, González, J.L., Padilla Zea, N. and Gutiérrez, F.L. (2009). Playability: How to Identify the Player Experience in A Video Game. Proceedings of IFIP Conference on Human-Computer Interaction, Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-03655-2_39
21. **(Senapathi, 2005)** Senapathi, M. (2005). A Framework for the Evaluation of CASE Tool Learnability in Educational Environments. In Journal of Information Technology Education, vol 4, 2005, pp 61–84. https://doi.org/10.28945/265
22. **(Somani and Deka, 2017)** Somani, A. and Deka, G. (2017). Big Data Analytics: Tools and Technology for Effective Planning. CRC Press, Taylor & Francis Group, NY, USA, ISBN: 9781138032392.
23. **(Suh and Anthony, 2017)** Suh, S. and Anthony, T. (2017). Big Data and Visual Analytics (1st ed.), Springer, Cham. https://doi.org/10.1007/978-3-319-63917-8.
24. **(Thomas and Cook, 2005)** Thomas, J. and Cook, K. (2005). Illuminating the Path: The Research and Development Agenda for Visual Analytics. Publisher National Visualization and Analytics Center, ISBN: 978-0769523231, ISBN: 0769523234.
25. **(Vanthienen et al., 2017)** Vanthienen, J. and Witte, K. (2017). Data Analytics Applications in Education (1st ed.). CRC Press, Taylor & Francis Group, Auerbach Publications, NY, USA, ISBN: 9781498769273.