RIGA TECHNICAL UNIVERSITY

Sintija Petroviča

IMPLEMENTATION OF THE PEDAGOGICAL MODULE IN THE EMOTIONALLY INTELLIGENT TUTORING SYSTEMS

Summary of the Doctoral Thesis

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RIGA TECHNICAL UNIVERSITY
Faculty of Computer Science and Information Technology
Institute of Applied Computer Systems

Sintija Petroviča
Doctoral Student of the Study Programme "Computer Systems"

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Scientific supervisor
Associate Professor Dr. sc. ing., Dr. paed.
ALLA ANOHINA-NAUMECA

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DOCTORAL THESIS PROPOSED TO RIGA TECHNICAL UNIVERSITY FOR THE PROMOTION TO THE SCIENTIFIC DEGREE OF DOCTOR OF ENGINEERING SCIENCES

To be granted the scientific degree of Doctor of Engineering Sciences, the present Doctoral Thesis has been submitted for the defence at the open meeting of RTU Promotion Council on June 10, 2019 at the Faculty of Computer Science and Information Technology of Riga Technical University, 2 Setas Street, Room 202.

OFFICIAL REVIEWERS

Professor Dr. habil. sc. ing. Zigurds Markovics
Riga Technical University

Associate Professor Dr. sc. ing. Arnis Cirulis
Vidzeme University of Applied Sciences, Latvia

Docent Dr. Ginevra Castellano
Uppsala University, Sweden

DECLARATION OF ACADEMIC INTEGRITY

I hereby declare that the Doctoral Thesis submitted for the review to Riga Technical University for the promotion to the scientific degree of Doctor of Engineering Sciences is my own. I confirm that this Doctoral Thesis had not been submitted to any other university for the promotion to a scientific degree.

Sintija Petroviča ……………………………. (signature)
Date: ………………………

The Doctoral Thesis has been written in Latvian. It consists of Introduction, four chapters, Conclusions, 50 figures, 35 tables, 14 appendices; the total number of pages is 201, not including appendices. The Bibliography contains 443 titles.

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INTRODUCTION

Research motivation

Since ancient times, the learning process in which a student works with a human-teacher according to the individualized approach is considered to be the most effective form of learning [1]. Over time, developers of computer-assisted instruction (CAI) systems have also tried to create computer systems that are able to simulate the teaching approach of human-teachers and offer individualized instruction (also known as tutoring) which corresponds to learning needs, knowledge and skills of each individual student [2]. As a result, a new generation of CAI systems – intelligent tutoring systems (ITS) – emerged in the early 1970s [3]. Over the years, these systems have been improved bringing their teaching and adaptation abilities closer to those of human-teachers.

For many years, the tutoring and its adaptation implemented by ITSs were considered almost equivalent to the one used by human-teachers, however, such systems could not simulate humans effectively. Research on human emotions and learning revealed that the main reason for these shortcomings is the lack of emotional intelligence [4] since human-teachers devote time and pay attention to both student's emotional and cognitive characteristics that can influence his/her learning abilities [5]. Recent research in psychology, neuroscience, education, and cognitive science has shown that emotions play a key role in the learning process, understanding of a problem domain, decision-making, and motivation [6]. Besides, over the last 20 years, there has also been a rapid development of a new branch of artificial intelligence (AI) called affective computing that deals with the design of systems and devices which are able to recognize, explain, and process human emotions [7]. Ideas from affective computing came also into the development of ITSs to improve the adaptability of such systems and to make them completely equivalent to human-teachers.

Research related to the emotional impact on the learning process has led to the emergence of a new generation of ITSs known as emotionally intelligent tutoring systems (EITS). EITS should be able to recognize student's emotions, determine the impact of the system's future actions on the student's emotions, select the most beneficial student's emotional state in order to improve his/her cognitive abilities. Furthermore, EITS may show system's emotions (by means of animated pedagogical agents) in reaction to student's emotions, actions or learning outcomes [5]. In the development of EITSs, the choice and integration of such pedagogical strategies, which consider not only the student's current knowledge level but also his/her emotional state, should be of great importance in order to increase the efficiency of the tutoring and improve the student's learning performance and outcomes. Although there are studies related to the choice of pedagogical strategies in traditional ITSs, the inclusion of emotional aspects in these strategies is actually a challenging task with a high degree of uncertainty and complexity [8]. During the last ten years, research carried out at the Riga Technical University (RTU) regarding the design and development of ITSs has been published in several doctoral theses. While most studies in previous years focused on student modelling, for example [9], more attention is now given to the pedagogical aspect [10]. This tendency suggests that the pedagogical side of ITSs should be as powerful as student modelling in order to provide adaptation not only to traditional student's characteristics, e.g.

knowledge level or learning style, but also to his/her emotional state. This in turn requires the development and integration of appropriate pedagogical strategies in the system. Consequently, this Doctoral Thesis is developed as a continuation of previous studies in the field of ITSs and EITS both in RTU and at international level with the aim of improving the adaptability of such systems by integrating the ability to recognize and adapt to student emotions.

The goal of the Thesis

The goal of the Thesis is to develop a pedagogical module of an EITS, which is able to adapt the tutoring process taking into account not only the current level of student's knowledge and skills but also his/her emotional state.

The tasks of the Thesis

In order to achieve the goal of the Thesis the following tasks are specified:

1) to identify the role, functions and interaction of the pedagogical module with other components in ITSs;
2) to analyse the role of emotions in learning process and to define requirements for the implementation of emotion-based tutoring process in ITSs;
3) to study the concept of EITS, analyse their architecture and characteristics;
4) to perform a comparative analysis of existing EITSs in order to identify unresolved tasks related to the adaptation of the tutoring process;
5) to develop methods and algorithms for elimination of previously identified shortages;
6) to develop the pedagogical module of EITS;
7) to evaluate the developed pedagogical module under experimental conditions.

Research object

Research object of the Thesis is EITS.

Research subject

Research subject of the Thesis is the adaptation of the tutoring process implemented by the pedagogical module as a response to the student's emotional state.

Research methods

Generally accepted research methods are used in the development of the Thesis. Theoretical results are obtained by using the following methods:

- study and analysis of the available scientific literature on ITSs and EITSs;
- analysis and comparison of the already developed EITSs;
- modelling of ongoing processes in an EITS.

The following empirical methods have been used in the development of the practical part:

- methods for data acquisition – questionnaires;
- methods for data processing and analysis:
  - descriptive statistics (arithmetic mean, standard deviation, median, skewness, kurtosis, minimum and maximum, frequency distribution and cross tabulations);

  - inferential statistics (Shapiro–Wilk test of normality, Levene's test, *T*-test for independent samples, Chi-squared test, Mann–Whitney *U*-test, Kruskal–Wallis *H*-test, Wilcoxon signed ranks test, Pearson correlation, Cramer's *V*, Cohen's effect size);
- prototyping for the implementation of the EITS.

Scientific novelty of the Thesis

The main scientific novelty of the developed Thesis is as follows:

- a summary has been developed describing the functions performed by ITS components, their required knowledge and mutual interaction;
- a summary describing the role of a pedagogical module in providing individualized tutoring has been proposed, a definition of the module's main goal has been given and necessary knowledge for the module and its types as well as categories of made pedagogical decisions by the module have been identified;
- a summary of pedagogical strategies and related terms used in ITSs has been provided by reflecting on their relationship and relevance in the adaptation of the tutoring process;
- requirements for implementation of emotion-based tutoring process and strategies in ITSs have been formulated by dividing them into several categories representing the whole tutoring process and three fundamental steps (theory teaching, practice and knowledge assessment) underlying all pedagogical strategies;
- a definition of EITSs has been given as well as characteristics, components and operating principles of such systems are identified allowing to distinguish them from traditional ITSs;
- a comparative analysis of existing EITSs has been provided by identifying the most important shortcomings of these systems regarding their adaptation capabilities;
- architecture of EITS has been developed, which combines an ITS, emotion recognition and game-based learning with the aim of improving the functionality of the pedagogical module and to facilitate influence on students' emotions, thus enabling students to improve their performance and change their attitude towards learning and knowledge assessment;
- a two-level (macro- and micro-level) adaptation approach has been developed, which defines operating principles of the pedagogical module before the start of tutoring and during the tutoring process where twelve operating scenarios for four different types of pedagogical agents are designed.

Practical value of the Thesis

The practical value of the Thesis is related to the proposed adaptation approach and developed algorithms and methods for the classification of learning-specific emotions and the analysis of identified emotions and attention span. The acquired information is further used by the developed method responsible for the implementation of the system's interventions and the adaptation of the tutoring process. In addition, the personality model has been created for the automatic identification of the student's achievement goal and learning style. These practically implemented mechanisms can be used not only in the EITS developed within the scope of the Thesis but also in the development of new systems. The developed EITS, which includes an adaptive educational game for the knowledge assessment, can be applied in the study process improving both the student's performance in the learning process and his/her results in examinations.

Approbation of the obtained results

The main results of the Thesis are reflected in 15 papers published in international scientific publications approved by the Latvian Council of Science.

1. Kaczmarek S., **Petrovica S.** Promotion of Learning Motivation through Individualization of Learner-Game Interaction. Proceedings of the IEEE Conference on Computational Intelligence and Games, 2018, pp. 324–331. (SCOPUS) (contribution to the paper ~65 %).
2. **Petrovica S.**, Pudane M., Anohina-Naumeca A., Lavendelis E. Why Do Computer Systems Need Emotional Intelligence? Innovation, Vol. 1, 2017, pp. 20–21 (contribution to the paper ~40 %).
3. Ivanova Goleva R., Pudane M., **Petrovica S.**, et al. AALaaS and ELEaaS Platforms. Enhanced Living Environments: From Models to Technologies, 2017. pp. 207–234 (contribution ~10 %).
4. **Petrovica S.**, Anohina-Naumeca A. The Adaptation Approach for Affective Game-Based Assessment. Applied Computer Systems, Vol. 22, December 2017, pp. 13–20 (Web of Science) (contribution ~90 %).
5. **Petrovica S.** Multi-level Adaptation of an Educational Game to Individual Student's Gameplay, Knowledge and Emotions. Proceedings of the 9th Annual International Conference on Education and New Learning Technologies, 2017, pp. 2220–2230.
6. **Petrovica S**., Anohina-Naumeca A., Ekenel H.K. Emotion Recognition in Affective Tutoring Systems: Collection of Ground-Truth Data. Procedia Computer Science, Vol.104, 2017, pp. 437–444 (SCOPUS, Web of Science) (contribution ~80 %).
7. **Petrovica S**., Ekenel H.K. Emotion Recognition for Intelligent Tutoring. Joint Proceedings of the BIR 2016 Workshops and Doctoral Consortium co-located with BIR 2016 (CEUR Workshop Proceedings, 1684), 2016, pp. 1–9. (SCOPUS) (contribution ~90 %).
8. **Petrovica S.**, Pudane M. Emotion Modeling for Simulation of Affective Student-Tutor Interaction: Personality Matching. International Journal of Education and Information Technologies, Vol. 10, 2016, pp. 159–167 (Web of Science) (contribution ~50 %).
9. **Petrovica S.** Tutoring Process in Emotionally Intelligent Tutoring Systems: Tutoring Process in Emotionally Intelligent Tutoring Systems. Psychology and Mental Health: Concepts, Methodologies, Tools, and Applications (Vol. 2), 2016, pp. 1094–1110.
10. **Petrovica S.**, Pudane M. Simulation of Affective Student-Tutor Interaction for Affective Tutoring Systems: Design of Knowledge Structure. International Journal of Education and Learning Systems, Vol.1, 2016, pp. 99–108 (contribution ~60 %).
11. **Petrovica S**. Tutoring and Assessment through Games and Emotions. Proceedings of the 7th International Conference on Computer Supported Education (Volume 1), 2015, pp. 539–544 (SCOPUS).

12. **Petrovica S.** Design of the Pedagogical Module for an Emotionally Intelligent Tutoring System. Science - Future of Lithuania. Electronics and Electrical Engineering, Vol. 6(2), 2014, pp. 138–146 (ProQuest; EBSCOhost; Google Scholar).
13. **Petrovica S.** Tutoring Process in Emotionally Intelligent Tutoring Systems. International Journal of Technology and Educational Marketing, Vol. 4(1), 2014, pp. 72–85 (DBLP).
14. **Petrovica S.** Adaptation of Tutoring to Students' Emotions in Emotionally Intelligent Tutoring Systems. Proceedings of 2nd International Conference on e-Learning and e-Technologies in Education (ICEEE 2013), 2013, pp. 131–136 (SCOPUS; IEEE Xplore).
15. **Petrovica S.**, Anohina-Naumeca A. Design and Implementation of Agent Interaction Mechanisms for Emotionally Intelligent Tutoring Systems. Scientific Journal of RTU. 5. series., "Computer Science. Applied Computer Systems", Vol. 13, 2012, pp. 44–53 (EBSCOhost; Google Scholar; INSPEC) (contribution ~65 %).

Conferences

Presentations on the main results of the Thesis were made at 9 international scientific conferences.

1. IEEE Conference on Computational Intelligence and Games, Maastricht, Netherlands, August 14–17, 2018, "Promotion of Learning Motivation through Individualization of Learner-Game Interaction".
2. 9th Annual International Conference on Education and New Learning Technologies, Barcelona, Spain, July 3–5, 2017, "Multi-level Adaptation of an Educational Game to Individual Student's Gameplay, Knowledge and Emotions".
3. 57th RTU International Scientific Conference, Riga, Latvia, October 13–18, 2016, "Emotion Recognition in Affective Tutoring Systems: Collection of Ground-Truth Data".
4. 4th International Workshop on Intelligent Educational Systems, Technology-enhanced Learning and Technology Transfer Models, Prague, Czech Republic, September 14, 2016, "Emotion Recognition for Intelligent Tutoring".
5. 7th International Conference on Education and Educational Technologies, Istanbul, Turkey, April 15–17, 2016, "Simulation of Affective Student-Tutor Interaction for Affective Tutoring Systems: Design of Knowledge Structure".
6. 7th International Conference on Computer Supported Education, Lisbon, Portugal, May 23–25, 2015, "Tutoring and Assessment through Games and Emotions".
7. 2nd International Conference on e-Learning and e-Technologies in Education, Lodz, Poland, September 23–25, 2013, "Adaptation of Tutoring to Students' Emotions in Emotionally Intelligent Tutoring Systems".
8. 1st IEEE Workshop on Advances in Information, Electronic and Electrical Engineering, Riga, Latvia, November 26–27, 2013, "Design of a Pedagogical Module for an Emotionally Intelligent Tutoring System".
9. 52nd RTU International Scientific Conference, Riga, Latvia, October 13–15, 2011, "Design and Implementation of Agent Interaction Mechanisms for Emotionally Intelligent Tutoring Systems".

Projects

National Research Programme "Cyber-physical systems, ontologies and biophotonics for safe&smart city and society", (SOPHIS), Project No. 2. "Ontology-based knowledge engineering technologies suitable for web environment", 2014–2017.

COST Action IC1303, Short Term Scientific Mission "Emotional Analysis for Ambient Assisted Tutoring", Reference Number: COST-STSM-ECOST-STSM-IC1303-161115-068104, November 2015.

Presentations at other public events

Presentations on the results of the Thesis were also made at the following public events and in RTU study courses.

1. Final meeting of the AAPELE project (COST Action IC1303) with the presentation "Truly Affective AAL Systems" (28.09.2017.).
2. Contest "Research Slam 2016" with the presentation "Artificial Intelligence and Emotions in Virtual Tutors" (07.04.2016.).
3. RTU study course "Computer System Design scientific seminar" (Master's study programme "Computer Systems") with the following presentations:
   a) "Affective Computing and Affective Tutoring Systems" (in Latvian in 2016; in English in 2017);
   b) "Emotions in Intelligent Tutors" (2018, in English);
4. RTU study course "Fundamentals of Artificial Intelligence" (Bachelor's study programme "Computer Systems") with the following presentations:
   a) "Intelligent Tutoring Systems: Past, Present, Future" (2015, in English);
   b) "Affective Computing and Affective Tutoring Systems" (2017, both in Latvian and English).

Thesis statements put forward for the defence

1. It is important to integrate pedagogical strategies of different levels in the pedagogical module in order to provide a fully-fledged adaptation of the tutoring process in ITSs.
2. ITSs require modelling of student's emotional state during the implementation of individualized tutoring process in order to ensure that capabilities of such systems are equivalent to those of human-teachers.
3. The currently developed EITSs are not able to provide a sophisticated adaptation of the tutoring process to the student's emotional state especially during knowledge assessment.
4. The combination of EITSs with a game-based knowledge assessment would allow reducing student's negative emotions and their negative impact on the learning process.
5. Game-based knowledge assessment leads to a wider range of emotions in students and contributes to the presence of positive emotions but does not improve students' assessment results significantly.

Structure of the Thesis

The Thesis includes Introduction, four chapters, Conclusions, Bibliography and 14 appendixes.

In Introduction, the motivation of the Thesis, the research goal, and tasks are defined. Applied scientific methods, novelty, practical value of the Thesis and approbation of the main results are also described.

The concept and architecture of ITSs are studied in Chapter 1. The main emphasis is put on the analysis of pedagogical module, its role, and functions in terms of individualization of the tutoring process. In addition, the definition and classification of pedagogical strategies are proposed in the chapter.

Chapter 2 is devoted to the analysis of relationships between emotions and learning and to the concept of "emotionally intelligent tutoring system". Exiting EITSs are examined to compare their capabilities from an emotional perspective, particularly focusing on the system's adaptability. At the end of the chapter, essential drawbacks and development problems of EITSs are identified.

Study of digital educational games and game-based learning are carried out in Chapter 3. In addition, a solution for integrating EITSs and educational games is proposed to improve learning efficiency. Furthermore, the two-level (macro- and micro-) adaptation approach with student's emotion analysis is developed and described in the chapter.

Implementation details of EITS and the educational game are specified in Chapter 4. In addition, an empirical study that was undertaken with the aim of evaluating the developed EITS is described in detail.

The main research findings and conclusions are presented in the last chapter of the Thesis.

1. INTELLIGENT TUTORING SYSTEMS AND TUTORING

The concept of ITSs, their architecture and constituent components are examined in this chapter. Functions and mutual interaction of architecture components are analysed by paying particular attention to the pedagogical module and its role in the implementation of the tutoring. Besides, pedagogical strategies are studied in the context of ITSs and tutoring.

1.1. Intelligent Tutoring Systems and Their Architecture

Tutoring realized by human-teachers has always been considered the most effective form for the acquisition of knowledge and skills [1], [2]. Therefore, it is only natural that this type of instruction came into the development of CAI systems leading to a new system's generation – ITS. ITSs simulate human-tutors and provide benefits of the tutoring by exploiting methods of artificial intelligence to provide a learning environment adapted (personalized content, feedback, navigation, etc.) to the characteristics of an individual student [1]. Adaptation is possible due to special types of knowledge integrated into the traditional architecture of such systems, which includes [11]: a) a student diagnosis module collecting and processing information about the student (his/her learning progress, behaviour, psychological characteristics, etc.) and a student model storing this information; b) a problem domain module able to generate and solve problems in the domain and a domain model storing knowledge intended to be taught; c) an interface module managing interaction between ITS and students through various input/output devices (e.g. mouse or keyboard [12]); and d) a pedagogical module responsible for the implementation of the teaching process and a pedagogical model storing pedagogical knowledge. A detailed analysis of this module has been made in the next subchapter.

Based on the analysis of ITS components, a diagram has been developed representing their mutual interaction and data exchanged, as well as showing an interaction with a student (Fig. 1.1). In addition, the summary has been made in the form of a table (Table 1.1) specifying all functions performed by ITS components, used knowledge and/or data for the implementation of these functions and the interaction with other ITS components.

1.2. Pedagogical Module and Its Role in the Provision of Tutoring

Traditionally, the pedagogical module is an ITS component that imitates the human-teacher and determines appropriate pedagogical strategies [13] with the aim of providing tutoring. Tutoring has always been a form of instruction where the tutor/student ratio is 1/1 to 1/3 (in most cases 1/1) and the tutor's control exists although this control may be shared with a student [14].

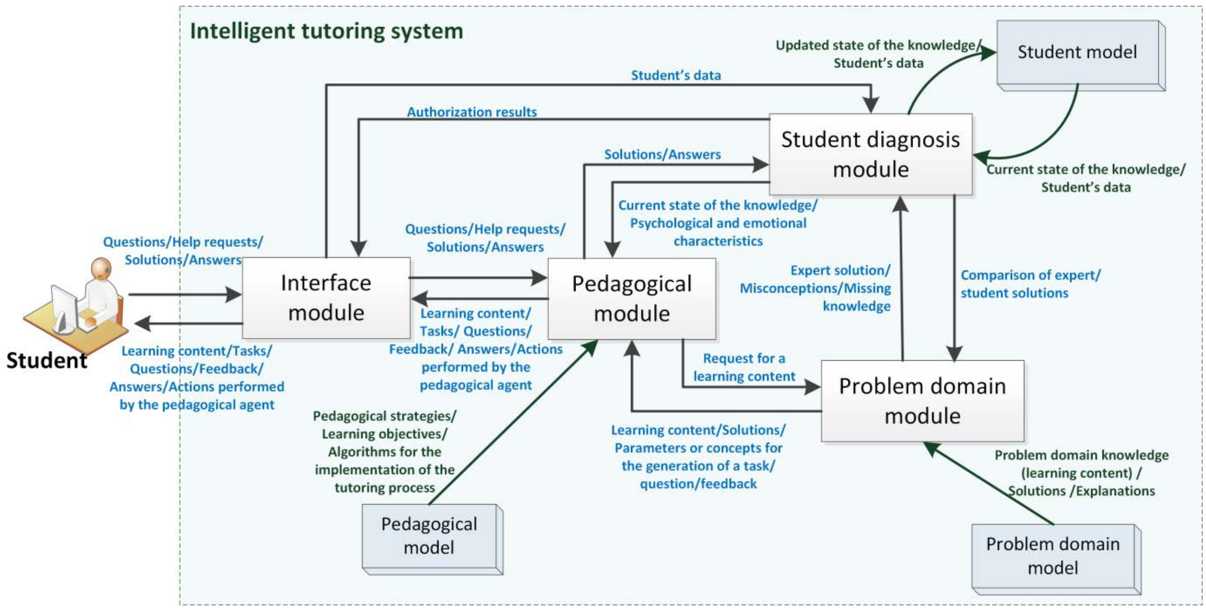

Fig. 1.1. Mutual interaction of ITS components and communication with a student.

An analysis of different ITS architectures and their pedagogical components [15]–[18] has been carried out in the Doctoral Thesis. Based on the analysis, the summary of synonyms used for a pedagogical component has been provided. Some of the identified names are, for example, pedagogical module, instruction (or instructional modelling) module, instructor module, teaching strategy module, tutorial/tutoring module, teacher module, etc. Regardless of the variety of names, the term "pedagogical module" is used in this Thesis because it generally focuses on the pedagogy and foresees both the use of pedagogical knowledge and teaching approaches for the implementation of the tutoring process.

Knowledge about tutoring is fundamental for the functionality of a pedagogical module because this knowledge determines when to intervene taking into account a student's knowledge state, learning style and emotions, thus allowing ITS to adapt its responses to an individual student. Specifically, general pedagogical knowledge, pedagogical content knowledge and curriculum knowledge are fundamental for any pedagogical module [19].

Existing ITSs have been analysed in the Thesis [18]–[22] and various types of information stored in these systems to provide full functionality of the pedagogical module have been summarized. The stored information can be as follows:

- instructional goals, which can be selected depending on the student's progress;
- knowledge about pedagogical strategies (or set of instructions);
- knowledge about the curriculum for teaching the particular learning content;
- knowledge about various teaching methods suitable for the particular learning content;
- algorithms for identifying the moment and type of an intervention and implementing it;
- knowledge about intervention process or intervention components;
- algorithms for generating tasks, problems and/or questions;
- algorithms for answering questions asked by students;
- algorithms for the implementation of interaction and control of the learning activities.

Table 1.1

Summary of ITS Components

Modules	Functions	Knowledge required	Interaction with other modules (sent data)
Student diagnosis module	• To collect information about the student and his/her characteristics by asking direct questions or monitoring actions performed by the student • To carry out student modelling – to determine the current knowledge level and skills (to create or update the student model) • To diagnose student's missing knowledge and/or misconceptions • To update information about the student's learning progress • To register activities done by the student • To anticipate possible student's responses to various teaching actions	• Information about the student – student's entered data, previous answers, solutions and/or actions • Acquired/unknown topics, misconceptions, various parameters related to student's cognitive, psychological and emotional characteristics, learning objectives, learning style, interests, etc. • Student solutions or given answers • Expert solutions/answers • Most common mistakes • Missing knowledge • Knowledge assessment results	• Information from the student's model (the current knowledge state, mistakes, psychological characteristics, etc.) is sent to the pedagogical module for the selection and implementation of further teaching actions • Authorization results (successful or unsuccessful authorization) are sent to the interface module • The comparison of expert's and student's solutions is sent to the problem domain module in order to identify acquired knowledge, mistakes made and/or missing knowledge
Problem domain module	• To store and retrieve problem domain knowledge and related components (theoretical material, tasks, solutions, answers, hints) • To generate questions, solutions (or intermediate steps), answers and explanations for the solution or comparison results of expert and student solutions • To infer new knowledge from the problem domain model for generating a particular task or problem solution (need for the ability to learn) • To identify mistakes in the student's solution and determine missing knowledge that caused them • To identify the most common mistakes in student answers/solutions	• Problem domain knowledge and relationship between related components • Algorithms for the generation of task or problem solutions (solution steps) and answers so that answers/solutions could be compared • Algorithms for the generation of explanations of the expert solution or comparison results of expert and student solutions • Algorithms for the knowledge retrieval and inference of new knowledge to support solution generation	• An expert solution is sent to the student diagnosis module with the aim of evaluating a student's solution, as well as identified missing knowledge is transferred to this module • Theoretical content, problems/tasks and/or feedback appropriate to the student's knowledge and problem-solving skills are sent to the pedagogical module as well as the required learning content for the generation of feedback, tasks, and questions is transferred to the pedagogical module

Table 1.1 (continued)

Summary of ITS Components

Modules	Functions	Knowledge required	Interaction with other modules (sent data)
Pedagogical module	• To store instructional goals, plans for their achievement and pedagogical strategies in the pedagogical model • To control and manage the learning process and interaction with a student • To select the most suitable pedagogical strategy for the organization of the learning process • To select a specific part of the problem domain (learning content planned to be taught), its presentation sequence and type • To generate tasks, problems and/or questions suitable for the student • To monitor the student's learning process • To identify the moment of intervention, its type and content as well as implement it • To respond to student's help requests and/or provide answers • To assess the student's current knowledge level	• Pedagogical knowledge and the comparison between the student's knowledge and expert knowledge • Instructional goals • Changes in student actions/progress – mismatches between student's knowledge and expert knowledge • Type and content of interventions • Information about the student's current knowledge level and skills received from the student model • Information about missing knowledge, which should be taught again • Information about the student, his/her characteristics, learning style, etc. received from the student's model	• Information to be presented to the student is sent to the interface module together with teaching actions, dialogue and ITS's attitude (represented by a pedagogical agent) • Student's submitted solutions or given answers are sent to the student diagnosis module for further comparison with the expert's solutions or answers • Requests for learning content, explanations and/or solutions for generated tasks or problems are sent to the problem domain module
Interface module	• To provide the system's graphical user interface and its customization • To imitate the visual image of a human-teacher, his/her actions and characteristics by using a pedagogical agent • To ensure authorization • To implement ITS communication with the student and vice versa • To manage the use of various input-output devices • To present information in the adapted form • To send a student input to other ITS components	• ITS usage level (novice, interm-ediate, expert, etc.) • Information to be presented • Teaching actions, dialogue and/or ITS's attitude towards the student's performance and actions (for the representation by a pedagogical agent)	• Information about solutions or answers submitted by the student, asked questions, help requests are sent to the pedagogical module • Entered or observed data about the student (identifying information, characteristics, actions performed) are sent to the student diagnosis module

When summarizing the information on the functionality and role of pedagogical module [13]–[17], it should be concluded that the main function of the pedagogical module is related to the adoption of various pedagogical decisions, which can be divided into three categories:

1) decisions determining when to teach (or to intervene in the learning process);
2) decisions determining what to teach (or with what to intervene in the learning process);
3) decisions identifying how to teach (or what teaching methods to use).

All of the above-mentioned decision categories are realised in order to achieve the main goal of the pedagogical module – to represent the instructional process and ensure its progress by simulating the human-teacher and his/her pedagogical approach or used teaching methods to eliminate differences between the expert knowledge and student knowledge [15], [17]. To achieve this goal, the summary of functions implemented by the pedagogical module (often referred to as instructional goals in some ITSs [13], [16], [17]) has been developed including:

- to adapt/improve pedagogical strategies based on the information in the student model;
- to generate, monitor, evaluate and modify the curriculum;
- to guide students in the learning process to promote their progress and outcomes;
- to assess student's knowledge and performance;
- to bridge students' knowledge gaps or to correct misconceptions;
- to help students to perceive, understand and acquire knowledge in an effective way;
- to promote student's engagement and motivation and help coping with negative emotions;
- to implement an interaction with a student.

Regardless of the instructional goal implemented by an ITS, the effectiveness of system's adaptation will depend on how good pedagogical content knowledge or so-called pedagogical strategies included in the pedagogical model are, and how successfully the pedagogical module is able to choose them at the appropriate moment [23].

1.3. Pedagogical Strategies and Their Role in the Tutoring Process

Pedagogical strategies are the primary tool used by human-teachers for controlling the flow of a lesson and student's progress [24]. In pedagogy, a pedagogical strategy refers to an instructional strategy, framework or methodology employed for organizing learning content and facilitating student's learning [25]. The main objective of a pedagogical strategy is to adapt and ensure the instructional process to bring the student closer to instructional goals [23].

Regarding pedagogical strategies, a detailed study on their role, functions, and application in ITSs has been done in the Thesis [26]–[28]. As a result, the following definition of a pedagogical strategy (in the context of ITSs) has been proposed: a pedagogical strategy is an ITS's action plan defined before the instruction or adapted in a real-time, which includes certain teaching actions derived from possible action sets for the achievement of a specific instructional goal. This plan is used in the pedagogical module to manage interaction with the student and to control the flow of instruction by sequentially arranging learning content tailored to the student's characteristics and at the right time presenting it. This allows creating a challenge aligned with student's knowledge and skills and facilitating his/her involvement in the learning process. Most pedagogical strategies, no matter how complex they are, are based on a fundamental three-step process [25]:

- theory teaching – presentation of a theoretical learning content;
- practice – problem-solving or application of theoretical knowledge in practice;
- knowledge assessment – provision of feedback through assessments.

It is also important to note that pedagogical strategies are mostly considered regardless of the problem domain. Depending on the moment of their choice and use in the process of adopting pedagogical decisions, strategies can exist at two different levels [23]:

- at macro-level (macro-strategies) – selected prior to learning based on student's static data collected in advance, e.g. prior knowledge;
- at micro-level (micro-strategies) – selected during the instructional process based on dynamic student's data acquired in a real-time, e.g. performance, actions, etc.

At these levels, the pedagogical module must be able to analyse the status of student knowledge and other characteristics (including emotions) and make appropriate pedagogical decisions to achieve certain instructional goals and to bring the student closer to the desired learning outcomes. Two more terms related to pedagogical strategies – metastrategy and instructional tactics – have been analysed in the Thesis. A metastrategy represents a higher-level plan (algorithm) for selecting from among a set of strategies based on changing goals and circumstances. Tactics, in turn, can be viewed as purposeful moves aimed at achieving a particular short-term goal in accordance with a specific strategy [29]. Overall, a hierarchical relationship exists between pedagogical strategies and related terms (Fig. 1.2).

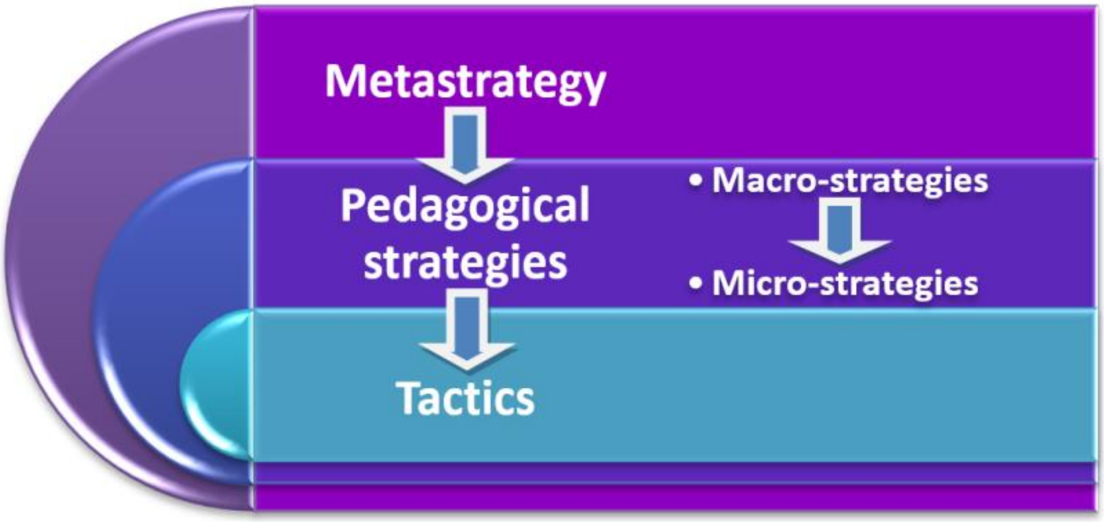

Fig. 1.2. The relationship between pedagogical strategies and related concepts.

So far one of the most important criteria for choosing a pedagogical strategy has been a learning style that defines a student's preferred way of learning. However, there is no common way of classifying learning styles, therefore, other ways to acquire information about a student in a broader context, such as personality analysis using the Five Factor Model (FFM), are being examined in the Thesis. FFM allows obtaining a description of the possible student's learning behaviour, personality and emotional characteristics [30] summarizing this information into five basic traits (also called OCEAN): Openness, Conscientiousness, Extraversion, Agreeableness, and Neuroticism [31].

By analysing already existing research related to the personality's influence on the instructional process, it should be concluded that knowledge about a student's personality can be used to identify various factors influencing instructional process [32]:

- a student's default mood that has an impact on a tendency to particular emotions;
- a student's learning goals;
- a student's intrinsic motivation to learn and being prone to academic achievements;
- a student's learning style;
- the most suitable teacher's personality and preferences for specific teaching methods.

Consequently, the most appropriate teacher's personality and pedagogical strategy will depend to a great extent on the personality traits of a student himself/herself.

1.4. Summary

The analysis of existing studies related to ITSs and their development has been carried out within this chapter with the aim of understanding and characterizing the main ITS components, their roles, mutual interaction, and functions in providing tutoring. In addition, the detailed study of the pedagogical module has been made analysing its goals, functionality, and role in pedagogical decision-making. Moreover, the concepts of pedagogical strategies and related terms have been examined in the context of the ITSs exploring how each of them is used in the adaptation of the instructional process.

- The following tasks have been accomplished in this chapter:
- the research on ITSs has been carried out determining their key characteristics, functional components, components' tasks, and mutual interaction, as well as analysing the knowledge stored and processed in these components for ensuring the tutoring process;
- the nature of tutoring has been described and the analysis of its realisation in ITSs has been carried out by putting particular emphasis on the pedagogical module and its role in the implementation of tutoring;
- the analysis of pedagogical strategies and related concepts has been made, as well as their role in the provision and adaptation of tutoring has been identified;
- the role of a student's personality has been analysed in the context of tutoring adaptation, exploring the impact of personality on various aspects of tutoring.

The following results have been achieved in this chapter:

- features characterising an ITS and components forming its architecture and implementing the adapted instructional process have been defined;
- the summary of ITS components, their functions, the necessary knowledge and/or data for the implementation of these functions has been developed, as well as the mutual interaction of these components from the viewpoint of the information exchange has been described;

- characteristics of tutoring and its differences from the traditional instructional process (e.g. teaching in a classroom) have been identified;
- the role of the pedagogical module in the provision of tutoring has been explored, the main goal of this module has been defined and the knowledge and types of knowledge required for the module to function properly have been identified;
- different types of information and pedagogical knowledge used by the pedagogical module for the implementation of the instructional process have been distinguished;
- three categories of pedagogical decisions, which the pedagogical module makes in ITS, have been identified and analysed;
- pedagogical strategies have been categorized depending on their acquisition source;
- terms related to pedagogical strategies and their role in the adaptation of the instructional process at different levels have been identified;
- student's characteristics influenced by the personality and different factors affecting his/her learning process have been identified for the adaptation of the tutoring process.

The main theoretical result in this chapter is related to the developed summary of the essence, functions, and mutual interaction of the ITS constituent components. The main goal of the pedagogical module is proposed based on its implemented functions and the categories of its made pedagogical decisions are identified. The definition of pedagogical strategies has been introduced and the hierarchy of their related terms is developed.

2. EMOTIONALLY INTELLIGENT TUTORING SYSTEMS

The impact of emotions on the learning process and existing theories and approaches that relate emotions to learning are examined in this chapter, and as a result, requirements for the implementation of an emotion-based tutoring process are defined. In addition, the study of the concept of an “emotionally intelligent tutoring system” (EITS) and an analysis of existing EITSs are carried out to identify problems associated with the development of such systems.

2.1. The Emotion-Based Tutoring Process

Previous studies have shown that emotions can affect various aspects of human behaviour and cognitive processes, e.g. attention, long-term memory, decision-making, remembering and analysing. Emotions and cognition are interrelated processes in learning situations where students are asked to analyse, reason, make conclusions, apply acquired knowledge, answer questions, solve tasks and provide explanations [6]. Positive emotions play an important role in the development of creativity and the ability to adapt to different problems during their solving, and are also able to increase students’ motivation to learn. Conversely, negative emotions can block thinking processes and hinder abilities to concentrate, remember, memorise, reason and draw conclusions [33]. In the learning process, three different functions of emotions can be distinguished [34]: 1) a signalling function, which indicates, for example problems with knowledge or motivation; 2) an evaluative function, which appraises events in terms of their value, goal relevance and goal congruence; and 3) a modulation function, which constrains or expands cognitive skills of a student, for example reduces his/her concentration skills or facilitates information processing.

A number of theories that relate emotions to learning are analysed in this Thesis, for example cognitive disequilibrium theory, control-value theory, academic risk theory, flow theory, and test anxiety theory [12]. These theories suggest that such emotional states as confusion, curiosity, interest, flow, joy, boredom, frustration, anxiety and surprise are particularly relevant in learning, and can influence a student’s performance and learning outcomes. Most of these emotions can be found in the learning process implemented by both ITSs and human-teachers, and developers of emotion-aware ITSs should therefore pay particular attention to these emotions [11].

In addition, emotion-based pedagogical strategies that are aimed at emotional regulation and coping have been analysed. Emotional regulation strategies involve a reduction in high levels of emotion arousal, and apply to both positive and negative emotions [35]. Emotional coping strategies focus on decreasing the impact of negative emotions by trying to eliminate them completely [36]. In addition to these strategies, theory-based approaches derived from the field of research into emotions are also considered in this Thesis. The approaches examined here include ECOLE (Emotional and Cognitive Aspects of Learning) [37] and FEASP (F(ear)E(nvy) A(nger)S(ympathy)P(leasure)) [38]. In these approaches, the main emphasis is placed directly on emotionally sound tutoring process and strategies that aim to increase positive and reduce negative emotions during learning. Based on an analysis of the theories, strategies and approaches mentioned above, common features are identified and requirements for the implementation of an emotion-based tutoring process in ITSs are defined. Requirements are divided into categories representing the whole tutoring process and three fundamental steps of pedagogical strategies (theory teaching, practice, and knowledge assessment). The developed requirements are as follows.

The whole tutoring process:

- the tutoring process and learning content should be clearly structured (this influences student's motivation and interest);
- clearly defined instructional goals and requirements for achieving them should be ensured;
- more freedom for a student should be provided regarding the choice of topics and tasks;
- the feedback provided after tasks or knowledge assessment should be appropriate to the student's knowledge; it should encourage not to give up in case of mistakes; it should highlight correctly solved aspects and then point to poorly mastered concepts, topics or tasks suggesting the student what should be done to address these knowledge gaps;
- the tutoring process should be organised in such a way that it is aimed at achieving instructional goals even in case of failure;
- possible causes and manifestations of negative emotions should be recorded to respond to these emotions in a timely manner by making changes to the instructional process;
- an opportunity to relax should be provided to the student (humour can be used as well);
- an interaction with a teacher and other students should be provided, also with the aim of receiving help;
- equal opportunities for all students to receive/access learning resources should be provided.

Theory teaching:

- a theoretical content should be clearly structured and sequential; it is necessary to show how topics are related to each other (this positively influences interest and motivation);
- the theoretical content should be presented in different ways, supporting the student's learning style and facilitating the perception of theoretical content.

Practice:

- tasks should be meaningful (they must have a value) for the student;
- the student should be able to choose a difficulty level for tasks or the system should offer tasks with a difficulty level that is consistent with the student's knowledge (or a little higher), thus creating a challenge for student's abilities and causing activity-enhancing emotions;
- tasks and learning environment should be adapted to meet the student's learning needs (this leads to a greater likelihood of positive, activity-enhancing emotions);
- tasks similar to those that will be in the knowledge assessment can be given in order to timely prepare students for tests (this decreases anxiety and improves confidence);
- play-like activities and tasks can be used (this positively influences engagement and motivation);
- mistakes and/or failures should be recognized as opportunities to learn.

Knowledge assessment:

- consistent and transparent assessment criteria and methods should be ensured;

- student's progress should be available to create a desire to strive for higher achievements;
- self-assessment tasks should be provided (this increases engagement and motivation).

2.2. Emotionally Intelligent Tutoring Systems and Their Analysis

Around 15 years ago, ideas from AC were introduced into the development of ITSs, and as a result, a new generation of tutoring systems appeared, known as EITSs. [11]. These systems are able to recognise a student's emotions and respond to them by adapting the tutoring process and showing emotions of the tutoring system itself (by means of pedagogical agents). By analysing the concept underlying this type of system [4], [39], [40], a summary of the synonyms used to describe EITSs is created in this Thesis. These synonyms include emotionally intelligent tutor systems, emotion-sensitive tutoring systems, affective tutoring systems, affect-aware tutors, etc. In addition, the various reasons for the need to consider emotions as one of the parameters in the development of ITSs are summarised in the Thesis. Some of these are as follows [41]:

- the possibility of ensuring an optimal emotional state for the achievement of better learning outcomes;
- the reduced risk of uncertainty and disturbing interventions of ITSs, and the improved adaption abilities of the system;
- the more effective imitation of pedagogical decisions made by human teachers, in order to respond appropriately and provide suitable feedback;
- the timely recognition of negative emotions and minimisation of their negative effect, with the aim of increasing students' motivation;
- the promotion of students' involvement and confidence.

Taking into account the above information about EITSs and their development purposes, the following definition of EITS is proposed: EITS is an ITS that imitates a human teacher and his/her ability to adapt not only to the student's knowledge but also to his/her emotional state with the aim of intervening (reacting accordingly) only in situations where this emotional state may become a threat to the student's willingness to engage in the learning process and negatively influence his/her knowledge acquisition and learning outcomes. In order to consider an ITS as emotionally intelligent, it should be able to:

- identify the most suitable emotional state of a student to promote learning;
- recognise the student's current emotion by analysing various sources of emotional data;
- analyse the impact of the identified emotions on the learning process and make pedagogical decisions to respond appropriately to these emotions:
  - to intervene in the learning process, if these emotions may negatively affect the achievement of a certain instructional goal;
  - to avoid interrupting the learning process if these emotions can promote learning (since disturbing students during the learning process can lead to negative emotions);
- in the case of intervention, adjust pedagogical strategies and choose a sequence of further tutoring actions based on both the knowledge and emotions of the student;

- analyse the influence of the tutoring actions performed on the student's emotional state, in order to use this information as feedback for the improvement of the functioning of EITS.

An analysis of the existing studies of EITSs allows us to conclude that the functionality of such systems requires an extension to the traditional architecture of ITSs by adding additional components in order to create a model of affective behaviour [41]. The first component is usually responsible for the automatic identification of a student's emotional state, and an emotional response module or affective (behaviour) pedagogical model is often integrated as the second component, which can be considered an extension of the pedagogical module. An emotional expression module that allows the EITS to express emotions is typically included as the third component.

Several different EITSs are analysed in this Thesis, focusing on the following aspects: identification of a student's emotions, expression of emotions by the system, and the adaptation of the tutoring process. In total, 17 EITSs are examined from various problem domains including physics, mathematics, the natural sciences, computer science, and languages. The detailed results of this analysis in terms of the identification of emotions (the sensors used, emotional features extracted, and classification methods applied) are reflected in Table 2.1 [41].

Table 2.1

Summary Regarding Emotion Identification in Existing EITS

Sensors	Features characterizing emotions	Methods used for the classification of features	Identified emotions
Physiological sensors • skin conductivity sensor • heart rate sensor • electromyograph **Touch or haptic sensors** • pressure-sensitive mouse • pressure-sensitive chair **Observational sensors** • video camera • eye tracker • microphone **Sensor-free approaches** • emotion prediction (e.g. OCC model) • surveys or self-assessment (e.g. Self-Assessment Manikin) • analysis of the student's interaction/behaviour	• facial features, gaze or regions of interest • body posture • physiological signals (skin conductivity, heart rate, muscle activity) • acoustic-prosodic, lexical features (speech intensity, energy, volume, duration and pauses) • dialogue features (e.g. the accuracy of the answer) • the usage of input devices • student's interaction with the system • student's behaviour	• neural networks • Naïve Bayes • dynamic Bayesian network • logistic regression • linear regression • step regression • support vector machines • nearest neighbour • decision trees • fuzzy logics • unsupervised clustering • discriminant function analysis	• anger • disgust • fear • joy (delight, happiness) • sadness • surprise • interest (flow) • confusion • boredom • frustration • anxiety • neutral emotions • confidence • shame • pride • disappointment

Table 2.2

Adaptation of Various Tutoring Activities to the Emotional State of a Student

Tutoring activities / EITSs	Planning of the tutoring, sequencing of tutoring actions	Theory teaching (selection of a topic and teaching method)	Feedback, help, hints, explanations	Practice, showing examples and problem-solving steps	Selection of practical tasks and their difficulty	Off-topic conversation	Knowledge assessment
AutoTutor [42]			+/+			+/+	
Cognitive Tutor Algebra I [43]	+/+		+/+		+/+		
Crystal Island [44]		+/–	+/+			+/+	
Easy with Eve [39]	+/+		+/+		+/–	+/–	
EER-Tutor [45]			+/+		+/+		
EMASPEL [46]	+/+		+/+		+/+	+/–	
FERMAT [47]	+/–		+/+		+/+		
GURU Gaze Tutor [48]		+/–	+/+			+/+	
Inq-ITS [49]		+/–	+/+				+/–
INES [50]			+/+	+/+	+/+	+/–	
ITSPOKE [51]		+/–	+/+			+/–	
MathSpring [19]	+/+		+/+	+/+	+/+	+/+	
MetaTutor [52]	+/+		+/+				
PAT2Math [53]	+/+		+/+		+/+		
PRIME CLIMB [54]			+/–				
VALERIE [55]			+/+			+/–	
WALLIS [56]			+/–	+/–			

Empty cell – adaptation of the particular tutoring activity to student’s emotions is not supported;
+/– – adaptation of the particular tutoring activity to student’s emotions is partially supported;
+/+ – adaptation of the particular tutoring activity to student’s emotions is fully supported.

For a better understanding of the current situation regarding the adaptation of the tutoring process and activities to the student's emotions in existing EITSs, a table summarising this information is presented in this chapter (Table 2.2). In total, seven activities are identified, including the initial planning of the tutoring process, all three steps of the tutoring process, and three additional activities that were found from an analysis of existing systems.

2.3. Results of Analysis of Emotionally Intelligent Tutoring Systems

Strengths of EITSs

In terms of the identification of emotions, it is notable that the initially developed EITSs were able to recognise only basic emotions, which involved relatively simple recognition based on the classification of facial features. However, the latest developments have focused on emotions that can directly influence a student's learning [41]. Most of the EITSs examined here use pedagogical agents that simulate the behaviour and emotions of human teachers. Agents are able to increase the ability of tutoring systems to communicate with students and show emotions, and are able to involve students in the learning process and motivate them.

Regarding the implementation of pedagogical strategies in the existing EITSs, it should be noted that most systems use more than one pedagogical strategy (usually two or three), the foremost of which is scaffolding. The provision of feedback is therefore the most common activity that is adapted to the student's emotions since its realisation is relatively fast and easy, involving the addition of an emotional character to the feedback. Pedagogical agents have an important role in the implementation of emotional feedback, since they express the emotions of EITS in response to the student's actions and/or results. The next most commonly used strategies are the Socratic method (asking students questions and prompting them for the right answers) and guided discovery learning (in which students acquire knowledge by themselves while searching for answers and learning from their mistakes).

During the teaching of theory, the student's learning style is taken into account in most cases, thereby promoting the acquisition of the theoretical content. The learning style is an essential factor in improving the effectiveness of EITSs, since an inappropriate form of content representation can give rise to negative emotions. The selection of practical tasks and their difficulty is mostly based on the zone of proximal development in which the difficulty of the task corresponds to the student's knowledge level or is slightly higher, in order to keep him/her interested in the learning process (creation of the flow state) [57].

Maintaining an off-topic conversation can be considered one of the emotional regulation strategies used by EITSs, as it helps the system to redirect the student's attention from the emotional situation.

Weaknesses of EITSs

In general, current methods for emotion recognition are based on various sensors (e.g. physiological sensors); these provide high levels of accuracy for the retrieval and classification of emotion-related features, but in real learning conditions, for example, computer classes, are not available. One possible solution for overcoming this problem is the combination of a sensor-lite approach that requires minimal use of the available sensors (e.g.

built-in cameras or microphones), with sensor-free approaches (listed in Table 2.1) that do not currently provide sufficient accuracy in emotion recognition.

Although several research groups have developed emotional pedagogical agents, their impact on learning is not yet convincing. Various factors, for example visual image, behaviour and the presence of pedagogical agents, can affect their design and development and can even influence their effectiveness on some students.

In tutoring planning, emotions are considered only in EITSs that teach mathematics. However, since tutoring in any domain needs to be planned, pedagogical strategies and their adaptation to the various characteristics of a student (including emotions) are of great importance.

Practice is one of the least supported tutoring activities in terms of its adaptation to emotions. Since most problem domains are focused on the application of theoretical knowledge in practice, it is important to include not only the acquisition of problem-solving skills but also to anticipate the identification of emotions during this learning activity. This also coincides with the idea of emotional coping strategies in which factors that affect the emotional situation should be addressed and the intensity of negative emotions reduced, so that students can continue acquiring skills. Consequently, this tutoring activity receives the same level of support in the currently available EITSs as in traditional ITSs.

As a tutoring activity, knowledge assessment is usually ignored in terms of the analysis of emotions for the adaptation. However, it is an integral part of the learning process, and for most students it creates a basis for negative emotions that affect not only student's thinking and reasoning processes but also self-assessment and confidence in his/her knowledge and skills.

In follow-up work, emphasis has been placed on addressing the identified shortcomings, with a particular focus on knowledge assessment in which students are more frequently exposed to negative emotions. In order to incorporate emotions into knowledge assessment and to use them to improve the learning outcomes of a student, game-based learning, one of the pedagogical strategies that is often used in EITSs, is applied in this Thesis for knowledge assessment. Game-like activities represent a pedagogical strategy that aims to achieve the most desirable emotions (e.g. joy and interest) in the learning process, thus reducing the impact of negative emotions on learning outcomes. Moreover, the use of games in the implementation of EITSs also corresponds to previously developed requirements for the provision of an emotion-based tutoring process [58].

2.4. Summary

The impact of emotions on the learning process has been examined in the chapter. Existing theories and approaches that relate emotions to the learning have been studied to determine learning-specific emotions and define requirements for the emotion-based tutoring process. In addition, existing studies on EITSs have been analysed to distinguish characteristics of such systems and the main differences from traditional ITSs. Besides, the already developed EITSs have been examined with the aim of exploring the current situation and identifying major challenges related to the development of EITSs.

The following tasks have been accomplished in this chapter:

- the influence of emotions on various learning-related cognitive processes has been analysed, and the functions of emotions in the learning process have been identified;
- a study of various theories relating emotions to learning has been carried out to identify those emotions that affect learning and should be included in the development of ITSs;
- emotion-based pedagogical strategies have been analysed to formulate requirements for the implementation of emotion-based tutoring processes in ITSs;
- the concept and development of EITSs have been studied to describe these systems, define their operating principles, and identify the main differences from traditional ITSs;
- an analysis of existing EITSs has been carried out to explore their abilities to recognise learning-specific emotions, to adapt the tutoring process accordingly and to express emotions;
- issues related to the development of EITSs and adaptation of the tutoring process to the student's emotions have been identified and analysed.

The following results have been achieved in this chapter:

- three main functions of emotions related to the learning process have been distinguished, and the effects of positive and negative emotions on learning have been recognised;
- learning-specific emotions have been identified;
- requirements and strategies for the implementation of the emotion-based tutoring process have been defined;
- various goals for extending the functionality of ITSs to include the identification of emotions and the adaptation of the tutoring process have been described;
- the definition of an EITS has been proposed and relevant characteristics and operating principles have been identified, allowing these to be distinguished from traditional ITSs;
- additional components forming the architecture and the affective behaviour model of EITSs have been identified;
- problems related to the determination of a student's emotions have been highlighted;
- the advantages and disadvantages of the use of pedagogical agents have been identified, and the potential of agents to reflect emotions via the system has been analysed;
- shortcomings related to the adaptation of the tutoring process to the student's emotions have been identified based on an analysis of tutoring activities adapted in existing EITSs.

The most important theoretical results of this chapter are the requirements for the implementation of an emotion-based tutoring process in ITSs with the aim of increasing the student's motivation and promoting positive emotions. A definition of EITS is proposed and the characteristics of such systems are identified. In addition, one of the most important achievements of this chapter is an analysis of the existing EITSs that highlights the problems related to the development of such systems.

3. AN INTELLIGENT TUTORING SYSTEM INTEGRATING KNOWLEDGE, GAMES AND EMOTIONS

This chapter provides an analysis of educational games and their adaptive capabilities, and proposes the integration of game-based knowledge assessment into EITSs. In addition, the design of the pedagogical module and tutoring activities, which are required to ensure the successful functioning of the module, are implemented using a two-level adaptation approach.

3.1. Exploiting Games in Emotionally Intelligent Tutoring Systems

A topical direction for current research is the combination of educational games with EITSs, as it is believed that games may improve the student's performance and attitude towards learning [59]. It is generally recognised that educational games are ideal learning environments since they reduce boredom, increase involvement in the learning process, offer various challenges and keep students in the zone of proximal development [31]. An analysis of existing research regarding educational games leads to the identification of several core elements and characteristics of well-designed games: clear goals and rules, adaptability, challenges, rewards, immediate feedback, learning from mistakes, a feeling of control over the game environment, interaction and collaboration with other players [58]. Moreover, the playing of games is an emotional process rather than a rational one, and this aspect should therefore also be considered when developing educational games [31].

Currently, a small number of EITSs have been developed as game-based environments that implement pedagogical actions in the form of interactive and play-like activities; however, the emphasis in these games is primarily on the development of knowledge and practical skills, rather than their potential for knowledge assessment [58]. In fact, knowledge assessment is considered to have the greatest influence on the next generation of educational games, as it can provide authentic assessment activities and situations with meaningful tasks [60].

Despite all the benefits that educational games can provide, their effectiveness in terms of improved motivation, learning process and outcomes is still in question, since the results of existing studies are often contradictory. This is usually because the principles of instructional design and the differences between individual players (or learners) are not considered in the design of educational games [61], [62]. The question of how the adaptation of individual game elements affects learning outcomes (whether or not it improves them) is often not investigated or analysed. In addition, an analysis of the latest research reveals that despite numerous studies relating emotions to games, emotions are considered in the adaptation of game elements only in rare cases [63]. In general, an emotion-based adaptation may be implemented with the aim of providing dynamic adaptation of game elements (e.g. game difficulty or audio-visual elements) and the adjustment of explicit, implicit or player-driven game tasks and their managed appearance in the game flow, to avoid unpleasant emotions such as boredom for the player [31].

To address the previously identified problem of neglecting the principles of instructional design in educational games, the best practices in pedagogy [64] are analysed in the Thesis to evaluate their potential for games. As a result, nine principles of instructional design, which were developed by American educational psychologist Robert M. Gagne, are identified for the implementation of a successful instructional process. In addition, various parameters (characterising both the player and the gameplay) that can be used for adaptation purposes are summarised in this Thesis. These parameters are divided into two categories depending on the point at which they can be used, i.e. before or during a game. These categories correspond to the pedagogical strategies (macro- and micro-) that have already been identified, and the adaptation can therefore be realised at two levels: 1) at the macro-level, which is implemented before learning (gameplay); and 2) at the micro-level, which is realised during the gameplay, e.g. based on the player's responses, actions, emotions, etc.

Based on existing theoretical research, an architecture is developed for an EITS that ensures the modelling of the student's emotions as part of the student diagnostic module, and implements game-based assessment as a part of the pedagogical module (Fig. 3.1).

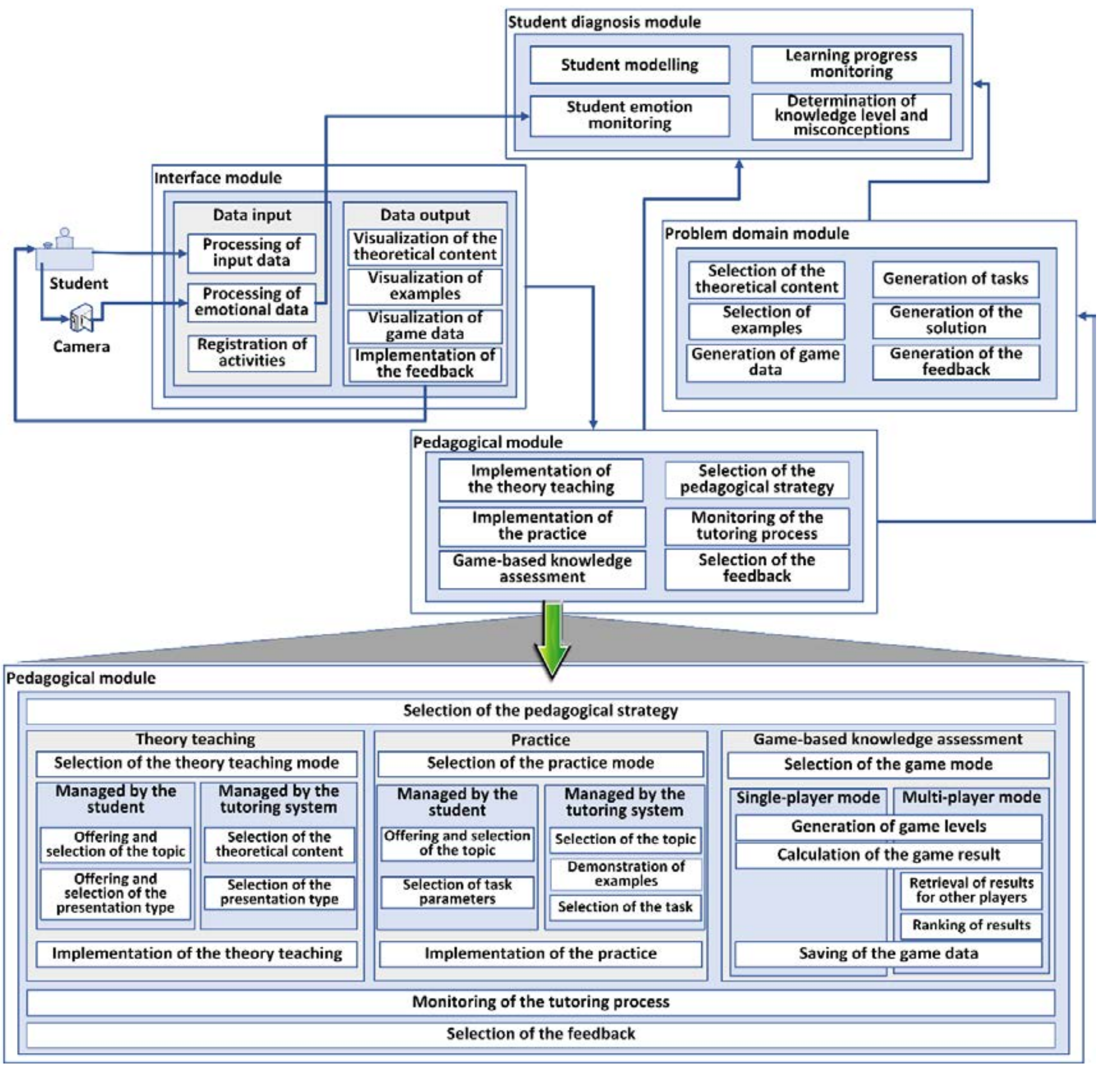

Fig. 3.1. The architecture of the EITS integrating emotions and game-based assessment.

3.2. Game-Based and Emotion-Based Adaptation of the Tutoring Process

A two-level (macro- and micro-) adaptation approach is developed to define the operating principles of the pedagogical module. The approach includes both levels of pedagogical strategies:

- the macro-level adaptation (macro-strategies) realized prior to learning on the basis of static data about the student and tutoring situation;
- the micro-level adaptation (micro-strategies) ensured during the tutoring process on the basis of dynamic data (acquired in a real-time) about the student and tutoring situation.

The Macro-Level Adaptation

The macro-level adaptation is implemented based on parameters that are available to the EITS in advance. In this case, the personality of the student is used and parameters related to this personality are acquired (e.g. the preferred learning style and tendency towards goal achievement) and the type of pedagogical agent and pedagogical strategy are selected. Personality traits are used as the basis for classification of the student. Depending on the prevailing personality trait, the student is matched to one of the four learning styles of Kolb – diverging, assimilating, converging or accommodating [31]. The overall process of the macro-level adaptation is shown in Fig 3.2.

The goal that the student wants to achieve is also important in the macro-level adaptation. For this purpose, a 2 × 2 achievement goal framework is used to identify whether students are trying to reach mastery and want to learn as much as possible to improve their knowledge (mastery goals), or whether they prefer to do better than others and/or to move faster through the learning process and acquire surface knowledge (performance goals) [65].

The Micro-Level Adaptation

The micro-level adaptation is realised on the basis of dynamic parameters that change during the learning process. The development of micro-level adaptation is based on the possible values of the parameters gathered, which vary in real time (classified according to Kolb's learning styles) [66]–[68]. A summary of these parameters is presented in Table 3.1. Based on this summary, the detailed operating principles of the EITS were designed for each tutoring step (theory teaching, practice and knowledge assessment). In addition, each of these steps are designed for four different types of pedagogical agent (PA): 1) Friend, 2) Expert, 3) Coach and 4) Evaluator, and each of the steps is represented using both **block diagrams** and **reacting rules** according to which each PA should act in response to student's emotions. In total, 12 different operating scenarios have been developed ensuring the detection of student's emotions and the adaptation of system's behaviour to them.

The first step is theory teaching (a level that presents a theory and demonstrations). This is designed in four different forms depending on the type of PA and its pedagogical strategy (the macro-strategy), and the student's learning style and emotions. When teaching is initiated, the amount of theoretical information that is intended to be presented to the student is first considered.

If this is minimal, then a brief introduction is given; otherwise, the theory is provided together with demonstrations. If students are also engaged in activities, then feedback is provided on their actions depending on the type of PA and the results of the actions. Emotional monitoring is carried out throughout the tutoring process, and if negative emotions are detected, then based on an analysis of these and the tutoring situation, the tutoring is either repeated, modified or continued. Positive emotions are encouraged by giving positive or motivational feedback.

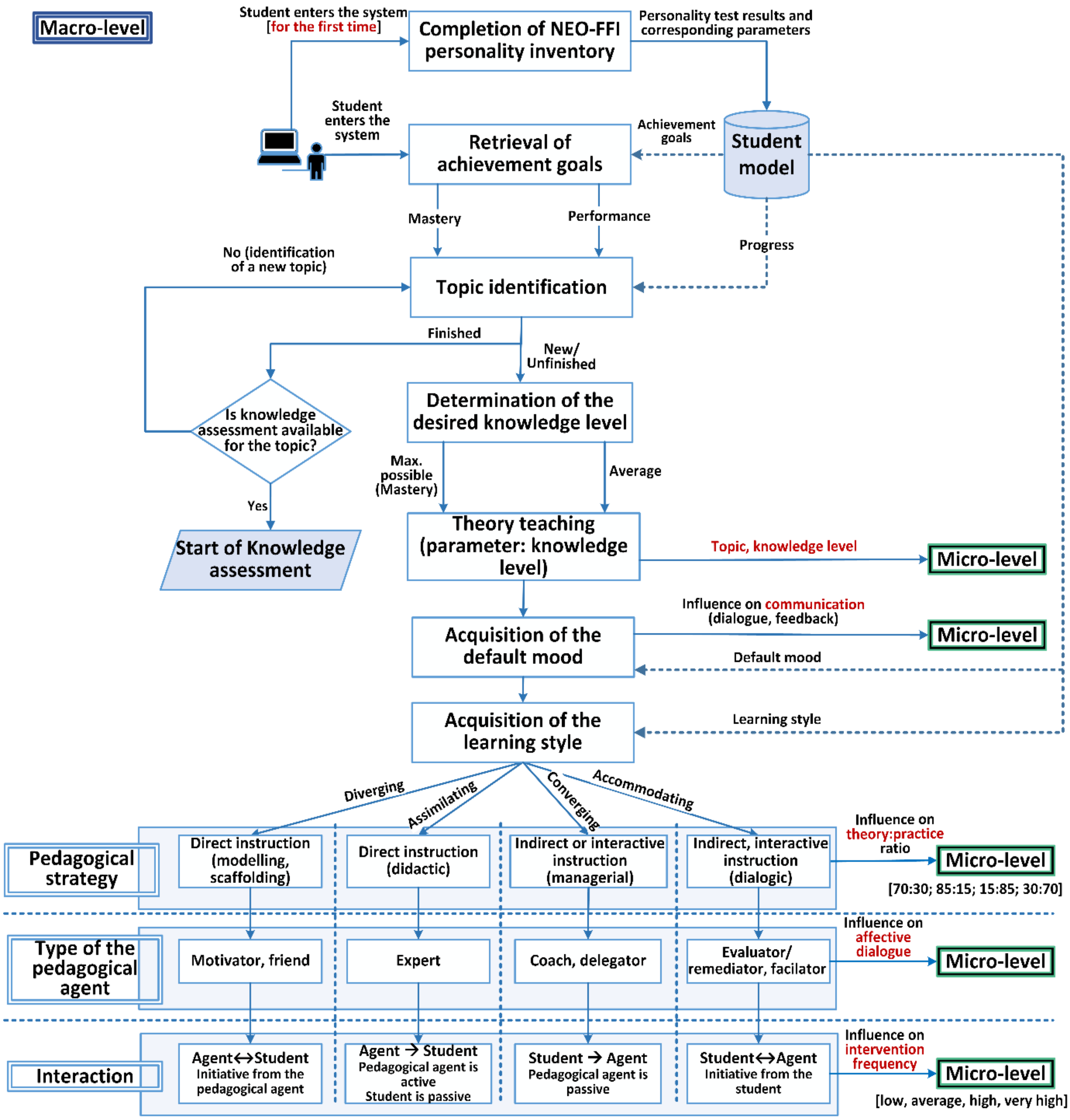

Fig. 3.2. The macro-level adaptation.

Table 3.1

Parameters for the Selection of Pedagogical Strategy According to the Learning Style

Learning styles / Parameters	Diverging	Assimilating	Converging	Accommodating
Sequence of tutoring process	The sequence and rules are important; there should be a possibility to restart the sequence in case of mistakes	Sequence and rules are important	The sequence is not important; the student needs also to have a possibility to choose a topic	The sequence is important (an order of topics is needed), but the student needs also to have a possibility to choose a topic
Learning goals	Clear (PA defined) goals, which the student must achieve (needs to see the "big picture")	Clear (PA defined) goals, which the student must achieve (needs to see the "big picture")	Must have a goal (PA or student defined), which the student must achieve	Must have a goal (PA or student defined), which the student must achieve
Preferred activities **Promotion of motivation (maintaining the flow state)**	Prefers to observe and evaluate others; needs to see the "big picture". Likes research, analysis and solving problems from different perspectives. Needs a possibility to freely exchange ideas without being punished for it	Needs the "big picture" of the whole tutoring situation. Prefers abstract problems and/or theory; problem-solving, which requires systematic thinking, goal setting, planning and research. Likes intellectually challenging tasks	Prefers problems of the real world; their connection to life are important. Needs imitation, practical/technical tasks, training, application of theory in practice; strong in decision making	Prefers to take a risk, likes challenging tasks, which require adaptation skills. Competition and activities, which bring some valuable results to the student, are important
Orientation to theory or practice	More theory	Just theory	More practice	Just practice
Demonstrations	Yes	Yes	No	No
Knowledge assessment	Multiple choice questions desirable (less chance of mistakes). It is important for the student to see personal growth	Mandatory (with clear results and a possibility to see the personal growth) but the type of assessment is not important	Prefers tests/questions with one answer. Needs standards to be achieved in order to see the growth relative to others	Prefers to achieve all by himself/herself or to learn from mistakes. Needs standards to be achieved in order to see the growth relative to others
Information provided	Must be true	Must be true	Can be partly true	Can be partly true or false
Involvement of emotions	Feels emotions and makes emotion-based decisions	Controls emotions or does not feel them during the learning	Controls emotions or does not feel them during the learning	Mostly feels positive emotions; usually hard to control emotions
Time limitations	Prefers no limits	Prefers no limits	Limits can be present	Limits can be present
Representation of progress	Personal growth is important. Personal achievements should be represented and goals should be set to improve the progress compared to previous achievements [Rewards, not points]	Personal growth is important. Personal achievements should be represented and goals should be set to improve the progress compared to previous achievements [Rewards and conditions for their achievement]	Personal growth compared to others or in terms of pre-defined standards is important [Rewards and points shown in scoreboard]	Personal growth compared to others or in terms of pre-defined standards is important [Points shown in scoreboard]
Feedback	A timely provided motivating feedback, which includes comparison with the student's previous achievements	A clear feedback, which informs the student about the result, what was or was not correct, why, etc	A motivational feedback that encourages the student to reach maximum (compared to other students or pre-defined standards)	A neutral or positive feedback if the student is too positive, or a motivational feedback, which encourages to reach maximum

After the theory level, the practical level is implemented in the form of various challenges (game levels). Depending on the task and its level of difficulty, additional options (such as help) are available, but the use of these options will affect the result (achievements/score). During the practice level, the student's performance and actions are analysed (the time required for problem-solving, whether help was requested, the correctness of the solution, etc.) and various interventions are carried out by the EITS depending on the type of PA assigned. Emotions are also evaluated to identify situations or actions of the system that caused negative experiences or facilitated positive ones. Negative emotions can be a sign of missing knowledge, a need for help or a challenge that is too easy. An example of the developed scenario and its corresponding reacting rules during the practice for the PA-Friend is shown in Fig. 3.3.

When the practice stage is complete, knowledge assessment is initiated, which also involves analysis of student's emotions. The main difference in the case of problematic situations (e.g. when negative emotions are detected) is that interventions are not carried out during the assessment itself; instead, the behaviour of the EITS is adapted afterwards. Minor changes are implemented in the interaction (or communication) between a PA and a student. This approach can be explained by the fact that a student's knowledge is typically evaluated through exams, in which they are asked to use only their knowledge without help from others. An exception is made if negative emotions are detected over an extended period or if a student needs more time for the provision of a correct answer. Otherwise, interventions can promote the emergence of negative emotions (e.g. anxiety or frustration).

Knowledge assessment starts with an activity that determines whether the assessment is being carried out for the first time. If so, then an explanation of the knowledge assessment rules is given, meaning that the EITS must intervene in this step to explain the rules. The student's emotions are also monitored to adjust the explanation process or to adjust the behaviour of the system. The next activity is the selection of suitable questions to assess the student's knowledge of a particular topic. These questions are then presented to the student. In this step, the student's emotions and the time spent on answering questions form an important source of information for identifying problematic questions (PQs). For example, if the EITS identifies that students feel anxiety during a specific question and the emotional state does not change within five seconds, then the EITS automatically adds a question to PQs to analyse the correctness of the answer in the next step. Measurement of the duration of this emotion is carried out based on an analysis of the related studies and a determination of the time required for a human to process stimuli and express an emotion in response (on average, emotions last for ~4 s) [69], [70]. In addition, the time required for reading and processing emotional data is added to the duration of emotions.

Moreover, questions, which required the use of available options, are also recorded as PQs. After submitting an answer, it is analysed and depending on its correctness and the student's current emotional state a feedback is provided to the student. An example of the developed reacting rules during the knowledge assessment for the PA-Friend is represented in Fig. 3.4.

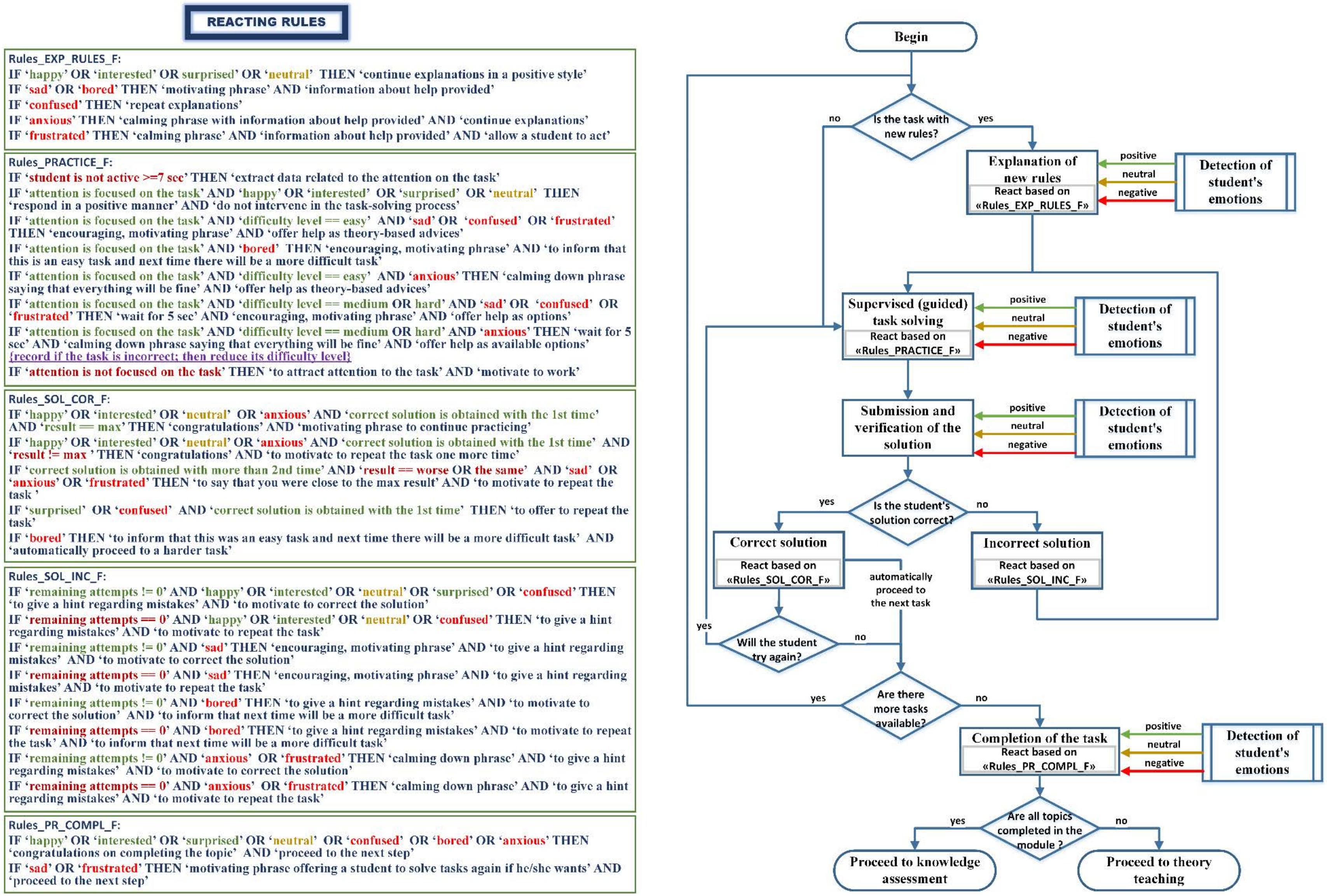

Fig. 3.3. Practice: PA-Friend.

Rules_EXP_RULES_F:
IF 'happy' OR 'interested' OR 'surprised' OR 'neural' THEN 'continue explanations in a positive style'
IF 'sad' OR 'bored' THEN 'encouraging phrase' AND 'information about available options'
IF 'confused' THEN 'repeat explanations'
IF 'anxious' THEN 'information about available options as a help' AND 'continue explanations'
IF 'frustrated' THEN 'calming phrase' AND 'information about available options'

Rules_ASSESSMENT_F:
{record question answering time for statistical purposes and for the identification of «problematic questions» (PQs)}
IF 'happy' OR 'interested' OR 'neural' THEN 'do not intervene in the knowledge assessment'
IF 'surprised' OR 'confused' OR 'anxious' OR 'sad' THEN 'wait for 5 sec' AND 'remind about available options' AND 'record a question as PQ for the later analysis based on time' {'analyse an answer (correct/wrong)' AND 'give additional explanations about a question in the form of theory' AND 'add a question to PQs IF the time spent on a question is: ≥20sec for «easy» questions; OR ≥30sec for «medium»; OR ≥45sec for «hard»; }
IF 'any option is used' THEN 'record a question as PQ for the later analysis' {'analyse an answer (correct/wrong)' AND 'give additional explanations about a question in the form of theory' AND 'add a question to PQs'}
IF 'bored' OR 'frustrated' THEN 'record a question as PQ for the later analysis with emotions' { 'analyse an answer (correct/wrong)'; IF 'the answer is wrong' THEN 'give additional explanations about a question in the form of theory' AND 'add a question to PQs' OR IF 'the answer is correct' THEN 'mark question as the easy one for a student' }

Rules_RESULT_F:
IF 'answer is correct' AND 'question == PQ' THEN 'give explanations about a question'
IF 'answer is correct' AND 'happy' OR 'interested' OR 'surprised' OR 'neural' OR 'confused' OR 'anxious' OR 'sad' OR 'bored' OR 'frustrated' THEN 'positive congratulations'
IF 'answer is wrong' AND 'happy' OR 'interested' OR 'surprised' OR 'neural' OR 'confused' THEN 'give explanations about a question' AND 'add a question to PQs'
IF 'answer is wrong' AND 'anxious' OR 'sad' OR 'bored' OR 'frustrated' THEN 'motivating, encouraging phrase AND 'give explanations about a question' AND 'add a question to PQs'
IF 'result < minimum required' THEN 'repeat the knowledge assessment'
IF 'result ≥ minimum required' AND 'result < maximum possible' THEN 'offer to repeat the knowledge assessment'

Fig. 3.4. Knowledge assessment: PA-Friend.

3.3. Summary

Benefits, basic elements and characteristics of educational games have been analysed in this chapter. The relationship between games and emotions has been examined and the usage of games for the knowledge assessment has been analysed. In addition, the implementation of the adaptation in educational games has been studied. Based on the summarized information about ITSs, emotions and educational games, the architecture of the EITS has been developed and the emotion-based adaptation with two levels has been implemented.

The following tasks are accomplished in this chapter:

- an analysis of the characteristics of educational games has been carried out in terms of the learning process, and the relationship between games and emotions has been explored;
- the concept of game-based assessment has been studied;
- existing educational games have been analysed to evaluate their adaptive abilities;
- an emotion-based adaptation has been studied in the context of educational games;
- various pedagogical principles have been examined with regard to their integration in educational games with the aim of promoting the student's motivation and improving learning outcomes;
- several parameters related to the adaptation in educational games have been analysed;
- the EITS architecture has been developed, with a particular focus on the pedagogical module;

- a two-level adaptation approach has been proposed to ensure the proper functioning of the pedagogical module before/during the learning process (or game).

The following results are achieved in this chapter:

- the basic elements and characteristics of educational games have been identified;
- mechanisms for emotion-based adaptation in the context of games have been determined;
- pedagogical principles that improve not only student's willingness to play but also facilitate his/her learning have been summarised;
- parameters that can serve as an adaptation source both before and during the game, and potential elements of the game involved in the adaptation, have been identified;
- an EITS architecture that includes game-based assessment has been proposed;
- the adaptation approach has been developed, with two adaptation levels (macro- and micro-) that are responsible for the operating principles of the pedagogical module;
- twelve operating scenarios have been designed for four different PAs in all three steps (theory teaching, practice and assessment).

The main practical results of this chapter are the proposed EITS architecture and the two-level adaptation approach, which reflects in detail all the activities in both adaptation levels (macro/micro). Adaptation at the macro-level is implemented based on a student's personality, learning style and achievement goals, and by initialising the appropriate type of PA and pedagogical strategy. Adaptation at the micro-level is ensured by taking into account the emotional states of a student and his/her activities undertaken during the learning process.

4. IMPLEMENTATION OF THE PEDAGOGICAL MODULE AND EMPIRICAL ANALYSIS OF THE MODULE

Details of the development of EITS are described in this chapter in order to evaluate the proposed two-level adaptation approach with all four PA types. Significant emphasis is placed on the detailed development of the knowledge assessment step, including the analysis of the student's emotions. In addition, an experimental study with 244 students is described to evaluate the influence of EITS on the knowledge assessment process and the student's emotions.

4.1. Implementation of the Emotionally Intelligent Tutoring System

A web-based EITS called ELIA (Emotions for Learning and Intelligent Assessment)1 has been developed by the author. The system is available in two languages (Latvian and English) for the two user categories of students and teachers.

Emotion Detection

Emotion detection is implemented by adopting an existing web-based tool called *Emotion API*[2] [31], [63]. By default, this tool allows the recognition of basic (i.e. not learning-specific) emotions such as joy, sadness, surprise, and anger, based on an analysis of facial expressions acquired from a camera. However, this tool gives also information about the user's level of attention, engagement and facial actions, which can be used for the recognition of learning-specific emotions such as confusion, frustration, boredom or anxiety. Hence, existing studies of emotion identification were analysed [71], [72] in order to identify typical facial actions for these emotions. As a result, a list of activated facial action units that are typical for each emotion was created; for example, frustration is characterised by raised inner and outer eyebrows, dimpler and negative valence. To improve the functionality of the tool with the identification of learning-specific emotions, a neural network was developed using the *Javascript* library *brain.js*[3] and was trained on particular facial action units acquired via *Emotion API*. Overall, the emotional recognition accuracy for the neural network reached 74.4 %, which matches the state of the art in terms of accuracy (60 % to 85 % [73]).

Identification of a Student's Static Characteristics

The identification of the student's static data (the personality, learning style and achievement goal) is used as a basis for the macro-level adaptation, involving the selection of the most suitable PA type and its pedagogical strategy. A survey of 182 students was also conducted to collect more precise data (characteristics) about them. The results of this survey are used for two purposes: 1) for the implementation of macro-level adaptation in the EITS; and 2) for the development of a personality model that allows for automatic assignment of learning styles and achievement goal [63]. Personality is acquired using the widely recognized NEO-FFI 60-item personality inventory [74] (for foreign students) and a modified version NEO-FFI-L with a 40-item inventory (for

[1] ELIA system – https://www.eliasystem.lv/lang.php?en
[2] https://knowledge.affectiva.com/docs/getting-started-with-the-emotion-sdk-for-javascript
[3] https://github.com/harthur-org/brain.js

Latvian students) [75]. For the identification of student's achievement goal, a 2 × 2 Achievement Goal Questionnaire [65] is used; for the learning style – a questionnaire that identifies Kolb's learning styles and is translated into Latvian by Associate Professor Dr. paed., *L. Mackēviča* [76].

Development of an Adaptive Educational Game

A game framework *Phaser*[4] has been used for the game development. In the first step, a webpage was created to integrate both the game environment and emotion acquisition to ensure an access to emotional data in the game. In addition, student's static characteristics (knowledge level, learning style, achievement goal) are retrieved as global parameters for the use in the game. All possible game states representing the overall architecture of the game are shown in Fig. 4.1.

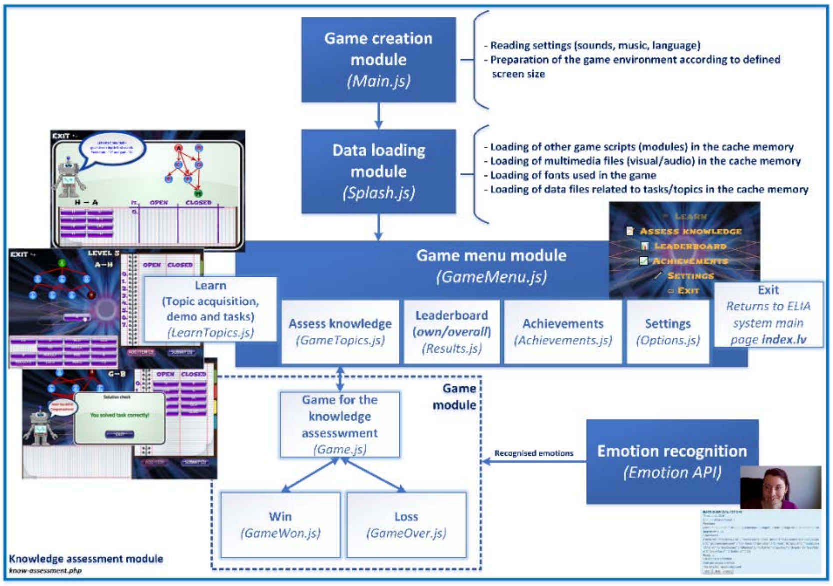

Fig. 4.1. Game modules and their relationship.

The initialization of the game is implemented with the script *Main.js*, which is responsible for the preparation of the game environment and reading main settings. Next, the script *Splash.js* is called that is responsible for loading all game states (modules), multimedia files and other files required for running the game. After loading all files, a user is automatically redirected to the main menu (the script *GameMenu.js*). In the main menu, the user can select a possibility to "Learn" topics (the script *LearnTopics.js*). However, this option is implemented partially without the analysis of student's emotions and adaptation to them; therefore, it was disabled during experiments with the developed system. An option to "Assess knowledge" initiated using the script *GameTopics.js* allows assessing student's knowledge using the game. The game is implemented as a quiz following one of the most popular games called "Who Wants to Be a Millionaire?" in which players try to win $1 000 000 by answering 15 multiple-choice questions with increasing difficulty. The next state is "Leaderboard" (the script *Results.js*) where students can see both their and overall (i.e., compared to others) results in the game. In addition, students can check their earned "Achievements" (the script *Achievements.js*). This option was created with the idea of promoting motivation to play and not only get better results in terms of points

[4] http://phaser.io/

but also to earn “badges” for accomplished missions. The last item in the game menu (besides the “Exit” button) allows changing game “Settings” (the script *Opions.js*).

Adaptation of Goals to be Achieved

Goals, which are set each time for students, are designed in such form that even in a case if the student achieves the last available goal, it can be adapted for making it harder to achieve. For mastery goals, a variable *time* is introduced, which represents student’s best time in a particular topic (e.g. “answer to all 15 questions faster than [*time*] to improve your last result”) and is retrieved automatically from a database using SQL queries. In turn, performance goals are designed using two variables – *time* and *student* who needs to be overtaken to get a higher place in the leaderboard (e.g. “get in the 1st place by answering to all 15 questions in [*time*] and getting ahead of [*student*]”). Data for replacing variables are obtained using specific SQL queries.

Analysis of the Student’s Emotions and Adaptation to These

The analysis of the student’s emotions and the adaptation to these emotions are implemented using two functions: *emotionAnalysis*() and *additionalAnalysis*(). The main goal of the function *emotionAnalysis*() is to acquire two consecutive dominant emotions of the same valence (positive, neutral or negative) in three or four identification cycles. For an emotion to be considered dominant, it must be registered within one cycle for at least 55 % of cases. This threshold was chosen by taking into account both the recommendations found in the literature (50 % to 70 %) and the proposed approaches for threshold calculation based on the number of recognisable emotions [77], [78]. If a dominant emotion is recorded, then the *additionalAnalysis*() function responsible for the adaptation is called. This function works only if certain emotions are detected in the longer term and it is necessary to carry out an analysis and to decide on interventions by the system.

The *additionalAnalysis*() function depends on the valence of the recorded emotions, and operates on a different principle that assumes that the frequency of system interventions is differentiated at the 50 % threshold. In the case of negative emotions, the frequency of interventions is above 50 %, while in the case of positive emotions, interventions occur in less than 50 % of cases.

In each case, the probability of intervention is further adjusted, taking into account the type of PA assigned to a student, the frequency of its interactions (low, average, high or very high) [79], and the fact that interventions that are too frequent (e.g. every time a negative emotion is identified) undermine the credibility of the PA [80]. The overall accuracy of emotion recognition (~75 %) should also be taken into account and existing uncertainty should be considered. In any case, the EITS should not be allowed to completely ignore emotions or to intervene each time an emotion is detected. Figure 4.2 represents interventions for all Kolb’s learning styles implemented in case of negative emotions.

An evaluation of the student’s attention span during the game is carried out using the *attentionAnalysis*() function, which is called only if the game has access to a camera. Every 0.25 s, this function acquires the latest data from the *Emotion API* tool, which (besides facial activity units) automatically retrieves attention data represented as a percentage [0–100 %]. This allows for timely interventions by the PA at a moment when a student is not focusing on knowledge assessment but has shifted his/her attention to some other activity. The goal of the PA is to return the student's attention to the game in such situations.

Implementation of the Game

If an option "Assess knowledge" is selected, then a list of available topics for the knowledge assessment is offered to a student. After selecting a topic, a script *Game.js* is initiated, which starts the game. The operation of the game has been implemented as follows:

1) initialization of variables;
2) retrieving questions from a database by selecting questions relevant to a student in the chosen topic based on the following rules:
   2.1) up to three easy questions not previously seen from the mandatory ones are chosen using a *RANDOM*() function;
   2.2) one easy question, which was the last one added to the problematic questions, is selected and added to the already selected ones in the previous step;
   2.3) all incorrectly answered easy questions (including mandatory ones) are selected and only one is chosen with the *RANDOM*() function and added to the created list;
   2.4) five more easy questions are chosen using the *RANDOM*() function;
   2.5) the first five questions are selected from the list;
   2.6) returning to step 2.1 and repeating all the steps for medium and hard questions.
3) setting a new goal to be achieved;
4) initialization of a student's emotion and attention reading cycles;
5) initialization of registration of student's performed actions and pressed elements;
6) initialization of a time tracking function;
7) creation and deployment of game elements;
8) assignment of proper functionality for each game element;
9) explanation of game rules if a student is playing the game for the first time;
10) output of the first question and launch of timers for tracking the total playing time, question answering time and student's emotions and attention for his/her further analysis;
11) assignment of a function *actionOnClick*() to all possible answers for the analysis of student's answer (correct or not). A detailed operation of the function is shown in Fig 4.3.

In addition to the game environment itself and the ability to follow-up on his/her results, each student can also check his/her progress in the profile. All topics in which knowledge assessment has been carried out can be displayed, and various indicators (score, number of questions answered, time spent, etc.) are summarised based on all attempts made. Points representing the results of knowledge assessment are calculated for each topic.

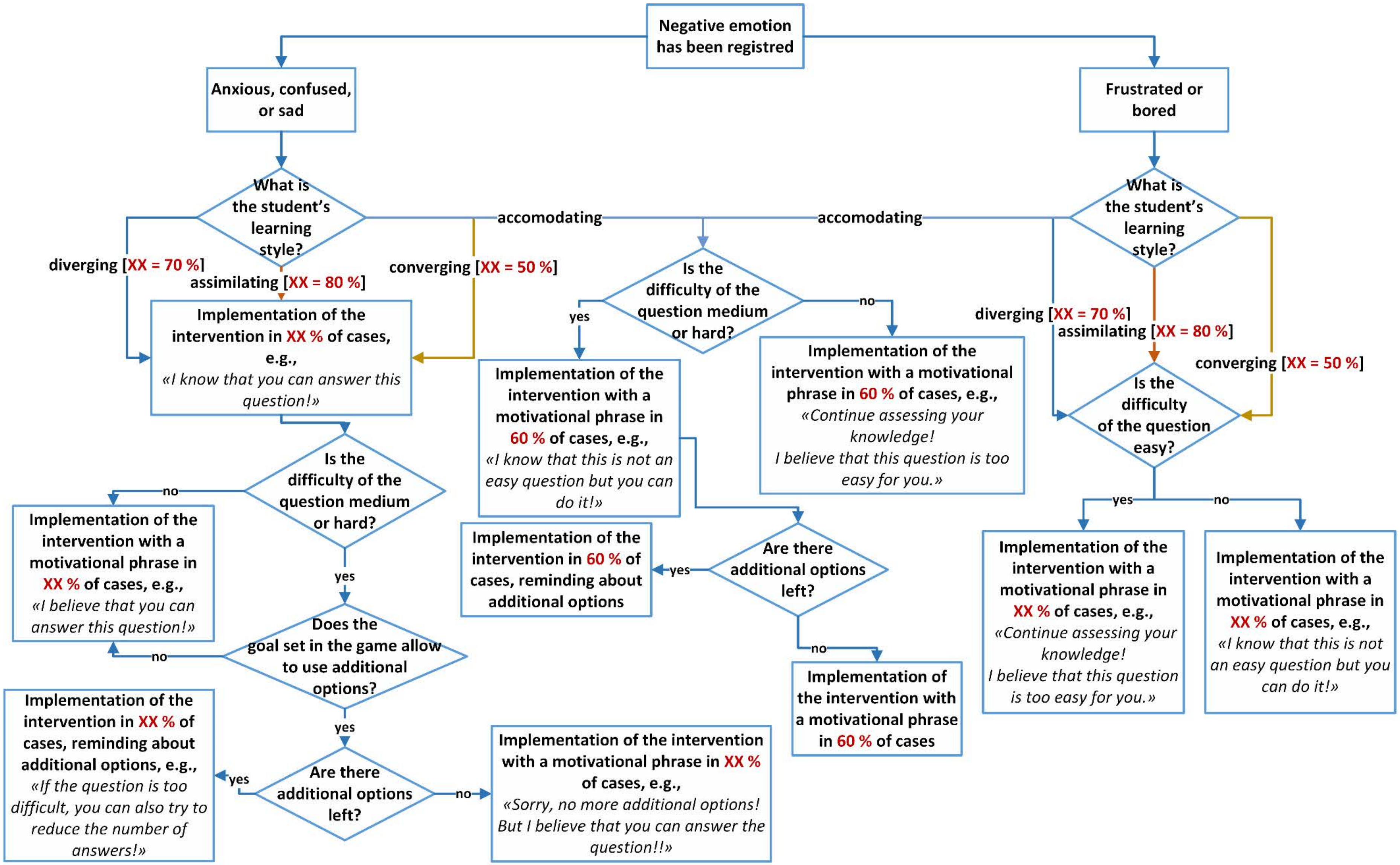

Fig. 4.2. Operating principle of the *additionalAnalysis*() function in case of negative emotions.

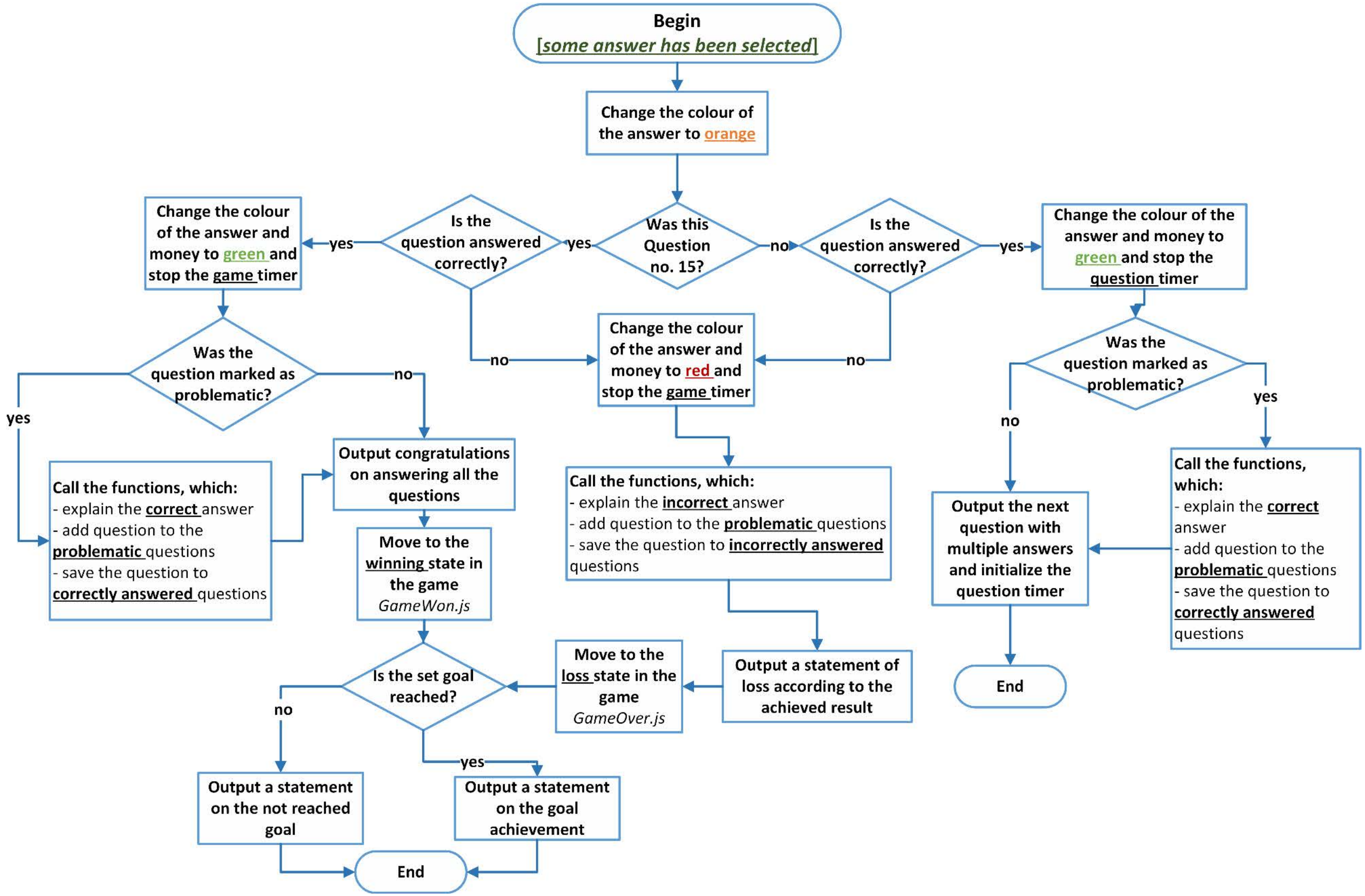

Fig. 4.3. Operating principle of the *actionOnClick*() function.

4.2. Methodology

The aim of the research was to investigate the impact of the type of knowledge assessment on student's knowledge and emotional state. Based on this aim, the following general hypothesis was put forward.

Hypothesis: Game-based knowledge assessment promotes positive emotions of student and leads to higher assessment results.

To achieve the aim, the following research questions were defined.

1. Do students' positive emotions during the assessment affect their assessment results?
2. Does the type of knowledge assessment influence the assessment results?
3. Are exam results higher for students who use the proposed tutoring system and the game for knowledge assessment?

To answer these questions, a detailed study plan was developed, participants were selected, variables were defined, and data acquisition and processing methods were chosen.

Participants, Experimental Design, and Data Analysis

The participants were 244 (200 male and 44 female) third-year undergraduate students (both from Latvia and from abroad) who were taking a course entitled "Fundamentals of Artificial Intelligence" in the Faculty of Computer Science and Information Technology at RTU. Experiments were run in two languages, Latvian and English, and were organised in two parts:

1) knowledge assessment on the topic "Uninformed search" under controlled conditions;
2) knowledge self-assessment (during the student's free time) on two other topics – "Heuristically informed search" and "Knowledge representation".

In the first part of the experiment, each group of students (four groups in total) was randomly divided into two sets – one set of students undertaking a written (paper-based) assessment in class, and another of students taking a computer-based class using the developed game (20–30 students, depending on the size of the group). In total, 153 students took part in the paper-based assessment and 87 students in the computer-based class. The main goal of the experiment was to evaluate the impact of different assessment methods and the use (or otherwise) of emotions for the purposes of adaptation to the emotional experiences and assessment results of students.

Before starting the experiment, all students were asked to complete a pre-study questionnaire on their preferences for assessment type (paper- or computer-based), the challenges and benefits experienced when taking a paper-based assessment, and when applicable, a computer-based assessment, and the typical emotions experienced before and during the assessment. After the completion of questionnaire, those students who were randomly selected for the game-based assessment via the ELIA system were taken to the computer class. The other group of students remained in the room with one or two teachers and took a printed version of the test consisting of 15 questions. Following the knowledge assessment under both experimental conditions, students were asked to complete a post-study questionnaire on their emotional experiences during the knowledge assessment and possible differences in emotional experiences if they had used the other assessment type. Thus, data related to the differences in assessment results and emotional experiences were acquired in both experimental conditions.

In the second part of the experiment, all of the students had the possibility of assessing their knowledge of two other topics. In total, 84 students participated in the self-assessment activity. In this study, data were collected on various parameters of gameplay, e.g. emotional data (if cameras were used), number of attempts made, number of correct/incorrect answers given, score, time needed to answer the questions, overall playing time, achievement of set goals and options used. The data obtained in the experiment were processed using *IBM SPSS Statistics 23* and *MS Excel*.

4.3. Results of the Study and Interpretation

Description of the Participants

The data from the pre-study questionnaire were analysed to characterise the participants involved in the study. In terms of preferences for the type of knowledge assessment, it can be concluded that on average, the students did not prefer a particular type of knowledge assessment. The results of the questionnaire showed that knowledge assessment is a problematic phase in the learning process, and is directly influenced by negative emotions of the students. Moreover, most of the students (~60 %) claimed that it was usually difficult to remember what they had learned, and that their inattention and number of errors increased as well. In general, students associated a lower level of anxiety to the computer-based knowledge assessment. Humour and positive attitude were also mentioned as possible activities from the teacher's side that could reduce negative emotions, meaning that emotional responses from the teacher were also important for students.

Impact of Students' Positive Emotions on Their Assessment Results

The impact of emotions on the assessment results was evaluated based on an analysis of the emotional data collected throughout the experiment. Differences between the emotional states of the students were measured for each type of assessment, based on the emotions reported by the students themselves. Overall, emotional expression tended to prevail in the case of computer-based assessment, since most students participating in this type of assessment reported positive, negative and mixed emotions. For the paper-based assessment, neutral emotions prevailed. The impact of the type of assessment on the emotions reported by the students was evaluated using a chi-squared test for the determination of mutual independence. A statistically significant interaction between the assessment type and the emotions reported was obtained ($\chi^2(3) = 38.89$, $p < 0.001$). The calculation of the effect size (represented as Cramer's V) allowed to conclude that the type of assessment had a large effect on the students' emotions ($V = 0.4$, $df = 3$).

The data on the students' emotions collected in both phases of the experiment were analysed to understand whether the game-based assessment facilitates positive emotions and positively affects learning outcomes. The most common emotions registered by students using EITS were flow (38 %), anxiety (23 %) and boredom (15 %), which represent similar dynamics to the flow model. The differences between the assessment results for each topic in terms of emotional data were also considered ("no emotional data" if the student was playing without emotion analysis, "more negative" if the student experienced more negative emotions, and "more positive" if positive emotions were experienced more often). Descriptive statistics on assessment results for each topic and emotional category are shown in Table 4.1.

A more equal sample size for each category was acquired for Topic 1, since many students were involved in the first part of the experiment and played the game using the emotion recognition functionality. An analysis of the assessment results showed that the students who experienced more positive emotions had slightly higher results (max. 2.5 points). Students who were playing without the emotion analysis performed slightly worse. However, the statistical analysis of the assessment results in each category did not show significant differences ($p > 0.05$). The statistics for the other two topics in which students could score a maximum of 5 points, were relatively poor in terms of emotional data, since most of the students preferred to play the game without cameras switched on. Based on the results acquired during the analysis, it can be concluded that the maintenance of positive emotions can serve as a driving force for the achievement of higher assessment results; however, these results are negatively influenced by the dismissive attitude of students to the use of cameras and the transfer of emotional data to EITS.

Table 4.1

Assessment Results of the Students in Terms of Emotion Categories

Emotion categories		***N***	**Mean**	**Std. Deviation**
Topic 1	No emotional data	42	1.70	0.59
	More negative	44	1.71	0.57
	More positive	41	1.73	0.57
Topic 2	No emotional data	64	3.85	1.23
	More negative	6	3.92	0.52
	More positive	13	3.68	1.57
Topic 3	No emotional data	54	3.16	1.42
	More negative	8	4.01	0.89
	More positive	9	3.32	1.39

Impact of the Type of Knowledge Assessment on the Students' Assessment Results

Overall statistics of knowledge assessment results in both assessment types (based on the data acquired in the first part of the experiment) are the following:

- in paper-based assessment, 92.8 % ($N = 142$) of students passed the test (with ≥ 1.25 points) and 7.2 % of students ($N = 11$) failed the test;
- in game-based assessment, 82.8 % of students ($N = 72$) passed the test, in turn, 17.2 % ($N = 15$) of students failed.

Overall, the assessment results were higher for the control group of students taking the paper-based assessment ($M = 1.89$, $SD = 0.42$, $Mdn = 1.95$) than for the experimental group of students participating in the game-based assessment ($M = 1.71$, $SD = 0.58$, $Mdn = 1.65$). To compare the differences between assessment results for both groups, a non-parametric Mann–Whitney *U*-test was used, which showed significant differences between the groups ($U = 5459$, $Z = –2.32$, $p = 0.02$). However, a further analysis of these differences showed a small effect size among both groups ($r = –0.149$) indicating that differences in the assessment type have a small effect on the assessment results. In addition, the direction of the effect ("negative") shows the existence of a small negative correlation between assessment type and results. Additional analysis and calculation of a determination coefficient ($R^2 = 2.2$ %) allowed concluding that the assessment type itself is not the determining factor affecting the scores, and remaining 97.8 % are influenced by other factors.

Impact of EITS and Game Usage on Students' Exam Results

In this part of the study, the data about the students who used and did not use the system and wrote the exam at the end of the study course were compared. In total, 178 students out of 244, who took part in the experiment, took the exam. The descriptive statistics on exam results in each of modules (max = 2 points) are available in Table 4.2. In order to compare differences in the exam results for each group, the Mann–Whitney *U*-test was used both for the first and second module, while for the third module a *T*-test was applied to compare the mean values. The table summarizes the results of both statistical tests as well as the estimated effect sizes.

Table 4.2

Exam Results of Students in Terms of Topic and Use of the System

Module	Used the system	Did not use the system	Used statistical test	Test results
1st module	$N = 91$ ($M = 1.58$, $SD = 0.39$)	$N = 87$ ($M = 1.44$, $SD = 0.41$)	Mann–Whitney *U*-test	$U = 4727$, $Z = 2.26$, $p = 0.024$, $r = 0.17$
	In total: ($M = 1.51$, $SD = 0.41$)			
2nd module	$N = 70$ ($M = 1.39$, $SD = 0.44$)	$N = 108$ ($M = 0.99$, $SD = 0.47$)	Mann–Whitney *U*-test	$U = 5582.5$, $Z = 5.39$, $p < 0.001$, $r = 0.40$
	In total: ($M = 1.15$, $SD = 0.50$)			
3rd module	$N = 57$ ($M = 1.11$, $SD = 0.47$)	$N = 121$ ($M = 0.79$, $SD = 0.48$)	*T*-test	$t(176) = -4.24$, $p < 0.001$, $d = 0.67$ ($r = 0.30$)
	In total: ($M = 0.89$, $SD = 0.50$)			

In general, the results obtained in all three modules are higher for the students who used the system compared to the students who did not use it. In the first topic, a small positive effect was found, while in the second and the third topic a medium effect on the exam results was obtained.

4.4. Summary

In this chapter, the implementation of EITS has been described. The main purpose of this chapter was to examine the adaptation approach (developed and described in the previous chapter) and its impact on students' assessment results and emotional outcomes in the context of knowledge assessment. In order to evaluate the functionality and the impact of the developed EITS and the game on the knowledge assessment and students' emotions, the chapter describes in detail the study carried out with the involvement of 244 students and the results of the study.

The following tasks are accomplished in this chapter:

- a detailed scheme was developed that reflects the functioning of the pedagogical module and the sources of data needed for adaptation;
- an analysis of existing emotion-related studies was carried out to obtain information on learning-specific emotions and their respective facial actions;
- development of an emotion classifier was carried out by training a neural network with classes of learning-specific emotions and their corresponding facial units;
- a survey of students was conducted with the aim of obtaining static characteristics, providing the macro-level adaptation and developing a personality model;
- a web-based game was developed using *Phaser* integrated with *Emotion API* for the retrieval of emotional data;
- the main game states were identified, not only for ensuring the functionality of the knowledge assessment but also for acquiring theory and carrying out practice;

- a method for the identification of achievement goals was proposed, both for starting the game for the first time and during the gameplay;
- two functions were developed that perform an analysis of emotions and attention depending on the student's learning style, with the aim of carrying out PA interventions;
- a function was implemented that is responsible for making pedagogical decisions and implementing changes during the knowledge assessment;
- implementation of the game was carried out based on the use of the abovementioned functions and realisation of the adaptive knowledge assessment;
- a function that displays the assessment results to a student was developed, including the calculation of the points obtained in the knowledge assessment;
- an experimental study was carried out to evaluate the impact of the developed EITS and the game on the knowledge assessment and the student's emotional states;
- the collected data were processed, and the results were analysed and interpreted to give conclusions regarding the experimental study and research questions.

The following results are achieved in this chapter:

- a web-based EITS called ELIA was developed for use by two different user groups, students and teachers;
- a classifier of learning-specific emotions was implemented;
- a personality model enabling automatic identification of the student's achievement goal and learning style was developed;
- two JavaScript-based technologies, the *Phaser* game development framework and the *Emotion API* emotion detection tool were integrated into EITS;
- the architecture of the game was proposed, reflecting all necessary game modules (states) for the implementation of the game functionality and adaptation;
- a method was developed for the adaptation of the student's achievement goal in each playing attempt;
- a function was developed that provides an analysis of the student's emotional data and, if necessary, calls the function for the implementation of PA interventions;
- a function was developed that carries out an analysis of the student's attention span and implements PA interventions in the case of low attention levels;
- a game was developed for knowledge assessment;
- an experimental study was carried out and described, including a detailed research plan and the selection of participants and methods for data acquisition and processing;
- an analysis of the data and results obtained was presented in relation to the research questions and hypothesis defined for this Thesis.

The most important theoretical result of this chapter is a summary of the facial action units for the learning-specific emotions, allowing them to be recognised directly from facial expressions. The most important practical result is the developed EITS, which integrates the two-level adaptation approach proposed in the previous chapter and provides a game-based knowledge assessment. In addition, a personality model was developed that allows the automatic identification of the student's achievement goal and learning style, and various algorithms were implemented for the analysis of the student's emotions and attention and for the adaptation of the tutoring process.

5. MAIN RESULTS AND CONCLUSIONS

When ITSs were able to recognize students' emotions, the next challenge emerged – the use of recognized emotions in adaptation of the tutoring process. Therefore, the goal of the Thesis was to develop a pedagogical module of an EITS, which would enable adaptation of the tutoring process not only to the student's knowledge but also to his/her emotions. This goal was achieved by fulfilling the tasks defined in Introduction. The tasks were split into several sub-tasks. The relationship between the chapters included in the Doctoral Thesis, the defined theses for the defence, fulfilled tasks, sub-tasks and achieved scientific results are reflected in Table 5.1. Based on the information shown in the table, it can be argued that the initially set goal has been fully achieved.

Summarizing the results of the theoretical analysis, practical implementation and empirical analysis of the EITS, the following conclusions can be drawn in this Doctoral Thesis.

1. The ability of an ITS to adapt to each individual student is of great importance in the implementation of tutoring; it is therefore necessary to know how to adapt the tutoring process and interact with the student when planning further pedagogical activities. The pedagogical module is directly responsible for this task, as it needs to be able to choose which tutoring activities to implement next. Pedagogical strategies play an important role in this case. Special attention is paid to the (macro- and micro-) pedagogical strategies in this Thesis, since they are not attached to a particular problem domain and can therefore be used in any ITS.
2. Emotional intelligence, which so far has not been taken into account in the development of ITSs, is an important factor in order to improve the adaptation skills of ITSs and to enable these skills to be equivalent to those possessed by human teachers. Overall, emotional states such as confusion, flow, joy, boredom, anxiety, frustration and surprise can be considered particularly relevant to learning.
3. Additional components are required for an EITS in order to provide functionality related to emotion recognition, the adaptation of responses and the tutoring process and for the system to show emotions.
4. Most prior studies related to the development of EITSs have focused on the determination of emotions, although there is still no consensus of opinion on the most appropriate method for the identification of emotions in the context of EITSs. The problem is that the use of different sensors limits the availability of such systems under real learning conditions.
5. Emotion-based pedagogical strategies are implemented only partially or are not included at all in existing EITSs, thus reducing their adaptation capabilities to students' emotions.
6. Knowledge assessment, one of the tutoring activities carried out by EITSs, is usually overlooked when evaluating the emotional states of a student.
7. One of the objectives of an EITS is to promote positive emotions for the student. The inclusion of game-like activities can promote joy and interest, and reduce the impact of negative emotions on learning outcomes; however, most existing educational games very rarely provide this adaptation, especially to the student's emotional state.

8. The integration of educational games within EITSs has a promising future, particularly in terms of knowledge assessment. A two-level adaptation approach is therefore developed in this Doctoral Thesis that places emphasis on the use of games and provides adaptation at two levels (macro- and micro-levels).
9. The results of an empirical study led to a partial justification for the initial research hypothesis, since the use of EITS and the game increased the students' interest and the presence of the flow state (thus contributing to positive emotions). Slightly higher assessment results were also observed for the students who felt positive emotions. The game allows knowledge gaps to be reduced for students with a low knowledge level and can influence the students' motivation by inducing a desire to achieve higher results.
10. An analysis of the student's reported emotions for different types of assessment led to the conclusion that the assessment type has a strong influence on the student's emotions, since a wider spectrum of emotions was identified by students who used the game for knowledge assessment.
11. The use of the game also positively influenced the students' exam results, as demonstrated by the high correlation between the use of the system and the results of the exam.

It is possible to evolve the research topic of this Doctoral Thesis in various scientific and practical research directions.

1. The use of other methods for the extraction of emotional data to improve the dismissive attitude of students regarding the transfer of their emotions and the use of the system as a whole, since this is a topical problem all over the world (ethical side of the emotion analysis and the privacy of emotional data).
2. The evolvement of a pedagogical agent with regard to the expression of its emotions. This would allow improving the credibility of EITS and bringing the agent's behaviour closer to the emotional interaction between a teacher and a student increasing confidence in such systems.
3. The improvement of the adaptation using machine learning methods in terms of the functioning of pedagogical agent and in the adaptation of pedagogical strategies.

Table 5.1

The Relationship Between the Chapters, the Defined Theses, Fulfilled Tasks, Sub-Tasks and Achieved Scientific Results

Tasks	Fulfilled sub-tasks	Achieved results
	CHAPTER 1 (*thesis 1*)	
1. To identify the role, functions and interaction of the pedagogical module with other components in ITSs	• the research on ITSs has been carried out determining their key characteristics, functional components, components' tasks, and mutual interaction, as well as analysing the knowledge stored and processed in these components for ensuring the tutoring process; • the nature of tutoring has been described and the analysis of its realisation in ITSs has been carried out by putting particular emphasis on the pedagogical module and its role in the implementation of tutoring; • the analysis of pedagogical strategies and related concepts has been made, as well as their role in the provision and adaptation of tutoring has been identified; • the role of a student's personality has been analysed in the context of the tutoring adaptation, exploring the impact of personality on various aspects of tutoring	• a summary of ITS components, their functions, the necessary knowledge and/or data for the implementation of these functions; • a definition of the main goal for the pedagogical module; • a summary of knowledge and types of knowledge required for the module to function properly and the categories of pedagogical decisions made by the module; • a summary of terms related to pedagogical strategies; • a summary describing student's characteristics influenced by the personality and different factors affecting his/her learning process
	CHAPTER 2 (*theses 2 and 3*)	
2. To analyse the role of emotions in the learning process and to define requirements for the implementation of emotion-based tutoring process in ITSs. 3. To study the concept of EITSs, analyse their architecture and characteristics. 4. To perform a comparative analysis of existing EITSs in order to identify unresolved tasks related to the adaptation of the tutoring process	• the influence of emotions on various learning-related cognitive processes has been analysed, and the functions of emotions in the learning process have been identified; • a study of various theories relating emotions to learning has been carried out to identify those emotions that affect learning, and which should be included in the development of ITSs; • emotion-based pedagogical strategies have been analysed to formulate requirements for the implementation of emotion-based tutoring processes in ITSs; • the concept and development of EITSs have been studied in order to describe these systems, define their operating principles, and identify the main differences from traditional ITSs; • an analysis of existing EITSs has been carried out to explore their abilities to recognise learning-specific emotions, to adapt the tutoring process accordingly and to express emotions; • issues related to the development of EITSs and adaptation of the tutoring process to the student's emotions have been identified and analysed	• requirements for the implementation of the emotion-based tutoring process in ITSs divided into several categories – the whole tutoring process and three fundamental steps of pedagogical strategies (theory teaching, practice and knowledge assessment); • a summary describing various goals for extending the functionality of ITSs to include the identification of emotions and adaptation of the tutoring process; • a definition of an "emotionally intelligent tutoring system" and a summary of EITSs relevant characteristics and operating principles; • a summary of additional components forming the architecture and the affective behaviour model of EITSs; • a comparison and the analysis of existing EITSs; • a summary of shortcomings related to the adaptation of tutoring process to the student's emotions

Table 5.1 (continued)

The Relationship Between the Chapters, the Defined Theses, Fulfilled Tasks, Sub-Tasks and Achieved Scientific Results

Tasks	**Fulfilled sub-tasks**	**Achieved results**
	CHAPTER 3 (*thesis 4*)	
5. To develop methods and algorithms for the elimination of previously identified shortages	• an analysis of the characteristics of educational games has been carried out in terms of the learning process, and the relationship between games and emotions has been explored; • the concept of game-based assessment has been studied; • existing educational games have been analysed to evaluate their adaptive abilities; • an emotion-based adaptation has been studied in the context of educational games; • various pedagogical principles have been examined with regard to their integration in educational games, with the aim of promoting the student's motivation and improving learning outcomes; • several parameters related to the adaptation provision in educational games have been analysed; • the EITS architecture has been developed, with a particular focus on the pedagogical module; • a two-level adaptation approach has been proposed to ensure the proper functioning of the pedagogical module before/during the learning process (or game)	• a summary of the basic elements and characteristics of educational games; • a summary describing pedagogical principles that improve not only student's willingness to play but also facilitate his/her learning; • various game parameters that can serve as an adaptation source both before and during the game; • the EITS architecture; • an adaptation approach that is responsible for the operating principles of the pedagogical module; • twelve operating scenarios for four different PAs in all three steps (theory teaching, practice and assessment)
	CHAPTER 4 (*theses 5*)	
6. To develop a pedagogical module for EITS. 7. To evaluate the developed pedagogical module under experimental conditions	• a detailed scheme was developed that reflects the functioning of the pedagogical module and the sources of data needed for adaptation; • an analysis of existing emotion-related studies was carried out to obtain information on learning-specific emotions and their respective facial actions; • development of an emotion classifier was carried out by training a neural network with classes of learning-specific emotions and their corresponding facial units; • a survey of students was conducted with the aim of obtaining static characteristics, providing the macro-level adaptation and developing a personality model; • a web-based game was developed using *Phaser* integrated with *Emotion API* for the retrieval of emotional data; • the main game states were identified, not only for ensuring the functionality of the knowledge assessment but also for acquiring theory and carrying out practice; • a method for the identification of achievement goals was proposed, both for starting the game for the first time and during the gameplay; • two functions were developed that perform an analysis of emotions and attention depending on the student's learning style, with the aim of carrying out PA interventions; • a function was implemented that is responsible for making pedagogical decisions and implementing changes during the knowledge assessment; • implementation of the game was carried out based on the use of the abovementioned functions and realisation of the adaptive knowledge assessment; • a function that displays the assessment results to a student was developed, including the calculation of the points obtained in the knowledge assessment; • an experimental study was carried out to evaluate the impact of the developed EITS and the game on the knowledge assessment and the student's emotional states; • the collected data were processed, and the results were analysed and interpreted to give conclusions regarding the experimental study and research questions	• a web-based EITS called ELIA for use by two different user groups, students and teachers; • a summary of learning-specific emotions and their respective facial actions and a classifier of learning-specific emotions; • a personality model enabling automatic identification of the student's achievement goal and learning style; • the architecture of the game with all necessary modules for the implementation of its functionality and adaptation; • a method for the adaptation of the student's achievement goal in each playing attempt; • a function that provides an analysis of the student's emotional data; • a function that implements PA interventions; • a function that carries out an analysis of the student's attention span and implements PA interventions in the case of low attention levels; • a game for knowledge assessment that uses a two-level adaptation approach; • an experimental study with 244 students; • an analysis of the data and results obtained in relation to the research questions and hypothesis

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