

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

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**INTELLIGENT TUTORING SYSTEM FOR  
ASSESSMENT OF USAGE OF COMPUTER  
AIDED DESIGN SYSTEMS**

**Summary of the Doctoral Thesis**

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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 defense at the open meeting of RTU Promotion Council on September 16, 2019 at the Faculty of Computer Science and Information Technology of Riga Technical University, 1 Setas street, Room 202.

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## **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.

Jānis Dāboliņš ..... (signature)

Date: .....

The Doctoral Thesis has been written in Latvian. It consists of Introduction; 4 chapters; Conclusions; 54 figures; 6 tables; 4 appendices; the total number of pages is 151. The Bibliography contains 130 titles.

# TABLE OF CONTENTS

INTRODUCTION.....	5
1. TEACHING OF COMPUTER AIDED DESIGN SYSTEMS.....	10
1.1. Currently Available Support for the Learning Process.....	10
1.2. Currently Available Knowledge Assessment Provision.....	12
1.3. Problems of Study Process and Knowledge Assessment .....	12
2. INTELLIGENT TUTORING SYSTEMS.....	14
2.1. Structure of intellectual tutoring systems .....	15
2.2. Agent-Based Intelligent Tutoring Systems.....	17
2.3. The Role of Feedback in Intellectual Tutoring Systems.....	18
3. INTELLIGENT TUTORING SYSTEM FOR COMPUTER AIDED DESIGN TRAINING (KNOWLEDGE ASSESSMENT) .....	21
3.1. Concept of ITS for the Assessment of CAD/CAM System Usage.....	21
3.2. ITS DPSLN Operation.....	30
3.3. ITS DPSLN Implementation .....	34
4. APPROBATION OF THE DEVELOPED ITS DPSLN .....	36
4.1. Work With ITS DPSLN.....	36
4.2. Approbation of ITS DPSLN in Student Groups .....	37
4.3. Approbation of ITS DPSLN in Enterprises .....	40
CONCLUSIONS AND RESULTS .....	42
BIBLIOGRPHY .....	45

# INTRODUCTION

The Thesis describes the approach that allows to follow (and analyse) the learner's actions during the use of computer-aided design systems (CAD), gives an insight into the range of problems and the topicality of the research, lays out the purpose and tasks of the study and describes approbation of the system elaborated. Computer aided design training and its aspects are described and analysed in the paper. It looks at the traditional and technology-supported learning process aimed at analyses of teaching CAD and provision of knowledge assessment, as well as identification of problems in the CAD system training process. It was concluded that technology-supported learning process would contribute to solving these problems. The study examines intelligent tutoring systems, their structure and implementation, discusses modules of intelligent tutoring systems with the aim of understanding the use of such systems in the training. The analysis allows setting requirements for the intelligent tutoring system in the CAD system training. As the main problem in the use of CAD systems and in the assessment of learner's results, there is an identifiable lack of information about the learner's actions during execution of his/her tasks. Since an instructor issues an assignment, a student executes it and submits the result, then the instructor acquires information only about the results of the learner's work, but not about the process itself. It is difficult (even impossible) for him/her to analyse the efficiency of the work performed – compliance of the tools/functions used to the assigned task, the sequence of the process, and its usefulness.

Based on the study carried out, approaches for assessment of usage of computer-aided design systems were offered for implementation within the framework of the study. Implementation of this approach in the intelligent tutoring system was given, describing it by specifying system requirements, architecture, modules, database and approach for implementation. The created system allows solving assessment problems of the use of CAD systems: an expert is being informed about actions of the learner during the execution of tasks, i.e. the process of task fulfilment.

## **Topicality of the theme of the Doctoral Thesis**

The topicality of the theme of the Doctoral Thesis is related to changes in the education system – the teaching and learning paradigm in Latvia and throughout Europe. By upgrading the introduction of competences as a complex for achieving the results of training, the approach developed in the Doctoral Thesis allows distinguishing skills from competences in the usage of CAD/CAM systems. The currently available tools allow one to evaluate the learner's skills. The result of the performed task shows whether the student had skills to complete the given design task using CAD/CAM system tools. However, the design can only be evaluated as a finished result without the ability to go into details of the actions performed by the trainee (or into the working procedure of the work of a designer), the logic, consistency, sequence and speed of the actions. Consequently, the assessment of the learner's actions in the CAD/CAM system application is provided only for his/her skills – a project design and/or any stages, without considering the assessment of the learner's competence,

knowledge, comprehension and experience. The purpose of the research is to create a computer system for the development of a user adaptive intelligent tutoring system. Such a computer system should be able to evaluate all stages of the project/technical drawing created in CAD/CAM systems – thus assessing the procedural knowledge, technical skills, and attitude with which the work is done (the capacity to master the system usage and make a motivated choice of the most efficient execution process).

### **Purpose of the Doctoral Theses**

The aim of the Doctoral Thesis is to develop an intelligent tutoring system (ITS), which implements the assessment of the usage of CAD/CAM systems, tracks (and analyses) the learner's actions during the use of computer aided design systems (CAD), as well as perform prototype testing and operational testing of the developed system.

### **Research tasks**

- To identify and analyse CAD/CAM system training processes, examine their aspects and knowledge assessment.
- To explore ITS development process, structure and methods.
- To analyse intelligent agent systems; develop a new ITS framework for assessing the use of CAD/CAM systems.
- To develop an ITS prototype implementing the assessment of CAD/CAM system usage process.
- To experimentally test the developed ITS prototype that implements CAD/CAM system usage assessment, and its correspondence with expert (teacher) assessment.

### **Object and subject of the research**

The **object** of the Doctoral Thesis is to assess CAD/CAM system training and usage for efficient execution of work for production purposes. The **subject** of the research is the method that allows using the adaptive features and their implementation concepts of intellectual tutoring and knowledge assessment systems rooted in agents for the assessment of CAD/CAM system usage.

### **Scientific innovation of the Doctoral Thesis**

- A new competency assessment method has been developed and presented demonstrating the use of artificial intelligence methods in solving real practical problems for assessing the usage of CAD/CAM systems.
- A concept of CAD/CAM system usage assessment system rooted in agents, with evaluation of the task execution procedure, has been developed. An algorithm for evaluating the trainee's actions in CAD/CAM system has been developed. Agents for ITS implementation have been defined; ITS prototype agent functions have been identified.

- CAD/CAM system training processes and the pedagogical approach, the current approaches and knowledge testing have been described.
- ITS prototype for the assessment of CAD/CAM usage has been implemented. Task samples have been developed and they are generated in ITS with an open opportunity to generate other tasks offered by experts.
- Approbation with feedback (knowledge correction) and detailed information on trainee knowledge in CAD/CAM usage has been developed.

### **Practical significance of the research**

The concept of identifying and evaluating knowledge, which is implemented in the Doctoral Thesis for the first time, is a practical contribution both to improving the learning process and production processes. The implemented prototype allows improving knowledge in the usage of CAD/CAM systems, identifying gaps in the learner's knowledge, analysing and improving the work methods. The system may be used in mastering and usage of various CAD/CAM systems.

### **Theses to be defended**

- The developed approach allows tracing the learner's actions and task execution process during the use of CAD/CAM systems.
- The developed system contributes to increasing the user's knowledge in the application of CAD/CAM systems by providing information on existing user competencies and knowledge levels; feedback contributes to the interest in learning CAD/CAM systems.
- The developed approach contributes to the objectivity of the assessment of user (learner) knowledge of CAD/CAM system usage.

### **Thesis approbation**

The results of the Doctoral Thesis have been published in reviewed scientific journals and full text editions of conferences, as well as reported and discussed at international and local conferences and in the study subjects taught or jointly led by the author.

### **Author's reports in scientific conferences**

1. 17th International Conference, "Perspectives in Business Informatics Research" BIR 2018, Stockholm, Sweden, September 24–26, 2018.
2. International scientific conference "SOCIETY. INTEGRATION. EDUCATION", Rezekne Academy of Technologies, Rezekne, Latvia, May 25–26, 2018.
3. Perspectives in Business Informatics Research: 15th International Conference (BIR 2016): Czech Republic, Prague, September 14–16, 2016.
4. 13th International Conference on Global Research and Education Inter Academia 2014, Riga, Latvia, September 10–12, 2014.

5. 54th International Scientific Conference of Riga Technical University, Riga, Latvia October 14–16, 2013.
6. Baltic DB & IS 2012 Tenth International Baltic Conference on Databases and Information Systems, Vilnius, Lithuania, July 8–11, 2012.

#### **Author's publications on the topic of the Doctoral Thesis**

1. **Dāboliņš, J.**, Intelligent tutoring system for assessment of usage of computer aided designing systems. **In:** *BIR Short Papers, Workshops and Doctoral Consortium: Joint Proceedings of the BIR 2018 Short Papers, Workshops and Doctoral Consortium co-located with 17th International Conference "Perspectives in Business Informatics Research" (BIR 2018). CEUR Workshop Proceedings.* Aachen: RWTH, 2018, pp. 323–334. ISSN 1613-0073. (SCOPUS)
2. **Dāboliņš, J.** Teaching of computer aided designing systems. **In:** *Proceedings of international scientific conference "Society. Integration. Education".* Volume V. Rezekne: Academy of Technologies, 2018, pp. 248–259. ISSN 1691-5887. Available from: doi:10.17770/sie2018vol1.3143. (SCOPUS)
3. **Dāboliņš, J., Grundspenķis, J.** Intelligent Knowledge Assessment for CAD/CAM Systems. **In:** Medvids, A., ed. *Advanced Materials Research.* Vol. 1117. 2015, pp. 287–290. ISSN 1662-8985. Available from: doi:10.4028/www.scientific.net/AMR.1117.287. (SCOPUS)
4. **Dāboliņš, J., Grundspenķis, J.** Intelligent Tutoring System for Learning Graphics in CAD/CAM. **In:** Ārpa V., Bruckner T., eds. *Perspectives in Business Informatics Research. BIR 2016. Lecture Notes in Business Information Processing.* Vol. 261. Springer, Cham, 2016, pp. 239–246. ISBN 978-3-319-45320-0. Available from: doi:10.1007/978-3-319-45321-7\_17.
5. **Dāboliņš, J., Grundspenķis, J.** The Role of Feedback in Intelligent Tutoring System. **In:** *Applied Computer Systems/ The Journal of Riga Technical University.* Volume 14, Issue 1. Riga: RTU Press, 2013, pp. 88–93. ISSN 2255-8691.
6. **Dāboliņš, J.** Trends of the Usage of Adaptive Learning in Intelligent Tutoring Systems. **In:** *Databases and Information Systems (Baltic DB&IS 2012): Tenth International Baltic Conference: Local Proceedings, Materials of Doctoral Consortium.* Lithuania, Vilnius: 2012, pp. 191–196. ISBN 978-9986-34-274-8. (SCOPUS)

#### **Approbation of the Doctoral Thesis in student training has been carried out IN the following courses:**

1. MŠM533 Automated Design of Clothing 4.0 KP (pers. responsible A. Viļumsone) (Professor A. Viļumsone's comment on the results of system approval is presented in Appendix 1 of the dissertation).
2. MVR701 Computer science (special course) 2.0 KP (pers. responsible I. Dāboliņa).

### **Approbation of the Thesis in enterprises**

On July 4, 2017, I presented ITS for Computer Aided Design System Usage Assessment (DPSLN) prototype at Polytropon Automation Systems, in the company office in Greece, in Thessaloniki. In the company, the idea of the system and the method used was of great interest, and ITS DPSLN was used to test the employee knowledge of two computer-aided clothing design companies. The conclusion of the company's marketing and sales manager regarding the approbation of the system is presented in Appendix 2 of the Doctoral Thesis.

# **1. TEACHING OF COMPUTER AIDED DESIGN SYSTEMS**

Computer aided design, along with computer aided manufacturing, emerged in the 1950s [1]. A well-known abbreviation of computer aided design and computer aided manufacturing systems is CAD/CAM. Currently, CAD/CAM systems are used in a variety of fields, which include design and manufacturing management processes (geometric modelling, machine vision, flexible manufacturing systems). Using specialized computer software, a created technical drawing, a specialized set of parameters (procedure description) describe the computer-aided designing. Design engineering, technical drawing and drafting combine extensive knowledge of theory and practice. Creation of a design is a very complicated process in itself [2], [3]. Usage of computer-aided design makes contribution to designers' work productivity, humanization of working conditions, project quality improvement, communication speed, flexibility and the structuring and expansion of the production data repository. When the result of a computer-aided design (a project created in a CAD system) is immediately (without a design draft or printing) given for production (cutting, machining) of a product, it is called computer-aided manufacturing (CAM system software).

Computer-aided design cannot exist without specialized (commercial) CAD systems – they are created for automation of design processes [4]. In CAD systems, vector graphics (objects are described mathematically) based on Cartesian coordinates are most commonly used, still there are systems in which raster graphics are used to display objects (objects are based on arranged sets of points) [5]. Design can be planar (for drawing line segments, curves and figures) or spatial (for 3D curves, surfaces and body representations). In order to ensure the production management processes, along with the graphic information on products, in most CAD systems, management, structuring and storage of information (materials, processes, dimensions, volumes, control measurements, etc.) is possible [6], [7].

Due to the global economy development, CAD/CAM integration takes place in different fields of manufacture (construction, aviation, shipbuilding, computer manufacturing, clothing manufacturing, etc.), at different stages of production (design, product lifecycle management, manufacturing systems management, etc.). In order to meet the need for skilled workforce, CAD/CAM system training is included in the engineering discipline studies in various fields (along with this trend, the drawing skills are gradually reduced).

The literature sources analysed during the development of the Doctoral Thesis allow concluding that for learning of computer-aided design both a teacher-led and independent learning activities of the learner are offered; a traditional teaching process is provided, however a technology enhanced learning process is not effectively ensured.

## **1.1. Currently Available Support for the Learning Process**

The learning content and its representation follows directly from the learning objective – computer-aided design training, where for execution of practical tasks one of the CAD systems is involved (depending on the learning content area and curriculum that includes mastering of the given system). For such specialized training the traditional form of

instruction is adapted using technology-based learning tools. Publishing of books and lecture notes is limited due to continuous development of systems (CAD/CAM system developers develop and market new, improved versions of the system at least once a year to ensure its speed, ease of use and compliance with the industry). If books are published, most often they are books for training in the universal (less specialized) systems. For example, books for learning AutoCAD systems have been published in Latvian as well [8], but the most commonly used publications are in Russian [9], [10] or English [11], [12] – a wider audience understands both languages. Books with description of CAD systems used for designing needs in specific industries are not published at all, or it happens very rarely, e.g. for learning about Lectra (application for clothing design, some modules for computer-aided furniture designing, in which 2D stages of the project are implemented: sketches, technical drawings, template drafting, their assembly, layouts, documentation, product lifecycle management, as well as 3D fitting of a completed design for its verification and making corrections in templates. The system includes a series of interconnected or partially linked modules for automated computation in the particular sector, algorithms and procedures). Only a couple of books have been published for learning [13], [14], the author has no relation to Lectra's representation and only outlines the operating principles of a particular system module (even not the entire system). A very similar situation exists regarding the publication of instruction materials of other specialized system, such as Gerber Accumark (software similar to CAD/CAM Lectra) [15]. Unfortunately, such books remain up-to-date for a short period; they quickly lose their relevance to usage in the learning process due to the rapid development and changes in CAD/CAM systems [3]. The content provision most often depends on the teacher – each year, according to changes in specialized CAD systems, a teacher makes changes in presentations, lecture materials and notes.

Although computer-aided design system training is most often done in accordance with the traditional teaching process in which a teacher delivers knowledge in the form of lectures and demonstrations, a student perceives the new information, takes it into account and consolidates his/her knowledge by carrying out practical tasks. However, given that CAD/CAM systems are taught based on information technology, majority of them have integrated technology enhanced learning tools. Online help is part of the system that allows the student to get information about system performance in general or on use of a particular function or tool for designing (systems may have integrated both – help where the user searches for information and the help that is available upon request for a particular function/tool that is active at that moment). Such help, reasonably used, allows one to choose an appropriate action algorithm to solve a problem.

Manufacturers of advanced CAD/CAM systems create special home pages, web sites, training materials and other resources of open or semi-closed access for mastering of their design systems. For example, for learning AutoCAD, an interactive tool for describing the use of features is offered, which offers examples and applications [16], and it is also possible to download specialized classes for learning (for a separate fee) [17]. In turn, the CAD/CAM system Lectra manufacturers are developing a school and university course, supporting the development of teaching/learning materials, announcing the best student achievements in

design on its website, and publishing the best projects (Lectra, 2017) [18]. For mastering the system, a limited-access to teacher support materials is available (available only to certified system teachers), which offers a teacher the recommended curriculum, the content of instruction: tasks, curve samples, algorithm cards, and descriptions of procedures, thus facilitating the teacher's work.

## **1.2. Currently Available Knowledge Assessment Provision**

Working with computer-aided design systems, the assessment is the teacher's opinion about the conformity of the created design and/or drawing to the specified requirements, thus assessing the student's level of the acquired knowledge, skills and abilities. This aspect forms part of the student learning motivation, the other part is the motivation to develop their design and/or to create more sophisticated designs [3].

Since computer-aided design is related to creation of practical design, students self-evaluate some projects automatically where they understand whether the project can be used in the next stage of the design. If the student fails to make the successive steps, then it is clear that in the first stage there are errors that prevent further progress of the project.

The teacher prepares appropriate practical tasks and tests for the course examination. Already within the framework of the course, the basic skills can be evaluated using particular small examples, and their completion is no longer evaluated in the exam (the result is taken into account in the overall assessment of the subject in the semester). The student must be able to finish each of these tasks within a very short time by using only a few operations and computer system tools. Thus, it is possible to test the abilities and skills that have been acquired at a given stage of learning. The rating of these examples is immediate – the teacher assigns a task, students finish it, the teacher evaluates the accomplishment.

In final examinations and/or course papers, skills and abilities to complete more complex tasks and make designs are tested by preparing a computer-aided design task that allows students to demonstrate all their abilities – not only to perform the learned design procedures but also to apply them creatively to other tasks. Such an assignment must have a variety of possible solutions, which can be used to assess the students' skills within the system and the ability to find the optimal solution. In addition, accuracy and compliance with technical requirements influence the final assessment.

## **1.3. Problems of Study Process and Knowledge Assessment**

During computer-aided design teaching teachers give insight into the design process, provide knowledge about the use of CAD system tools and demonstrate which algorithms of operations are to be performed for completion of computer-aided design tasks. Quite often such demonstrations are repeated: the student has completed his work, but has done it by repeating the teacher's presentation, thus the level of mastering the procedure has been low. This problem highlights the need for short sample demonstrations – sequential task completion with instructions and screenshots, demonstrating the process of modelling and

designing objects. In this way students can control the rate of their learning progress, and the teacher can offer other similar exercises for execution, thus making sure that the specific task execution procedures and algorithms of operations are understood. Some CAD/CAM system companies offer reels (e.g. [18]–[20]) to demonstrate the use of sophisticated software tools or designing of small projects.

When creating graphic files, along with the skills of using the system the precision and speed of creating the graphic result is important. The graphical tasks in the CAD/CAM environment have their own specific sequence/order, however, the quality of the tasks performed (accuracy, speed, etc.) is influenced directly by the drawer's knowledge and skills of using the system. The assessment of such designs includes evaluation of the final result and documentation, still there is no uniform approach to checking the knowledge in working with CAD/CAM systems; it is not possible to check the work sequence, its progress, the procedures performed and the design development process. In order to evaluate the use of CAD/CAM systems, standard tasks that are used to assess the student's initial knowledge (that has been acquired in the initial stage of training) are usually developed. The number of CAD/CAM system functions required for performing these tasks is small (usually not more than 10), their performance evaluation is traditionally based on the correspondence of the created drawing to the task [9], [13], [21].

## 2. INTELLIGENT TUTORING SYSTEMS

The first chapter compares the traditional teaching/learning process with the technology-supported learning process with the aim of identifying the most suitable one for assessing CAD/CAM system usage. It has been concluded that improvement of the CAD training process can take place through the use of the intelligent tutoring system (ITS). The main objective of ITS is to provide instructional guidance in adapting the tutoring process to the level of each particular learner's knowledge and skills [22]. If a teacher is involved in the traditional learning process, then in a technology-supported process ITS replaces the teacher in full or in part. Learning content is a component composed by an expert or an expert group – a teacher or independent experts who develop the content of the training. An expert cooperates with the content of learning and supplements it – gives information. If a learning process is in place, which is fully implemented using an intelligent tutoring system, the expert is the only one who creates the teaching/learning content.

ITS collaborates with the learning content component by receiving study materials, tests and supplementary literature. Upon collaboration with the learner, ITS provides information for improving the content of the learning according to the learners' activities, success and difficulties in the learning process.

Knowledge in the use of the computer aided design systems shall be obtained from the initial training when the knowledge provided by the teacher is taken over and used in the computer system. A step-by-step approach is the most common way of learning the computer aided design systems – the teacher shows how every action can be performed, and the trainee repeats it on his PC. Sometimes (very rarely) learning takes place remotely through the user guide or video training. An important step of learning is feedback: if the trainee has not understood the actions to be performed and is unable to perform a lesson task, the teacher answers the questions, shows individually what actions are to be taken to continue and/or correct the execution of the task. In most cases, the increase in the knowledge acquired at the start of training is very small – the trainee does not understand the nature of computer aided design, is confused about the use of system tools/functions and unable to perform the tasks of the lesson. Therefore, before developing a serious project, it is proposed that the trainee performs simple tasks for acquisition of graphic basic units such as as drawing lines, parametric or non-parametric display of tetragons, circles and other geometric figures. When the trainee has mastered the principles of system usage, further training may occur with very rapid increase in knowledge (linear, where the slope coefficient for the line graph depends on the capacity of the trainee, the time spent in training and the quality of its use). After the initial training, the use of the system follows during which knowledge is consolidated by carrying out realistic design tasks. This also requires the use of knowledge of the object to be designed covering the necessary parts of the drawing – the base grid, lines, drawing lines, construction lines and other required project attributes. Knowledge is complemented by the practical use of the computer aided design system (the stage may be integrated in the training process where the trainee performs study finals or specialized training course project as well as during the performance of sectoral practice tasks, i.e., during studies or work). At this

stage, acquisition of new knowledge does not occur rapidly. Further education (or further training) is the next stage of knowledge acquisition. If the designer has an interest in in-depth learning of the system, it is possible to acquire it at the level of the connoisseur in advanced courses or at higher levels of studies. This stage also comprises the training of experts whose working techniques in the CAD/CAM system need to be improved. Further training stages depend on the specific system – the frequency and complexity of updates, and these stages are repeated periodically.

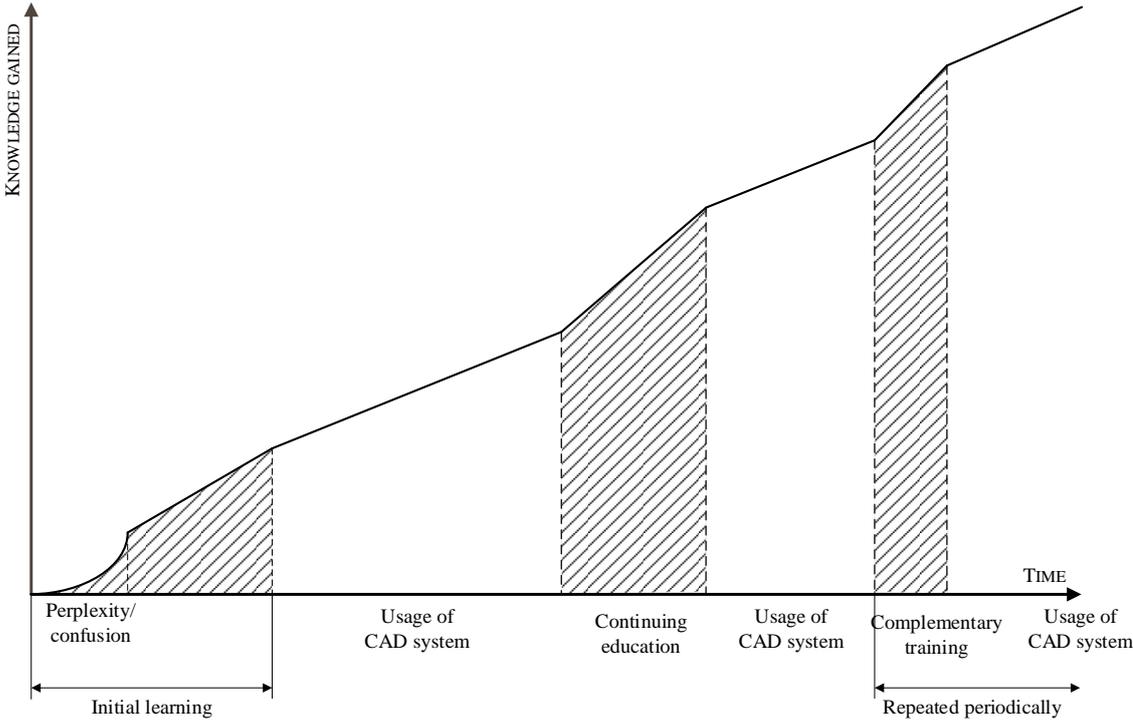


Fig. 2.1. The scheme of CAD/CAM learning process.

All stages of the training identified by the empirical method (the author of the Thesis has more than 15 years of experience in CAD/CAM training) are graphically depicted in Fig. 2.1.

The learning stages of CAD/CAM system in which the teacher participates are highlighted to denote the stages in which the assessment of the learner’s actions is required for obtaining knowledge. Therefore, ITS is necessary for tracing the learner’s actions, analysis and evaluation of trainees in the light of the already identified drawbacks of the process – no analysis of the process is provided that would allow increasing the knowledge acquisition rate.

**2.1. Structure of intellectual tutoring systems**

The structure of ITS is based on the core components of the traditional teaching process: the teacher, the learner and the content of the training. These components define the basic components of ITS architecture – modules. Modules are interconnected and their number can be supplemented depending on the system goals and objectives, problem areas and other

aspects. The system consists of an expert module, a student (learner) module, a training module (learning content), and a user interface. Each system component (module) provides separate functions.

Based on these modules, an intellectual tutoring system follows the training process, evaluates the learner's activities and knowledge, their changes, adapts the learning content to the learner's individual needs without the intervention of the teacher, thus completely or partially replacing the human-teacher training process.

The teacher's skills and knowledge are integrated into a computer system through various teaching materials, tasks (for execution), task sequences (samples). ITS expert module, in addition to the knowledge repository, is supplemented by the teacher/expert teaching style/methods and reactions. The content of this module comprises teaching aids prepared for training in the system. Each material can be divided into several parts depending on its purpose and use: topic framework, study material, task variants and tests. The learning content is integrated into the system subject to the technical support of its operation. The content can be prepared by one or more authors.

The student module is designed to store information about the student: his/her personal data, the study material to be acquired and already acquired (the subject studied, tasks performed), in order to gather information about the learner's approach to learning (style) and evaluate his/her learning progress. The accumulated information allows tracing the learner's learning process, obtaining information about the time spent in the system, the success of the tasks performed. The student receives the study material, which, depending on ITS integrated approach, is adapted to the student's level of knowledge and abilities. The student can choose the study material or task of another level. All information is accumulated in ITS student module to analyze student activities and tailor teaching materials to meet student needs.

ITS training module without human, i.e. teacher involvement ensures the teaching/learning process – determines the so-called virtual teacher's actions that reflect the learning material in a manner and sequence appropriate for the learner. The virtual teacher's activities are governed by a set of rules (training strategy and instructions for its implementation) developed by a learning expert. Each rule consists of assumptions and conclusions. The presumption of the rules is the student's knowledge, actions and other information accumulated by the student module, while the conclusion is the response that the system performs according to the rules.

Learner registration and identification in the system that does not fit into any of the system's basic modules and is implemented through the user interface should be described separately. This function should ensure the creation of a new model in the student module, when a learner is registering for the first time, or activation of an existing student model on demand (input of the identification information).

Most of the above mentioned ITS features describe the system's ability to adapt to the learner. To carry out such adaptation, collaboration between the artificial intelligence system and the learning environment must be achieved. The rules according to which this collaboration is organized cannot be clearly defined, as all such cases as real subjects (learners) can experience in interaction with the system are not foreseeable. The ability of the

system to learn is realized through agents – the properties of agents, such as ability to respond to actions, ability to judge, plan, learn and make decisions, as well as the openness of multi-agent systems, are important advantages of agent technology in the development of ITS [23].

## **2.2. Agent-Based Intelligent Tutoring Systems**

An agent is an independent software program, which exists in an environment and is able to perform various actions in an effort to achieve its goals [24]–[27]. An intellectual agent is an agent having the ability to learn – it is able to obtain information through sensors and process it, acquire new knowledge and use it through effectors. For the implementation of intelligent training systems, collaborative agents are used: the common goal of integrated agents in the system is the implementation of the training process, and the promotion and diagnosis of learning outcomes. The structure of the system provides collaboration and communication protocols (for the physical transmission of messages and for the characterization of the message syntax) – the ability of the agents to exchange messages.

The agent generates a sequence of actions in the environment according to what it receives from the environment. These actions cause a change in the environment, which thus goes into different states. If the sequence of actions is performed according to the expected – so that the environment has been changed as intended in the system, then the agent has done its job well. This notion of desirability is reflected in the assessment of any particular sequence of environment states [28]. The environments in which agents may work are very diverse. Their number is practically unlimited from the point of view of the implementation of system designer ideas. Depending on the task of the system and the type of implementation, different parameters characterizing the implementation of the environment can be distinguished [28]: observability, certainty, continuity, sequence, strategy. Upon learning the role of agents in the intellectual system [23], [28], [29] the most important (from ITS aspect) characteristics of intellectual agents are defined: activity, proactivity and communication ability. Several types of agents can be used in ITS implementation: a simple reflex agent, a model-based reflex agent, a goal-based agent, a usefulness-based agent.

Agent systems can be either single agent or multi-agent systems. If the agent acts alone in the system (solves a particular problem), then such a system, obviously, is a single agent system. As soon as at least two agents are integrated in the system, it is considered to be a multi-agent system. If agents compete with each other to get the desired result – a change in the environment (like in a chess game), it is called a competing agent system.

Each ITS module described above can be implemented as one or more agent systems. Therefore, different agents can be distinguished in each of the modules [23], [29], [30]. The agents used to implement ITS of the Doctoral Thesis are described in Chapter 3.1.2 (Chapter 3.1 of the Summary).

### **2.3. The Role of Feedback in Intellectual Tutoring Systems**

Since feedback is considered to be a learner motivator [22], [31]–[34], then one or several agents responsible for implementing the feedback are integrated into the training module and user interface. The development of an ITS requires the consideration of both human needs and requirements and the potential of information technology [35]–[37], [38]. The type of feedback and its representation in ITS depends on the use of didactic means (teaching theory, curriculum content, teaching methods and organizational form).

In order to implement effective feedback, it is necessary to understand the learner's responses to the learning material and to analyze the opportunities for improving learning outcomes. In addition, ITS adaptability (one of the feedback roles) means taking into account the trainee's knowledge of the subject matter, interests and learning styles [33], [37], [39].

Feedback in ITS is instant (immediate) – step-by-step [29], [32]. This means giving a response after each learner's step. In this process, the feedback agent keeps information about the learner's activities at all times. Only negative feedback can and should be realized in ITS. As with any negative feedback, also the feedback implemented by ITS, it is necessary to minimize the difference between the goal (standard, proper execution of the task and/or the result) and the actual outcome (learner performance).

The author's practical work and experience shows that in test assignments feedback in its classical (step-by-step) understanding can be a hindrance to proper task testing. Therefore, in a system where knowledge is tested (with a view to clarifying the competences of the learner and not to improve his/her knowledge), information should be provided after the task has been completed. Such information is not to be considered as feedback in the sense of cybernetics, but as a resulting (output) information of the test work that can be used as input information for other activities in ITS (and hence can be regarded as feedback conditionally).

Currently, the only feedback in the computer-aided design system training process is the teacher's response to the learner's actions and/or inactivity, as well as to the task performed. As previously found, this is a disadvantage in the whole process due to two aspects. Firstly, the teacher lacks information on the learner's actions, with the necessary additional information, so that the learner could master the use of CAD/CAM systems more successfully. Secondly, the learner is not informed about where he has made mistakes and failures in the task; thus, there is no motivation for improvement. Consequently, the creation of an ITS for the assessment of learner's actions and knowledge would allow successful feedback on the training of CAD systems and the implementation of knowledge testing. The tools integrated in ITS would make it possible to detect not only the correspondence of the completed task/project outcome to its purpose, but also to cover the process by which the learner performed the work, the learner's response speed to execution steps, hitching, identifying deficiencies not only in the usage of certain tools/functions of the computerized design system, but also the procedural knowledge of designing.

Analyzing the types of feedback, it can be concluded that the feedback to the knowledge assessment of the computer aided design system users is most appropriate after the execution of the task (see Fig. 2.2) – it does not interfere with the work process (similar to the previous

training) and also allows to evaluate the time spent on execution of the task and on each action (the information provided to the expert). This, in turn, makes it possible to compare the effectiveness of knowledge and activities of two employees/trainees. Whereas for testing the basic knowledge of trainees – provision of training process – it is also useful to envisage ITS feedback during the execution of a task (in the form of an advice and hint), if the agent tracing the learner’s activity finds long pauses in performance of the task, it can transfer information to the interface agent for the necessary assistance. However, such assistance should not be hasty so that the task does not become too simple and the learner does not lose interest in the training process at all.

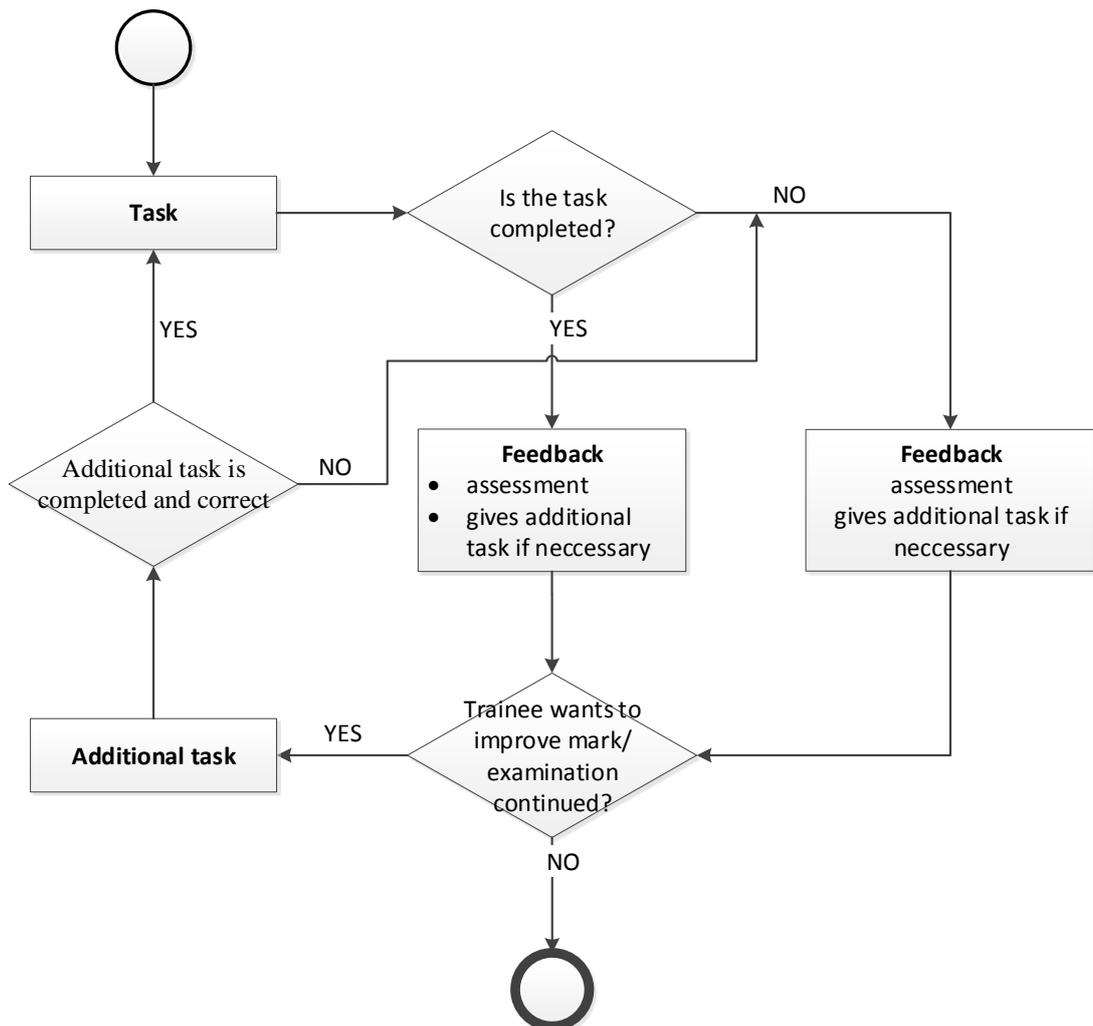


Fig. 2.2. Assessment activities diagram.

Analysis of literature sources shows that in the case of learning systems (and also intelligent tutoring systems) practically all researchers use the term “feedback” with a meaning different from that used in cybernetics. The following terminology has been used in this Doctoral Thesis: informative feedback refers to any information provided by the teacher or ITS (either during or after the execution of a task), which does not contain instructions for improvement of the user’s knowledge. For example, there is no reference to additional

literature and/or learning materials recommended for learning, or no additional tasks to be solved. “Corrective feedback” in the context of the Thesis is understood as information that the learner receives during and/or after the task is solved. The information includes both assessment of the performance and suggestions for improving the outcome by learning additional material and performing tasks. It should be noted that where it does not create misunderstanding, the term “feedback” is used instead of these two terms.

### **3. INTELLIGENT TUTORING SYSTEM FOR COMPUTER AIDED DESIGN TRAINING (KNOWLEDGE ASSESSMENT)**

Selecting a platform for development of an ITS, it is useful to know that the CAD/CAM systems currently available on the market are based on MS Windows platforms. In an analysis of the situation industry experts conclude [40], [41] that also the systems that were built on other platforms, during the initial computerized design development stage, are currently built for MS Windows environment exclusively. This is due to the need to migrate data between systems and collaborating companies; ensuring data compatibility between computer aided design systems is a complex task. Most systems store data in similar formats; registry libraries are used simultaneously; moreover, because of business competition, the stored formats, even if they are with the same extension, are incompatible when using a different CAD/CAM system. For these reasons, CAD/CAM is provided only on the Windows platform. Therefore, ITS for the assessment of CAD/CAM system usage should also be designed for the Windows platform.

#### **3.1. Concept of ITS for the Assessment of CAD/CAM System Usage**

As already mentioned in Chapter 1 of the Doctoral Thesis, currently it is not possible to assess the skills of an employee (complying with the above factors), since only the final outcome is available to the assessor. Therefore, it is possible to evaluate only the outcome of the task, but not the process. Process analysis is important for reducing the work capacity of the design work and hence reducing the resource capacity (time, manpower and salary, total project cost) of these works. It is not possible for a teacher to analyze erroneous and/or labour-intensive decisions of a user unless he/she observes the learner the during the entire task performance, recording any learner's action [42]. Already in the previous chapters it has been concluded that performance monitoring can be done with IT support in the learning process, implementing it in the form of ITS. In Chapter 2 of the Thesis it is concluded that agent activity and collaboration allow not only to store information on user actions in the system, but also to give the learner feedback with action analysis.

Graphic tasks in the CAD/CAM environment have their own specific sequence (see Fig. 3.1), while the knowledge of the drawer/designer and the skills in usage of the system directly affect the quality of the tasks performed (accuracy, speed, etc.).

## Performing graphic tasks in the CAD / CAM

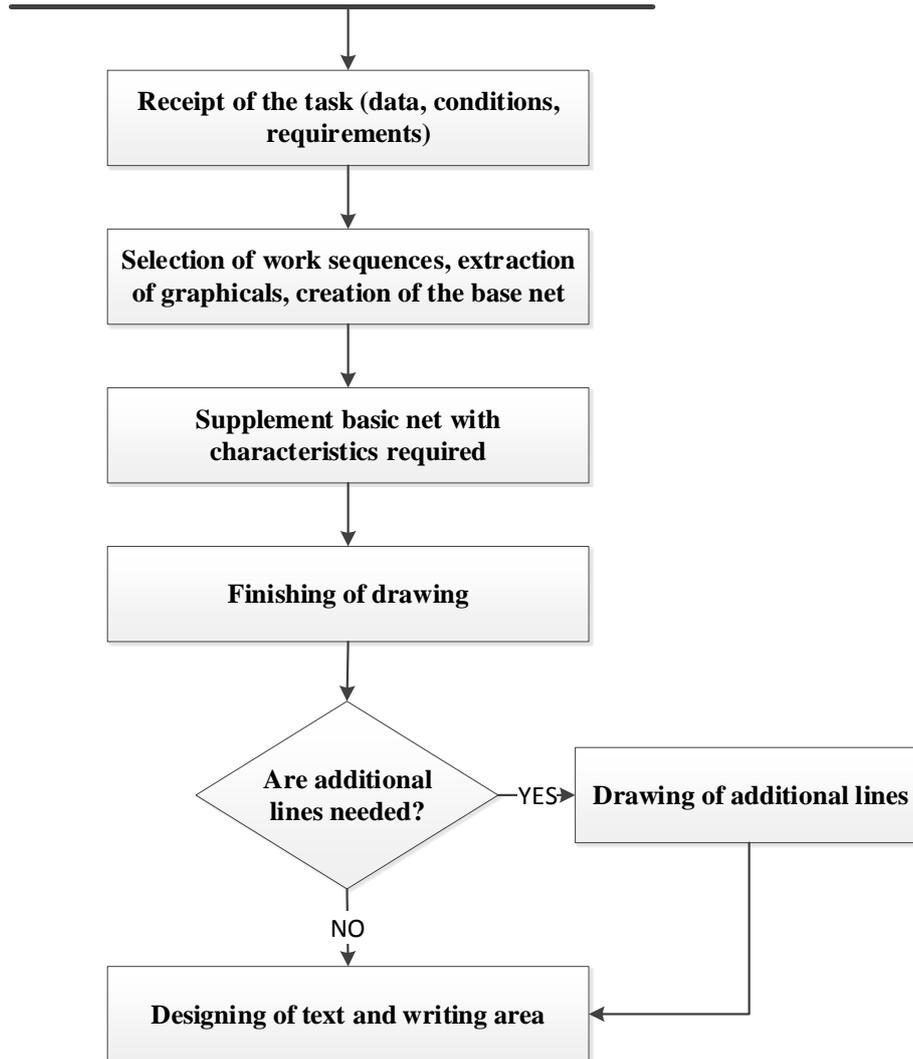


Fig. 3.1. The structure of performing graphic tasks.

In order to ensure the described resource capacity assessment, the modules required for implementation of ITS for assessment of CAD/CAM usage do not differ from the traditional ITS modules, while the actions to be integrated into them are different.

Implementing ITS for a specific problem area, the student module content is modelled to correspond to the objectives and tasks of the system and so that the system can use it for the implementation of the training. Since the purpose of ITS DPSLN is not training in the traditional sense – the implementation of teaching as a methodological presentation of the learning content with ITS DPSLN is not planned, then the student module should not contain the information (which ITS student module traditionally contains) about the learning content that the student has to learn, and that he has already mastered. ITS DPSLN student module contains information on the tasks that the expert has sent to the student for execution, on tasks that have already been completed, and on the student's success. ITS for Assessment of Computer Aided Design System Usage (DPSLN) should gather information on all learner's actions in a computer-aided design system and analyze the actions and knowledge levels.

ITS DPSLN implements the assessment of CAD/CAM system usage, tracks (and analyzes) the learner’s actions during the use of computerized design system (CAD) – compares the learner’s performance with the expert’s actions (Fig. 3.2).

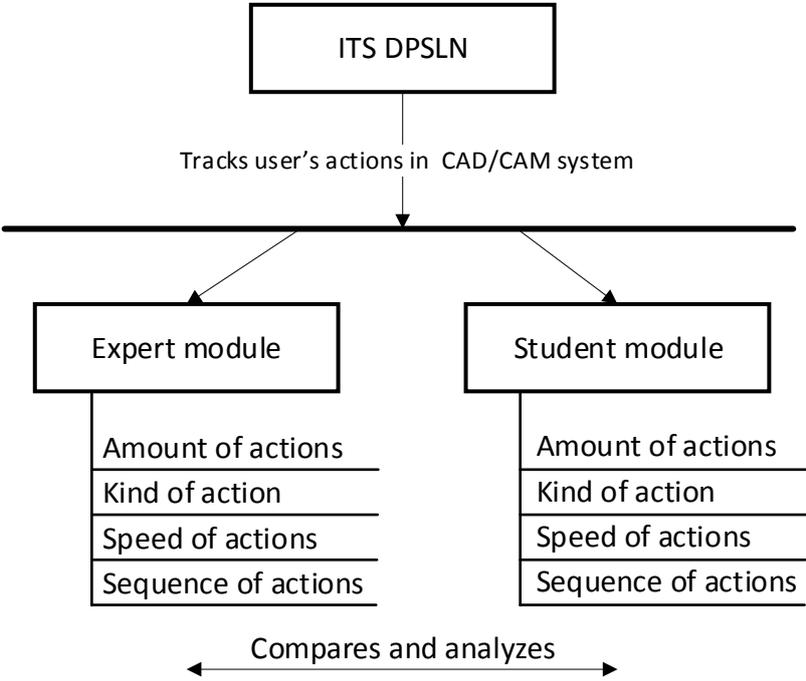


Fig. 3.2. ITS DPSLN student and expert module performance detailing.

ITS DPSLN reading the screen tracks the learner’s activities, lists them, records the type of activities (the functions and tools that the learner chooses in order to accomplish the task), and lists the speed and sequence of the steps by analyzing work organization during the use of the CAD/CAM system.

In order to implement an ITS, which evaluates the execution of learning tasks in CAD/CAM systems, it is necessary to generate tasks, their execution parameters and difficulty levels in the expert model. The expert module architecture of ITS for assessment of CAD/CAM usage, unlike the expert module integrated into the traditional ITS, alongside the expert model and expert-generated task management includes also tracking of the expert’s actions. Such a component is necessary for the system to fulfil its main task of evaluating the learner’s performance of the tasks using CAD/CAM systems as compared with the expert’s performance.

Since the goal of ITS DPSLN is not instruction but evaluating the usage of CAD/CAM systems, only the functions related to task storage, task integration, assignment and knowledge assessment are used from the traditional ITS Training Module for ITS DPSLN implementation. To assess the learner’s skills in using the computer aided system, integration of learner knowledge assessment and task assignment functionalities into ITS training module is necessary.

User interface has to serve as a communication platform where the problem is delivered to (assigns the task to the learner, informs about the performance rules), adopts solutions.

All of these modules need to collaborate by providing and receiving information, retrieving tasks from the database and sending information about their execution. Separate ITS functions can be realized as separate agents, whose features include the ability to communicate, collaborate and learn from one another to achieve the training goals.

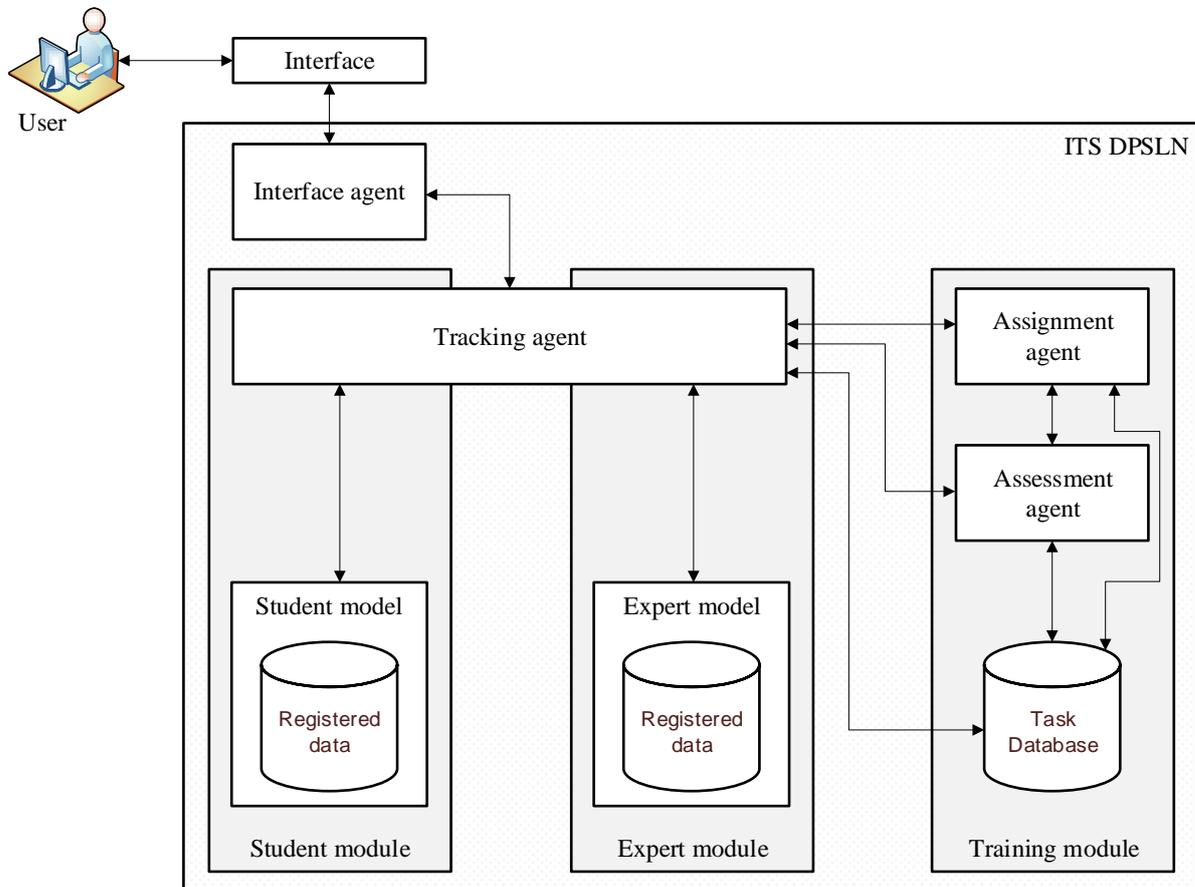


Fig. 3.3. ITS DPSLN architecture.

In the Doctoral Thesis, it is proposed to develop ITS DPSLN as a multi-agent system consisting of four software agents that transfer data among themselves and two agents – an expert and a trainee agent, which communicate with the interface agent. Other agents carry out activities according to the agent activities in the intellectual training systems (described in the Doctoral Thesis, Chapter 2.2) [43]. The involved agents are an interface agent, a tracking agent, an assignment agent and an assessment agent. Agents track the trainee’s activities, insert the tasks given by the expert into the database and support the assignment agent in assigning tasks, while the assessment agent evaluates the tasks performed by the learner according to the information obtained from the other agents (Fig. 3.3).

ITS DPSLN architecture uses the three classic modules – the student, expert and training module; their operations are supported by the agents’ actions. Agent activities ensure fulfilment of the main task of ITS DPSLN, which is not implemented in a traditional ITS – to track and record user actions step by step by separating them into separate, accountable and verifiable items (functions used, their number, time spent on the execution/use of each function).

Agent involvement is particularly important for ITS core functionality – to implement a full-fledged mechanism for assessing learner’s knowledge. Thus, the entire training process is improved. It has already been found in Chapter 1 that the lack of information about the activities of the learner is considered to be the main shortcoming of the current training process.

The interface agent complemented by the action tracking agent monitors changes in the database of functions; if any changes have occurred, step-by-step tracking (formative evaluation), feedback – suggestions for improving knowledge and error correction is provided. Feedback is published to the user only if it is necessary for the adjustment of activities (the learner is not disturbed in his/her work by positive statements). When the competency assessment is done (assessment of expert background and skills, actions in CAD/CAM system), information about the user is provided only at the end of the work (summative assessment).

ITS DPSLN activity algorithm consists of the processes necessary for tracking, recording, analyzing and storing user activity. The system operation is shown in Fig. 3.4.

When starting work with ITS DPSLN, registration takes place; information about the type of the selected activity is transferred to the next process. Data contains user information (retrieved from a pre-made database – user model data: registration, actions performed), the selected CAD/CAM systems for testing (or task generation), the selected tasks and functions registered according to CAD/CAM (prior to starting work, tools and functions of CAD/CAM system must be registered in ITS DPSLN database so that all actions are recognized during the screen reading).

After verifying the data and checking the conformity of CAD/CAM system and the task, the user can start the task execution. By activating any screen point (recorded as numerical values in orthogonal coordinates), ITS DPSLN while invisible to the user (screen reading without disturbing the user) checks whether the activated coordinates have the function required to perform the task. It lists both useful actions and those that were not included in the task by the expert. The information is included in the system database for further analysis.

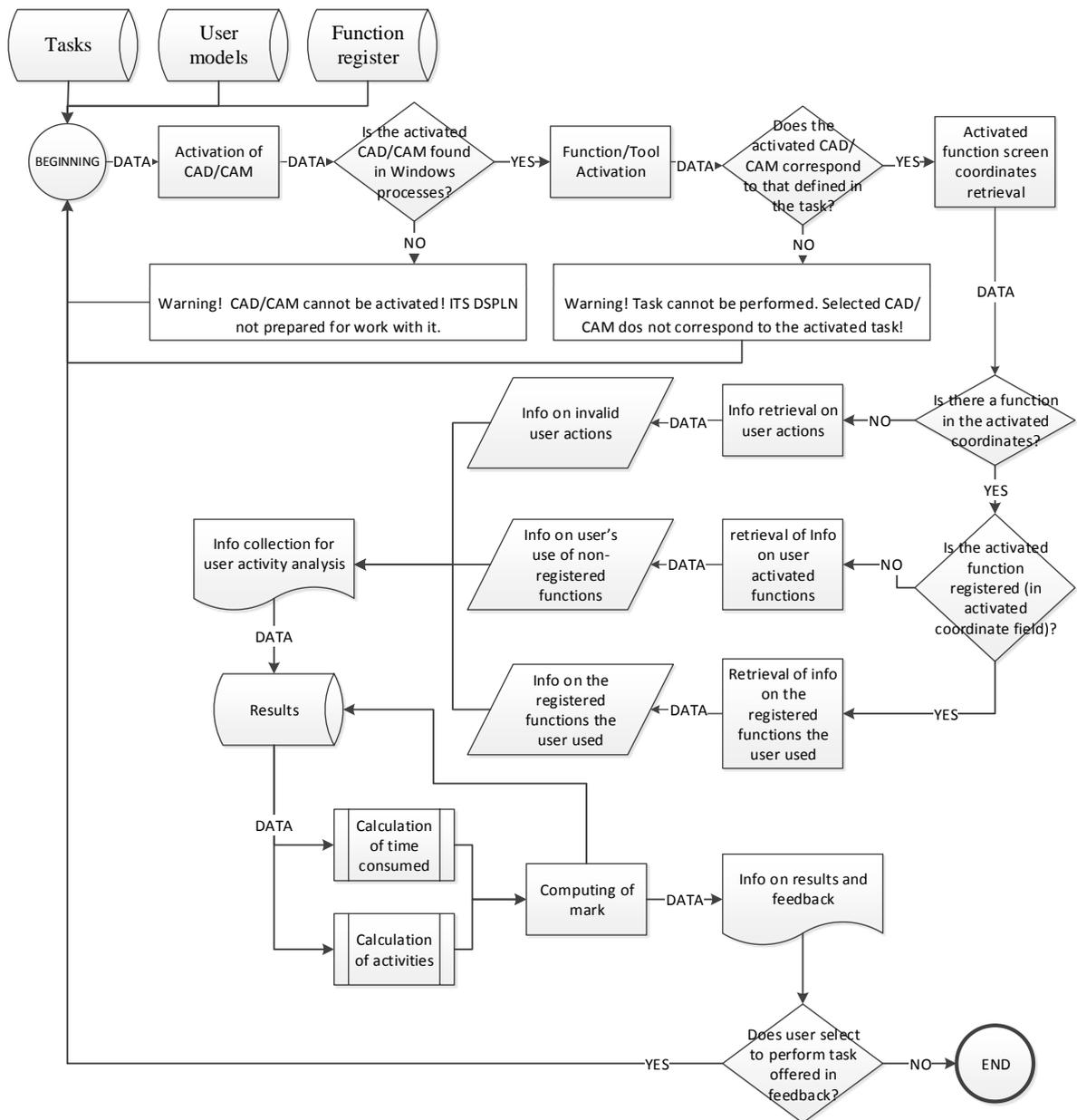


Fig. 3.4. ITS DPSLN operation algorithm.

Data containing information about the task, the functions registered with it, a list of actions performed by the user (both of the expert task designer and the learner), the execution time, the number and type of functions used is retrieved from the database. Based on this data the mark is computed (the score calculation is described in detail in Chapter 3.1.5. of dissertation). The mark and other results – user information, feedback and tasks are stored in the system database. If the user chooses to follow the feedback link proposal, the system activates the start-up window and allows starting the execution of the task, if not, ITS DPSLN will finish work.

The system operates with the aim of tracing all the activities of the learner, comparing them with the teacher's/expert's performance, and identifying the error-related actions, making conclusion about their significance and impact on the work as a whole.

All the knowledge testing activities described above are implemented through all the described agents; all information is recorded in the database. There is a single database for all modules (Fig. 3.5); it stores all user registration data, information about the tasks created by the experts, the tasks performed by the trainee and the assessments obtained.

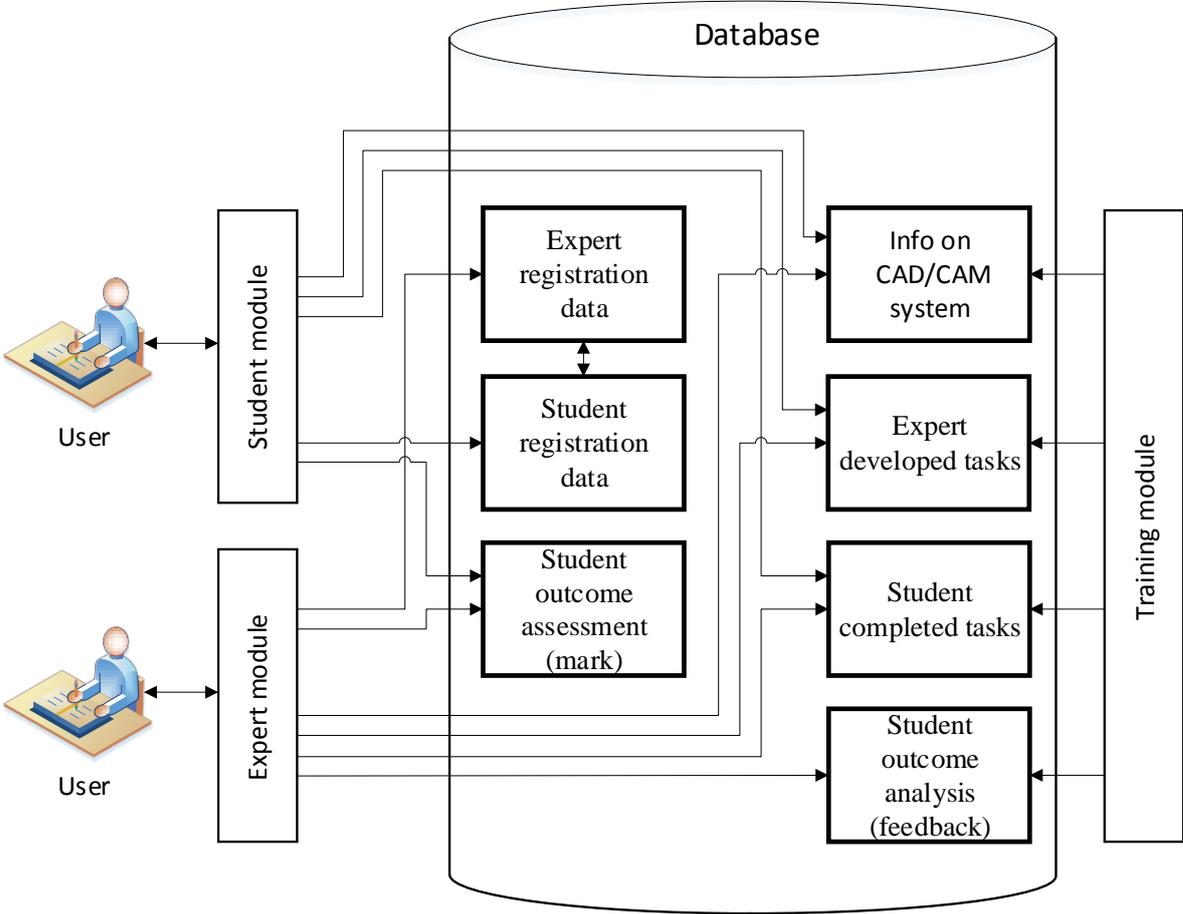


Fig. 3.5. ITS DPSLN database content.

At first, the basic elements, which will be used for knowledge assessment in the CAD/CAM systems, are defined for ITS for the assessment of computer-aided design system (DPSLN) usage. These elements are defined separately for each CAD system but they are universal in terms of their geometric characteristics.

Creating tasks for CAD/CAM in traditional instruction is most often the responsibility of the teacher, unless a book is published in which simple tests are given as examples. To test the knowledge, the expert/teacher prepares the test sample and identifies the functions necessary for the execution of the particular task. Since there are not many samples and semi-prepared knowledge test tasks in CAD/CAM systems, most often each teacher creates his/her own set of tasks.

With the currently existing training and knowledge testing in the field of CAD/CAM systems application, the assessment of the work is based on outcome evaluation – the expert (teacher) assesses the learner’s progress, and verifies the visual correspondence of the result,

the scale and number of graphical items. Based on these parameters, the expert assesses the performance, which may also be subjective.

In order to avoid the problem of the trainee choosing the path that he knows best to achieve the result (using only the functions that he finds useful), which is not always the fastest and most effective way, there is a need to make an inventory of actions performed creating an object. The assessment of trainees' knowledge is done by comparing the tasks performed by the learner with the expert's performance. First of all, recording of activities, process and time for the expert is created in the system, and this information is at the disposal of the expert agent, which further informs the assignment and knowledge assessment agents. In order to evaluate the trainee's activities, the number of actions the student has performed correctly is identified; hence the assessment of his/her performance is expressed by formula (3.1).

$$A_d = 10 \left( \sum_{i=1}^n DA_i \right)^{-1} \left( \sum_{i=1}^n DE_i \right), \quad (3.1)$$

where

$A_d$  – mark for the task done, if only the number of steps is taken into account for the calculation of the mark.

10 – maximum mark/points of the currently used rating system in Latvia.

$DA$  – steps performed by the learner.

$DE$  – steps performed by the expert.

$n$  – number of steps,  $n$  is a set of natural numbers.

It has already been described that not only the use of the functions/tools in the system by the trainee (with the aim of obtaining appropriate tools for work efficiency) is important, but also the time consumed affects the assessment of the designer's work. The faster the employee/trainee is able to do the job, the more valuable this employee is for the industry. To calculate the mark (formula (3.4)), which depends on the completion time, two coefficients are introduced: a coefficient, if the trainee has kept the time set by the expert (calculated according to formula (3.2)), and a coefficient if the trainer has exceeded both expert's time and also the given additional time (calculated according to formula (3.3)).

$$K_1 = \left( \sum_{i=1}^n LA_i \right) \left( \sum_{i=1}^n LE_i \right)^{-1} - 1, \quad (3.2)$$

$$K_{pl} = \left( \sum_{i=1}^n L_{pl_i} \right) \left( \sum_{i=1}^n LE_i \right)^{-1}, \quad (3.3)$$

$$A_1 = 10 - K_1 K_{pl}^{-1}, \quad (3.4)$$

where

$A_1$  – mark for the completed task if only the execution time is considered for the calculation

of the mark.

$K_1$  – coefficient, which depends on time (the time in which the expert completes the task).

$K_{p1}$  – coefficient, additional time given by an expert if the task is complicated.

10 – the maximum mark of the grading system currently used in Latvia.

$LA$  – completion time of trainee's task.

$LE$  – completion time expert's task.

$L_{p1}$  – additional time given by the expert.

$n$  – the number of minutes of time tracking, where  $n$  is a set of natural numbers.

The final score is calculated by summing up the two marks obtained (formula (3.5)) that can be corrected using coefficients. Correction is required if one of the task execution components (number of actions, execution time) is more important than the other. The sum of both coefficients must be “one” – not to make an inappropriate correction (not to exceed the maximum mark value of 10). By default, the coefficient values are  $\frac{1}{2}$  – thus, both the time that the trainee has completed the work and the number of operations used are equally important for the final mark. According to the expert's knowledge and experience, these coefficients can be adjusted. If the expert knows that time is most significant for completion of the task (for example, a simple test task that uses a small number of functions) then he/she makes changes in  $K_2$ , and  $K_1$  is computed, given that the sum of both coefficients cannot exceed the value of 1.

$$A = K_1 A_d - K_2 A_1, \quad (3.5)$$

where

$A$  – mark for the task performed.

$A_d$  – mark for the task performed, if only the number of steps is taken into account for the calculation of the mark.

$A_1$  – mark for the task performed, if only time is taken into account for the calculation of the mark.

$K_1$  – coefficient of the significance of the number of operations.

$K_2$  – coefficient of the significance of the time of completion.

Along with the mark, users get information about their performance. A list of all the functions/tools used by the learner, the time spent, as well as the information displayed to the user after the task execution is available to the expert. The trainee learns about the time at which the task had to be done, the admissible additional time and the time he/she had spent to accomplish the task, action and time weighting coefficients, as well as the mark obtained for the performance. In addition, information is provided that depends on the success of the task execution. Information for the user is considered as feedback if it contains instructions for the user to correct (improve) his/her performance. If a user has achieved good results (mark 7 and higher), he/she receives information about the mark without corrections for subsequent actions. In such a case, the user has the opportunity to choose a task for execution if he/she wants to continue working (see Fig. 3.6). In the case of a lower mark (under 7), the

information contains feedback with recommendations for further actions to improve knowledge (correction).

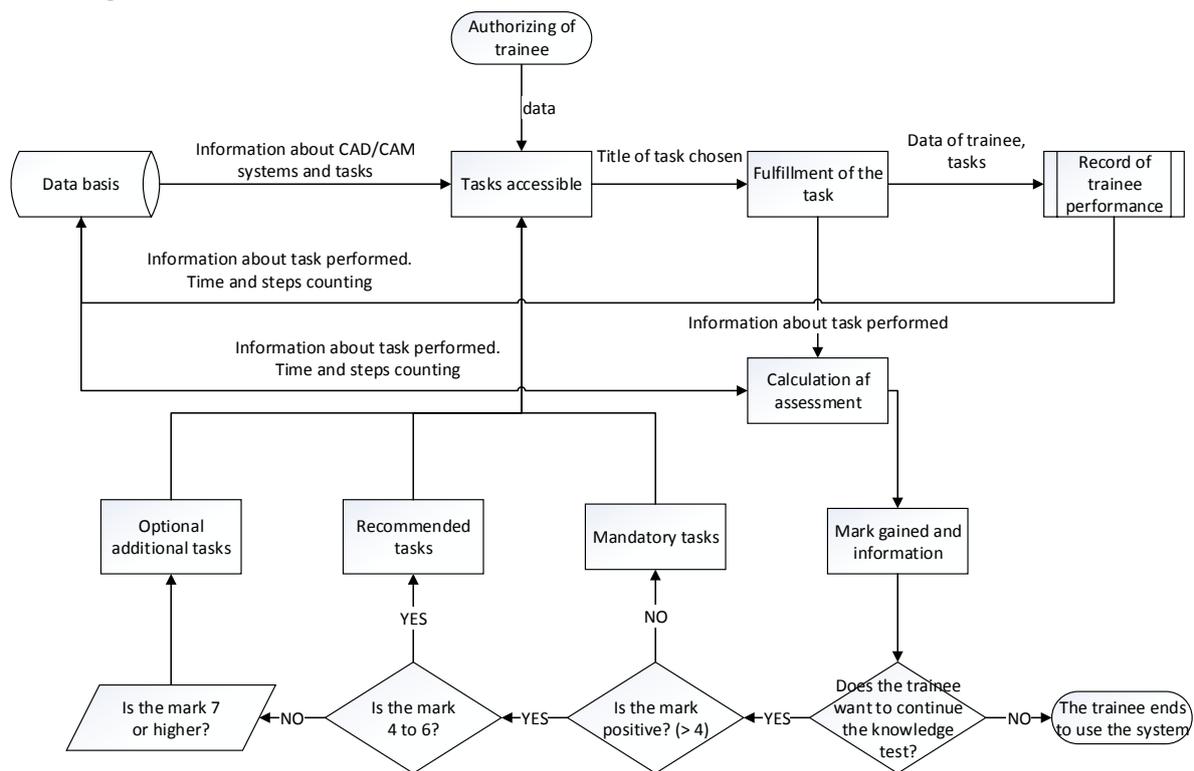


Fig. 3.6. The process of task evaluation.

Figure 3.6 demonstrates the process of assessing the performance of tasks, which shows that if the trainee chooses to continue, he/she can acquire additional tasks. If the trainee is scheduled to perform several test tasks during a single working session, then, alongside with the additional or recommended tasks, the trainee is prompted to perform the scheduled task. If the mark is poor, the learner is offered to complete the tasks that are easier than the initial test task. Even if the user interrupts the work in the system, the system offers these easier tasks in the next session, yet the user can choose to perform the test task (for which he/she got a poor mark) once more.

### 3.2. ITS DPSLN Operation

The objective of ITS DPSLN is to test the learner's knowledge for performing computer-aided design tasks, analyze the learner's performance, compare it with the solution proposed by the expert and provide informative feedback to both the learner on the results of the task performance and to the teacher on the learner's errors, thus providing information regarding the topics to be highlighted in the class. The system must be compatible with CAD/CAM systems and able to "observe" the processes that take place in the systems. Since in the case of an intelligent tutoring system it is not always possible to specify every possible response required from the software [44], only the main requirements for the system are described here [45].

ITS DPSLN is a system designed for use on a stationary or portable computer; its operation must not interfere with and/or interrupt the operation of the CAD/CAM system, interfere with it or initiate operations and/or processes not selected/performed by a CAD/CAM system user.

Anyone who creates and activates his/her user profile is considered as a system user. Users are divided into three categories: users of the public part (learners) who have access to the tasks and feedback for the accomplished tasks, experts who have access to the creation, execution and learners' outcomes in the use of CAD/CAM systems during the use of ITS DPSLN, and the administrator who has access to all information and database management. The administration of the system takes place in its closed section (only for authorized users), the administrator can change user data, the location of the database, and perform other actions coordinated with ITS DPSLN holders.

The system requires an Internet connection – its database is stored in the cloud, without prejudice to users' ability to change their location or workstation (to the extent that they are not limited by the licensing and access conditions of the CAD/CAM system). The database should store information about the latest versions of the system, users, work cycles, accomplished and integrated tasks, and other activities carried out in accordance with the objectives of the system.

ITS comprises software, database and access to the computer system to manage the data it contains. The software part communicates with CAD/CAM for obtaining data from the system (Fig. 3.7.) to perform data retrieval and further transmission to the database. ITS does not interfere with the CAD/CAM system work, however, by using screen reading and intellectual agents that exchange data, it carries out recording of user (trainee) activities and assesses the tasks performed by sending these data to the database. ITS also lists the performance tasks carried out by the expert in order to store a sample in the database with which the agent compares the user's performance. The administrator accesses the database through the Web to make adjustments to it, obtain information about the system, its usage, and update installation.

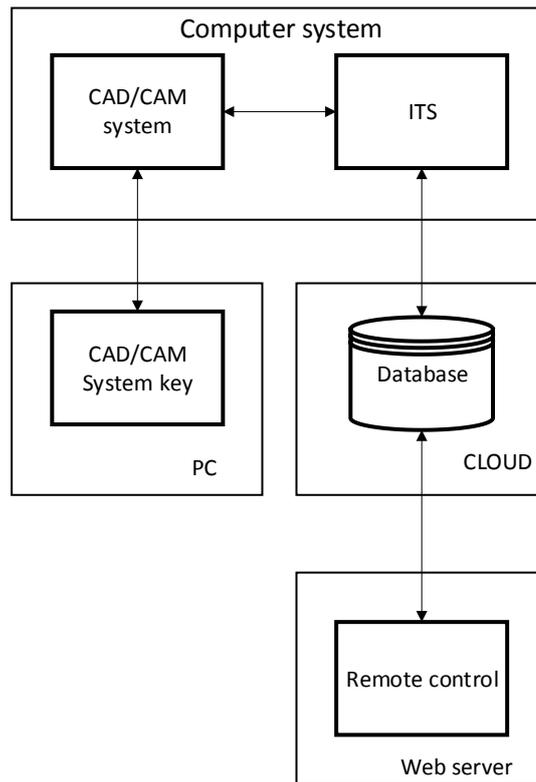


Fig. 3.7. The scheme of ITS performance [46].

To start work using ITS DPSLN, the user is registered in the system. Features available to the expert are: adding new tasks, customizing the CAD/CAM tracking window (transparent, not interfering with the use of the CAD/CAM system) to ITS DPSLN, adding CAD/CAM system tools and function keys to ITS DPSLN. The trainee receives a job assignment, he/she can move CAD/CAM system tools and function keys in the desired layout (provided this option is integrated in the CAD/CAM system) and activate performance checking (action tracking and analysis) that can be interrupted, if the learner decides not to continue working or at the end of the work, when the task is completed.

ITS DPSLN users (trainees and experts) receive information (feedback) about the training and usage of CAD/CAM systems. System integrated agents that transfer data for comparison of a trainee's performance with the expert's accomplishments, take into account the completion time of the task and analyze the usage of each CAD/CAM system function. Upon finishing work, users receive information and follow-up analysis. The trainee receives information about the mark received, the mistakes made, if any, and additional tasks, if the task is not performed on a sufficiently high level – the minimum mark of 4 is not reached. The trainee receives feedback after completion of the task. If the trainee fails to complete the task, he/she can terminate the work session and address the instructor directly or remotely, or use the CAD/CAM system help wizard to handle the task execution; even these steps are recorded and the expert is informed by ITS DPSLN. The expert receives information about the learner's mark and recommended tasks, as well as detailed information (full review) about the actions performed by the learner and the time spent on them.

ITS DPSLN performs the following activities.

1. At the start of training, the trainee receives a test task for the examination of the knowledge and skills acquired under a respective topic.
2. The trainee performs a task for training in the selected CAD/CAM system.
3. ITS DPSLN conducts a knowledge assessment comparing the performance of the trainee with the data provided by the expert.
4. The trainee receives the result (feedback) when the system agents have extracted information about the adequacy and correctness of the performance of the trainee.
5. If work is done at an inadequate level, the trainee tasks concerning a respective topic are being offered to the trainee (the system determines the shortcomings and knowledge gaps identified and offers simple tasks for knowledge and skills acquisition concerning specific CAD/CAM system functions).
6. If the work is done in accordance with the requirements, the assessment and transition lead to the end of the training session.

The limitations of ITS DPSLN development are related to the development of CAD/CAM systems. As mentioned at the beginning of the chapter, ITS DPSLN shall be developed on the Windows platform or support it due to specific operation of CAD/CAM systems. The interface of ITS DPSLN should support moving and/or adding function keys, depending on the layout of the CAD/CAM system interface. The Internet access is important for ITS DPSLN. The system retrieves and stores information in the database through the network therefore an active Internet connection is important for its operation.

The system requirements are derived from the analysis of the most popular CAD/CAM systems, their operation and structure, the approaches to CAD training found in literature [1], [3], [16] and the standards governing software development [44], [45].

In addition to other requirements, the system should include screen reading with a tracking agent, that records changes in the environment (in CAD/CAM system) (see the scheme in Fig. 3.8. ). It includes adding and deletion of new keys (functions – graphic elements, mathematical geometric transformations, description and other detail creation keys); function button positioning (moving) on the program screen; changing the function (button) name; turning On/Off Tracking Feature; creation of a database structure that includes the function name, positioning ( $x$ ,  $y$  axis); changing the size of the screen function button according to the function buttons of the CAD/CAM system used.

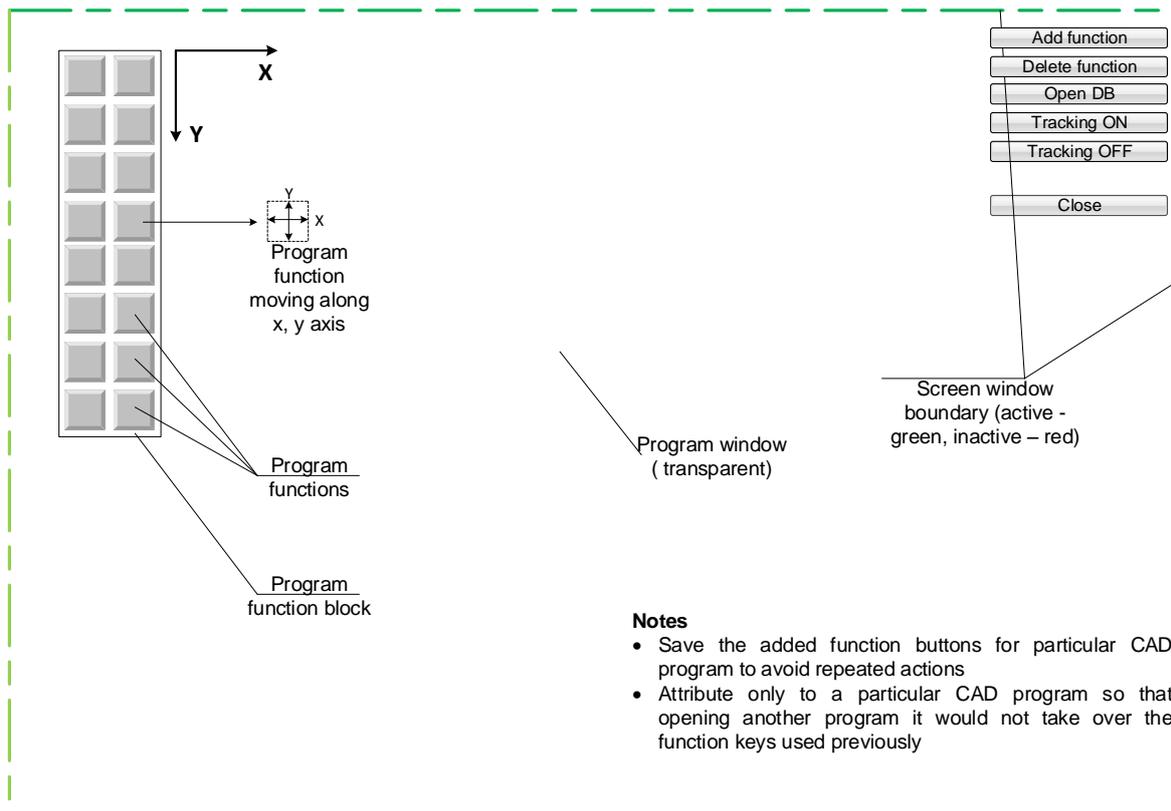


Fig. 3.8. ITS DPSLN interface prototype.

### 3.3. ITS DPSLN Implementation

To provide a centralized data and file storage, ITS DPSLN has a web-based application that stores system installation and updates on the web ensuring work with the latest version of the system for each user regardless of the user's location. This approach facilitates the availability of the system (ITS DPSLN) – the developer delivers the latest version on the web, and the user does not need to store the system installation in his/her data system.

ITS DPSLN is a web-based application implemented with .NET Framework 4.5 technologies – WPF (Windows Presentation Foundation), WCF (Windows Communication Foundation), executing service operations, EF (Entity Framework 6.0), MSSQL and C #, C ++ programming languages. A technology that does not come with the .NET Framework – Dropbox – is also used. Dropbox serves for shared data storage. The agents are implemented in the programming languages C# .NET, C++, MS SQL and technologies/libraries – WPF, WCF, WF, Dropbox API, OpenCV, Spatial SQL are applied. Data is stored in the SQL database.

ITS DPSLN consists of two separate projects – “DwgClient”, which has logic for the entire client side (user interface, error messages, etc.) and the service side “DwgService”, which provides database operations, incoming data processing and linkage to active clients. Each project consists of several layers to separate the logic according to its functionality and facilitate navigation in the program design process. To make the program run faster, two programming languages are used, where C# is responsible for all business logic, database and

service operations, while C++ performs image processing and use is made of the C++ library – Opencv. The Microsoft Management Studio 2012 MSSQL database is used for database operations.

The user authorizes in ITS DPSLN using any Internet browser, in case of the first user authorization from a specific workstation, then client applications from the server where the system is stored are downloaded, and the application installation on the client side is performed. Otherwise, any client application updates are checked, and then only the modified files are downloaded. During the user operations, data exchange between the database located on the server side and that of the client application takes place.

## **4. APPROBATION OF THE DEVELOPED ITS DPSLN**

The created ITS makes it possible to assess the learner's knowledge of the CAD/CAM system usage systematically, i.e., testing and analyzing each step of the task performed and the task completion time. Such a system (ITS DPSLN) also allows analyzing the quality of the developed tasks and their suitability for testing the required knowledge. If the teacher integrates self-assessment tasks into the system, then the created ITS also allows for self-assessment of one's knowledge – gaining an understanding of the acquired. This allows the trainee, regardless of the teacher, to control his/her level of knowledge and timely learn the omitted, if any knowledge gaps are discovered [46].

To implement ITS DPSLN goal – to test and assess the learner's knowledge in the use of CAD/CAM systems, it is necessary to develop test tasks that are integrated into ITS and used in accordance with the curriculum and the skills to be assessed.

### **4.1. Work With ITS DPSLN**

Using ITS DPSLN for the first time one shall register with the system or log in if the user is already registered. As system users have different roles, expert authentication takes place upon entering expert data automatically; the system recognizes the user category. In turn, in order to register as an expert, a box “As Expert” was created. Ticking this menu opens additional boxes in the login window, which need to be filled in for the registration or connection to be successful. An administrator password has been created to prevent someone from arbitrarily registering in the system as an expert. This password contains letters, numbers and special characters making it safe. As already mentioned, this password is stored in the database in a separate table for AdministratorPassword.

After authorization in the system, the user selects the software – CAD/CAM system in which the work will take place, the software version and the task to work on. Depending on the role assigned, the user (expert or learner) either starts executing the task or creates a new sample of the task. The expert can also work with the data generated by the action tracking agent by activating “Agent” menu. To view action tracking agent information on the learner's completed task, “View Results” menu should be activated. The task management tab allows you to edit, add, and delete tasks. In this tab, after the task has been registered and completed (expert's task exemplary execution, from which the knowledge assessment agent obtains information), the time taken for the task performance by the expert (upper limit to a whole minute), as well as the additional time entered by the expert, which is taken into account when the learner executes the task.

The Application Manager tab allows you to perform all necessary operations with applications (CAD/CAM systems), such as add new ones, edit, delete, add new functions, edit and delete them. When you activate the registered application, its functions, their names and image are displayed.

The informative feedback is collected in a separate tab for the expert. In this tab, the expert sees the time spent by the learner, the extra time allocated for the task, the calculated

coefficients: the importance of the number of actions coefficient  $K_1$  and the completion time coefficient  $K_2$  (retrieved from the section “Task management”).

The learner’s mark (calculation formulas are given in Chapter 3.1.5.) and information (analysis of the errors given to the learner and the suggested tasks) are shown in separate tab fields (Fig. 4.1).

OPERATION OUTPUT	SEE THE RESULTS	TASK MANAGEMENT	PROGRAM MANAGEMENT	FEEDBACK
Patērētais laiks:	TIME			
Atvēlētais laiks:	CONSUMED TIME			
Eksperta dotais papildlaiks:	ALLOTTED TIME	ADDITIONAL TIME GRANTED BY EXPERT		
Darbību skaita svarīguma koeficients (k1):		IMPORTANCE OF NUMBER OF ACTIONS COEFFICIENT		
Izpildes laika svarīguma koeficients (k2):		IMPORTANCE OF COMPLETION TIME COEFFICIENT		
Atzīme:	MARK			
Informācija:	INFORMA			

Fig. 4.1. Agent information – ITS DPSLN feedback.

The user finishes work in the system closing it with the function key in the upper right corner (a cross).

## 4.2. Approbation of ITS DPSLN in Student Groups

As described above, the aim of the Doctoral Thesis is knowledge assessment; therefore, in the context of this Thesis, the author does not go into details of teaching methods or didactic methods. In order to use ITS DPSLN, it is up to each teacher/expert to create tasks. By tailoring detailed and specialized design tasks for specific CAD/CAM systems, a task database is created that is required for the acquisition of CAD/CAM systems in a particular industry. In turn, simple, general tasks can be set up to test trainees’ knowledge in any CAD/CAM system – for checking the usage of basic graphic element functions (CAD/CAM system tools).

ITS DPSLN approbation was included in the implementation of Riga Technical University study subject MŠM533 Computer Aided Design of Clothing and took place in the CAD/CAM laboratory of the RTU Institute of Design Technologies. Overall, the system was

used by 46 students (in several groups). Students studying this subject acquire the computer-aided design system GRAFIS, they do not know about the system when they begin the course. In accordance with the techniques described in Chapter 1, ITS DPSLN is at first tested for checking simple tasks (see Fig. 1.5. in the Thesis).

According to the system's operating algorithm, before the knowledge test, the CAD/CAM system (software) is activated, system GRAFIS creates a task name. When the system is operating in the mode where the functions (their listings) are added, the menu systems are active for finishing work (close), selecting application software, deleting functions from the list, temporal intermission of work, and saving the accomplishment.

The trainee, starting work in the system, must first register and then choose the task to be performed. Then the system offers to start the task performance. Like during the course of an expert's activity, all the implemented functions are listed, their duration, quantity and frequency of use are fixed. For the learner, to complete the task, an image of the final result what the drawing should look like, with its lines, divisions, auxiliary lines and dimensions, is available. Here the task used for system verification is a tetragon with diagonal and perpendicular split lines. If a trainee submits a job he has not completed, the system provides information stating that the task has not been completed and is not valid for verification. If the knowledge assessment agent, by analyzing the information on the trainee's activities recorded in the action tracking agent's database, finds differences as compared with the expert's performance, it gives an assessment and records it in the database. The interface agent communicates this corrective information to the trainee.

The analysis of differences is based on the evaluation of two actions; for example, if the trainee does not draw a tetragon using the appropriate function but draws it line by line, the agent evaluates the mutual positioning of the lines.

When the trainee has completed and submitted the assignment, he is given a feedback – the time consumed, time allotted, time spent by the expert, additional time given by the expert, significance coefficients of the number of operations and time of completion (described in Chapter 3 of the Dissertation), a mark and additional information on the accomplishments on which the mark depends. If the student chooses to continue working in the system, then he/she is given a corrective feedback – the opportunity to complete an additional task, for re-examination of knowledge. If the student's score is insufficient, a simpler task is suggested, if a good result is achieved, a more complex task is offered. Thus, the student gets additional experience of work with CAD/CAM systems.

In the trainee's collaboration with ITS DPSLN, three use cases can be identified: authorization, registration and testing of knowledge. The use case diagram (Fig. 4.2) shows all three cases of use. The action "Feedback" is presented differently because it is limited in the case of competence testing.

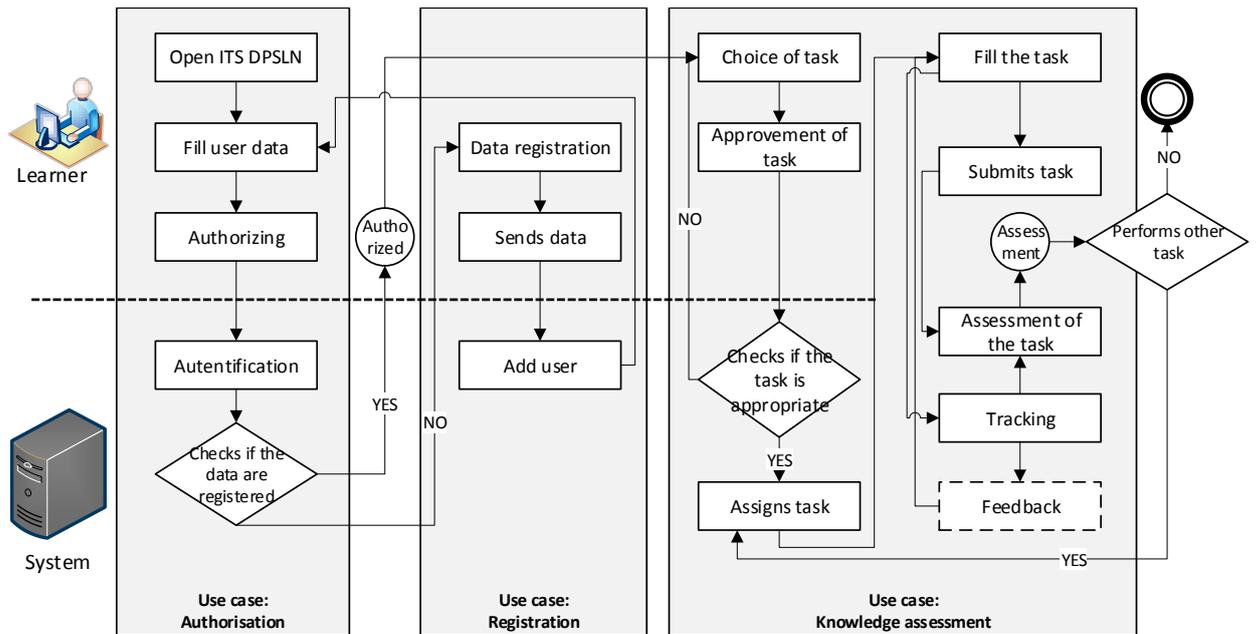


Fig. 4.2. Use case diagram.

Similar use cases can be identified in expert collaboration with ITS DPSLN, only the knowledge test has to be replaced by creation of tasks and checking of trainee performance.

Students (as already mentioned 46 students of RTU Institute of Design Technologies) performed the task. The registered user actions were listed, time for each function usage was recorded, and the time spent on the entire task was summed up. All 46 students were given the task “Tetragon”. The expert performed the task in 9 minutes using 6 functions in total 34 times (34 actions). Student performance time varied from 10 to 45 minutes, functions 6–11, actions 35–53.

For calculating a mark (formulas given in Chapter 3.1.5), a formula with the same weighting coefficients of the parts of the mark is used:  $K_1$  – coefficient of significance of the number of operations ( $K_1 = 0.5$ ) and  $K_2$  – coefficient of significance of completion time ( $K_2 = 0.5$ ), thus balancing the significance of time and number of operations in the task [46]. It is not uncommon to learn in negotiations with employers that working with CAD/CAM systems the rate of performance is most important (which can be facilitated by efficient performance, but good knowledge of the CAD/CAM system and its functions does not always give the ability (competence) to draw quickly and precisely). Therefore, the table also gives a mark, if time is considered the most important performance indicator, then  $K_2$  – execution time significance coefficient ( $K_2 = 0.8$ ), and  $K_1$  – the number of actions significance coefficient ( $K_1 = 0.2$ ).

Analyzing the results of approbation, it can be seen that for more than half of the learners the time of completion exceeds the expert’s performance by more than two and even three and four times, however, considering the number of operations, it is evident that some students have performed the tasks rationally but slowly. The effect of the execution rate on the mark can be adjusted by coefficients  $K_1$  and  $K_2$ . Table 4.1. of the Doctoral Thesis shows that by increasing the time weighting to the coefficient of 0.8 those students who have had a very

long execution time score one point lower. Such a reduction may seem small, but the experience of the author and colleagues shows that downgrading to more than one mark does not seem appropriate if the student has done the job and submitted it. The results of the approbation prove one of the benefits of the system: by reviewing the information gathered by the action tracking agent (feedback), it is evident which functions have taken more time, where there were longer breaks in the work that may indicate embarrassment, and other results that allow the teacher to highlight directly those problem functions that present more difficulty. Similarly, the information gathered by the agent allows analyzing the data by the frequency of function usage, repetitions and the use of the “delete” function.

As it is known, each drawing can be created using a variety of sets of graphical items (elements), while the system allows to delete the redundant graphic items, which is considered to be a drawback in user/learner actions (unless deletion is an inevitable operation required to delete a separated line segment). Recording of such activities, identifying and analyzing their time intensity allow achieving higher training results.

In oral interviews, students acknowledged that they did not regard the knowledge test system as disturbing or affecting their work. The majority of students acknowledged that they had not paid attention to the operation of the system at all, since performing tasks in the CAD/CAM system is already a highly challenging and difficult task. Some students acknowledged that they considered moving icons on the screen for personal use was not useful, while for others, this aspect seemed to be very important. All students confirmed that feedback was the main advantage of ITS DPSLN. An immediate mark and information about accomplishments allow one to get the results for the job done and motivation. Also, those students whose work was rated lower than the average acknowledged that feedback was motivating. Most students found the fact that the work was assessed by a system and not by a lecturer could be considered rather as an advantage and the system superiority compared with a real teacher’s assessment.

### **4.3. Approbation of ITS DPSLN in Enterprises**

The use of CAD/CAM systems in a company differs from student training by the level of user knowledge and, most often, the confidence in it. A manufacturing specialist is convinced of his skills and competence in using the system according to his/her purpose in fulfilling design tasks [3]. However, quite often it turns out that a manufacturing specialist uses irrational working techniques when choosing to implement design tasks with familiar system functions (tools), without respecting the improvement of work organization or acquisition of new techniques. It may turn out to be a problem for the production manager as it may be difficult to achieve the set production goals based on the experience of other companies; the company employees may have difficulty working with CAD/CAM system files received from their partners and implemented by other work methods.

For testing the skills of a clothing design company’s staff in the usage of CAD/ CAM systems, the task of drafting a skirt block pattern was integrated into ITS DPSLN. Such a task, in its essence, regarding the work sequence and the decomposition of the actions to be

performed, is much more complicated than the task of checking simple functions (as was used for examining students' knowledge). The complexity of the task lies in the fact that each designer can create the drawing differently – using different methods and techniques.

The model developed by an expert for creating a skirt block pattern was integrated for assessment of the knowledge of employees of a clothing manufacturing company (the knowledge of designers of garment producing company was tested; group consisted of sixteen employees). The expert's time for creation of the entire drawing was 16 minutes, 22 actions were performed, 7 commands were used.

In this approbation, assessment was not only unimportant, moreover, it was also inadequate for the work performed: each employee constructed the design using different techniques, created it with different methods, and used various functions and different decomposition of operations.

It was not possible for ITS DPSLN to give an assessment of the performance, as well as in the case of training the company employees (when people with experience in the CAD/CAM system, i.e. experts are taught) it was not really needed. The main benefit of using ITS DPSLN was the following: tracking the actions and defining the timing of design steps precisely.

When checking the staff knowledge in using CAD/CAM systems, a function list turned out to be useful that made it possible to get an idea of consistency of specific operations with the purpose and task of the tools integrated into the system. In complicated drawings, the smaller number of functions used does not always mean a better CAD/CAM system usage. It is not uncommon that an employee using tools known to him performs the work for which more rational functions are available in the system. For example, during the approbation it was found that two template bonding (merge) function in some employees' performance was replaced by four other functions (marry-attach-piece split-extract). Such actions take a lot of time, and the accuracy of the result (the retrieved template) is questionable.

## CONCLUSIONS AND RESULTS

The goal of the Doctoral Thesis is to develop an intelligent tutoring system (ITS) that implements the assessment of CAD/CAM system usage, follows (and analyzes) trainee actions during the use of a computerized design system (CAD), and to perform prototype testing and operational verification of the developed system, which was achieved executing a series of **tasks**.

- Information on training processes has been gathered and analyzed and its aspects and knowledge assessment methods have been examined that allowed defining general requirements for the training and knowledge assessment process and identifying problems in the traditional knowledge assessment process of the CAD/CAM system usage.
- ITS development process, structure and methodology have been studied (traditionally used modules, agent approach) that identified the necessary system components, concepts (that differ from the traditional ones with tracking user actions step-by-step) and paradigms used, as well as specified the requirements for the system.
- Intelligent agent systems have been analyzed with the aim of identifying the benefits of such systems in the development of ITS; a new ITS structure for knowledge assessment was developed in order to implement a system based on conclusions drawn upon theoretical research for assessment of knowledge of CAD/CAM system usage.
- A concept of intellectual agent-based knowledge assessment system based on the results and conclusions of the research was developed.
- Following the developed concept, ITS prototype was implemented, which performs assessment of CAD/CAM usage process.
- The developed ITS prototype has been experimentally tested in the training laboratory at Riga Technical University and at the CAD/CAM system Polytropon Automation Systems, a company in Greece.

The research identified the following **problems** concerning the development of intellectual tutoring systems for training and knowledge assessment.

- There is no intelligent tutoring system to support the assessment of use of CAD/CAM systems. The instructor can see only the input data (tasks) and the output data (the learner's accomplishment); however, the fact whether the trainee has performed the task himself/herself, timely and with useful techniques remains unclear. In addition, a trainee may be a real individual working in production, where the recording of the time spent on industrial development and the reduction of the time consumed present a very important and resource-intensive task.
- Insufficient learner support for evaluating and understanding the work performed (lack of feedback in the CAD/CAM mastering process):
  - Normally, the trainee is offered a prepared task/project for execution without additional knowledge of the sequence of execution and the usefulness of the functions.

- Evaluation of the final result consists of the final outcome assessment by the expert; the process and procedural knowledge are not evaluated at all.

In solving these problems, the following major new **theoretical results** have been achieved in the Doctoral Thesis:

- An algorithm has been developed that allows assessing the learner's performance using the CAD/CAM systems based on the consumed time, analysis of the number of the functions used and frequency of use, the usefulness of the functions used, and comparing the learner's performance with the sample solution developed by the expert – a competency assessment method demonstrating the use of artificial intelligence methods in real practical problem solving for assessment of CAD/CAM system usage.
- A principally new concept of ITS rooted in the agents, structure and architecture for the assessment of trainee knowledge in usage of CAD/CAM systems with assessment of the progress of the task execution has been developed.
- CAD/CAM system training processes and the pedagogical approach as well as the existing approaches and provision of knowledge testing have been described.
- Task samples have been elaborated and generated into the created ITS with an open possibility to make other tasks that expert would consider necessary.
- Approbation by feedback (correction of knowledge) and detailed information on learner knowledge in the CAD/CAM system usage has been developed.

The theoretical results obtained have been **implemented in practice**.

- In the Doctoral Thesis an intelligent tutoring system prototype for identifying and assessment of the trainee's knowledge in usage of CAD/CAM systems to improve the learning and production processes has been developed.
- The implemented prototype allows to improve knowledge in working with CAD/CAM systems, to identify gaps in trainee knowledge, to analyze and improve work methods. The system can be used in mastering various CAD/CAM systems and the process of their usage.

The development of prototypes and the results of the experimental test allow the following **conclusions** to be drawn.

- The developed ITS DPSLN can provide the missing link between the learner and the expert for assessment of the development of graphic designs, training support and providing feedback.
- The ability to generate new tasks for testing and assessing of knowledge and to preserve the existing already used tasks for the use of various CAD/CAM systems allows the expert to gradually introduce the learner to the usage of CAD/CAM systems, and to adapt tasks to the learner's knowledge level with the help of feedback.
- The analysis of the developed ITS results allows identifying gaps in the learner's knowledge based on the listing of functions/tools used for the performance of the learner's task, and its comparison with the performance of the expert.

The work results allow confirming the theses submitted for defence. Approbation of the developed ITS DPSLN allows to conclude that the system tracks user actions in the CAD/CAM system, the agents integrated in ITS collect information about changes in the system (environment), analyze it and provide information on the actual user competency and the level of knowledge. Feedback provides the corrections needed to improve knowledge, thus enhancing trainees' interest in CAD/CAM learning. The knowledge assessment algorithms integrated in ITS DPSLN provide an objective assessment for each trainee.

Directions for **further research**.

- ITS DPSLN action tracking agent learns from the list of its integrated functions, and upon developing the research there is an option to integrate an algorithm allowing calculation of the frequency of use and usefulness of the functions (tools) used in CAD/CAM systems. Such information would allow supplementing the calculation of the mark with a function usefulness coefficient.
- Upon the system approbation, to analyze generation of various hints and tips in the system during task execution.

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