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THE VIRTUAL EDUCATION SPACE: CONCEPT, ARCHITECTURE, APPLICATION

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Abstract

The e-learning environment known as VES (the Virtual Education Space) was created at the University of Plovdiv "Paisii Hilendarski" in Bulgaria step by step for years as each subsequent version was built on the previous one. Initially a learning system called DeLC (the Distributed e-Learning Center) has been implemented to support blended and independent learning at the Faculty of Mathematics and Informatics at the university. DeLC was a successful project, but we identified some problems, connected with interactions between the virtual and the physical world where in fact the learning process takes place. In the following period, we started the development of ViPS (the Virtual Physical Space) based on concepts of CPSS (Cyber-Physical-Social System) and IoT (Internet of Things). VES is the ViPS adaptation to education. VES is the successor to DeLC, it provides e-learning content and e-learning education services for planning, organizing, and conducting the learning process at the Faculty of Mathematics and Informatics of the University of Plovdiv.

VES supports various forms of e-learning such as blended learning, self-paced learning, lifelong learning, inclusive and game-based learning (GBL). The following aspects of VES are essential: 1) users are the focus of attention; 2) physical "things" are virtualized; 3) there is integration between the virtual and the physical worlds. Since ViPS is developed as a CPSS ecosystem, users are the focus of attention. This determines the need to develop personal assistants to participate in the processes of the ViPS space on behalf of and in the interest of users. Three intelligent agents are modeled in VES: an internal educational agent, an external educational agent, and a career consultant. MATE (the Multi-Agent Testing Environment) is a component supported in the ViPS space for training and testing of students in a game-based manner. MATE is a set of autonomous agents, each one of which has responsibilities in the common architecture that arise from training and testing needs.

As a CPSS space, VES introduces new approaches and scenarios to solve complex problems in the field of e-learning. VES provides a reference architecture, which can be adapted for various forms of education supported by information and communication technologies.

Keywords: cyber-physical-social system, CPSS, e-learning, virtual education space, intelligent agent.

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ВИРТУАЛЬНОЕ ОБРАЗОВАТЕЛЬНОЕ ПРОСТРАНСТВО: КОНЦЕПЦИЯ, АРХИТЕКТУРА, ПРИМЕНЕНИЕ

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Аннотация

Среда электронного обучения VES (Virtual Education Space — виртуальное образовательное пространство) создавалась в Пловдивском университете «Паисий Хилендарский» в Болгарии шаг за шагом в течение многих лет, при этом каждая последующая версия была построена на предыдущей. Первоначально была внедрена система обучения под названием DeLC (Distributed e-Learning Center — Центр распределенного электронного обучения) для поддержки смешанного и самостоятельного обучения на факультете математики и информатики университета. DeLC оказался успешным проектом, но мы выявили некоторые проблемы, связанные с взаимодействием виртуального и физического миров, в котором фактически происходит процесс обучения. В последующий период мы начали разработку ViPS (Virtual Physical Space — виртуальное физическое пространство) на основе концепций CPSS (Cyber-Physical-Social System — кибер-физическая социальная система) и IoT (Internet of Things — интернет вещей). VES — это адаптация ViPS к образованию. VES является преемником DeLC, оно предоставляет контент и образовательные услуги электронного обучения для планирования, организации и проведения учебного процесса на факультете математики и информатики Пловдивского университета.

VES поддерживает различные формы электронного обучения, такие как смешанное обучение, самостоятельное обучение, обучение на протяжении всей жизни, инклюзивное обучение и обучение на основе игр. Важны следующие аспекты VES: 1) пользователи в центре внимания; 2) физические «вещи» виртуализированы; 3) существует интеграция между виртуальным и физическим мирами. Поскольку ViPS разрабатывается как экосистема CPSS, пользователи находятся в центре внимания. Это определяет необходимость разработки персональных помощников для участия в процессах пространства ViPS от имени

и в интересах пользователей. В VES моделируются три интеллектуальных агента: внутренний образовательный агент, внешний образовательный агент и консультант по вопросам карьеры. MATE (Multi-Agent Testing Environment — мультиагентная среда тестирования) — поддерживаемый в пространстве ViPS компонент для обучения и тестирования студентов в игровой форме. Это набор автономных агентов, каждый из которых имеет обязанности в общей архитектуре, возникающие в связи с потребностями обучения и тестирования.

Как пространство CPSS, VES представляет новые подходы и сценарии для решения сложных проблем в области электронного обучения. VES предоставляет эталонную архитектуру, которую можно адаптировать для различных форм обучения, поддерживаемых информационно-коммуникационными технологиями.

Ключевые слова: кибер-физическая социальная система, электронное обучение, виртуальное образовательное пространство, интеллектуальный агент.

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1. Introduction

The possibilities of modern digital technologies and their application in the educational process is a subject of growing interest, especially in the global COVID'19 pandemic. Software companies and universities develop different educational environments, which, despite their unconditional advantages, have a number of shortcomings related to didactics, methodology, pedagogy, and psychology. There are various specifications (e. g. SCORM, QTI) that encourage the integration of methodological and pedagogical models in the educational environment and solve this problem to some extent. The fact is that face-to-face learning has no effective alternative and the use of appropriate educational environments can support and enrich the learning process as an additional didactic technology.

In this article, we will introduce an e-learning environment known as VES (the Virtual Education Space). The above considerations are embodied in the construction of VES. This space was created step by step for years as each subsequent version was built on the previous one. We initially implemented a learning system called DeLC (the Distributed e-Learning Center) to support blended and independent learning at the Faculty of Mathematics and Informatics at the University of Plovdiv. DeLC functions as a network from individual e-learning nodes that support a full or partial cycle of training in different laboratories, departments, faculties, colleges, schools, and universities. Each e-learning node is a standalone host of a set of e-learning services [1]. DeLC was a successful project, but we identified some problems, connected with interactions between the virtual and the physical world where in fact the learning process takes place.

In the following period, we started the development of ViPS (the Virtual Physical Space) based on concepts of CPSS (Cyber-Physical-Social Systems) [2] and IoT (Internet of Things) [3]. ViPS is a reference infrastructure to support the development of CPSS-like applications [4]. The main challenge to consider is the integration of the virtual and the physical world in both directions. The first bottom-up direction focuses on the virtualization of physical “things”. The top-down direction aims to “locate” system intelligence close to

the physical world. In this aspect, special attention is paid to the support of different user groups.

As a reference architecture, ViPS has to be adapted to the different domains. VES is the ViPS adaptation to education; it supports various forms of e-learning such as self-paced learning, blended learning, lifelong learning, and inclusive learning.

The rest of the paper is organized as follows: a short review of ViPS is considered in Section 2, Section 3 presents selected applications operating in VES, and finally, Section 4 concludes the paper.

2. ViPS infrastructure

According to the concept presented above, the ViPS architecture needs to provide virtualization of real objects that are important for the current domain. In this aspect, the architecture reflects and presents in the virtual world an essentially identical model of the real physical world, in which the processes, users, objects, and the interaction between them are realized dynamically in a personalized and context-aware way. During this virtualization, appropriate digital presentations are generated, which consist of two parts:

- A model of the significant inherent attributes of the physical objects;
- A model of some additional attributes for the object, usually characterizing its presence in the physical space as events, time, space, and location.

In practice, the virtualization of “things” is supported by the ViPS middleware, which includes two subspaces: the Analytical Subspace and the Digital Libraries Subspace, as well as the Event Engine and the Operative Assistants with different functionalities and responsibilities (Figure 1).

The Digital Libraries Subspace was created as a structure of open digital repositories with information specific to the respective domain. New domain-specific components are periodically archived and stored in separate libraries (DoLs) and they become a part of ViPS. In this way, ViPS is enriched with information about each new application.

The Analytical Subspace provides tools for digitizing and presenting information related to the

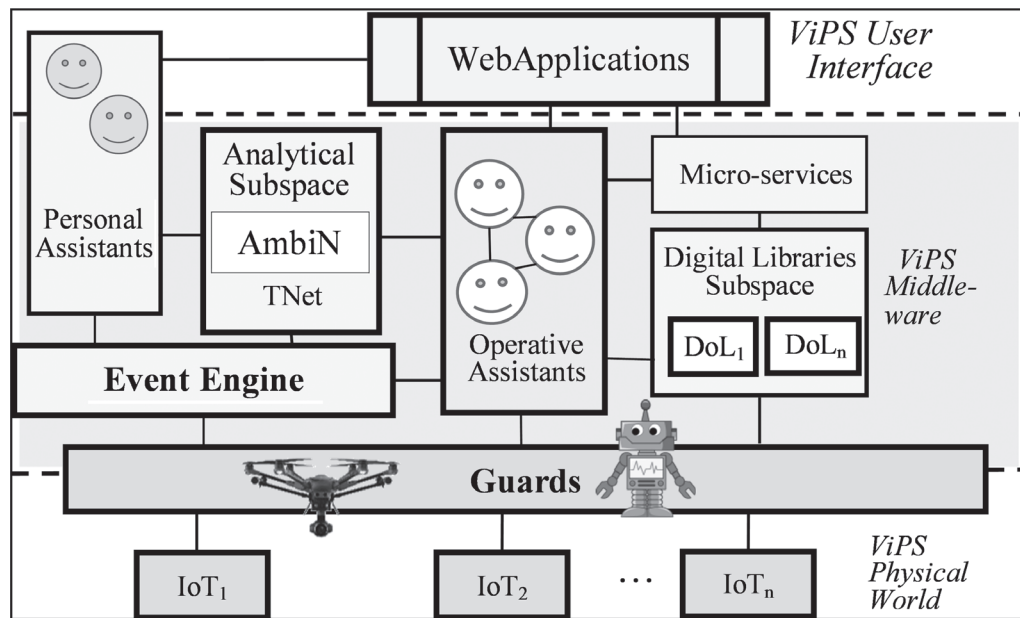


Fig. 1. The ViPS software architecture

time, space, and location of objects. In this sense, the Analytical Subspace is made up of the following basic components — TNet, AmbiNet, and the Event Engine:

- TNet provides an opportunity to present the temporal aspects of things, events, and locations.
- AmbiNet provides the ability to model the spatial characteristics of “things” and events through context-aware ambients [5].
- The Event Engine models and interprets different types of events that are relevant to the current domain.

Since ViPS is developed as a CPSS ecosystem, users are the focus of attention. This determines the need to develop personal assistants to participate in the processes of the ViPS space on behalf of and in the interest of users. Each PA prepares and manages a structure known as a personal schedule that includes completed and upcoming user activities.

Guards act as an intelligent interface between the virtual and the physical worlds. They provide data on the state of the environment in the physical world, which, after processing, transmit to the virtual environment of space. Many IoT nodes are integrated into the architecture of the Guards, which provide access to sensors and actuators of the “things” of the physical world.

Operative Assistants provide access to the resources of the two subspaces and interact with Personal Assistants and Web applications. In addition, Operative Assistants interact with the Guards to provide ViPS with the necessary data from the physical world. The public information resources of the space are open and accessible through appropriate Web Applications, which are usually applied in a certain domain.

Several ViPS adaptations are currently being developed in the domains of smart farming, smart cities, and e-learning.

3. Virtual education space: architecture and applications

The Virtual Education Space (VES) is a ViPS adaptation in the e-learning domain. The following aspects of VES are essential:

- Users are the focus of attention;
- Physical “things” are virtualized;
- There is integration between the virtual and the physical worlds.

VES is the successor to the Distributed e-Learning Center (DeLC). It provides e-learning content and e-learning education services for planning, organizing, and conducting the learning process in the Faculty of Mathematics and Informatics of Plovdiv University. VES maintains the internationally accepted standards for e-learning SCORM 2004 [6] and QTI 2.1 [7] and takes into account the current trends in the development of Internet technologies, but the integration between the virtual and the physical worlds is not satisfactory. VES upgrades DeLC version 2 while retaining all its characteristics; below, we will look at some DeLC services that have been expanded in VES.

The development of VES as a CPSS-like space enhances the ability to adapt and personalize the services offered for different applications and different groups of users, especially for disadvantaged people. The main architecture of VES is presented in Figure 2. VES supports various forms of e-learning such as blended learning, self-paced learning, lifelong learning, inclusive and game-based learning.

3.1. Blended learning, e-testing

Tests are the primary mechanism for verification and control of the learners’ knowledge. That is why the electronic testing system is the kernel of VES [8]. The system allows conducting individual electronic

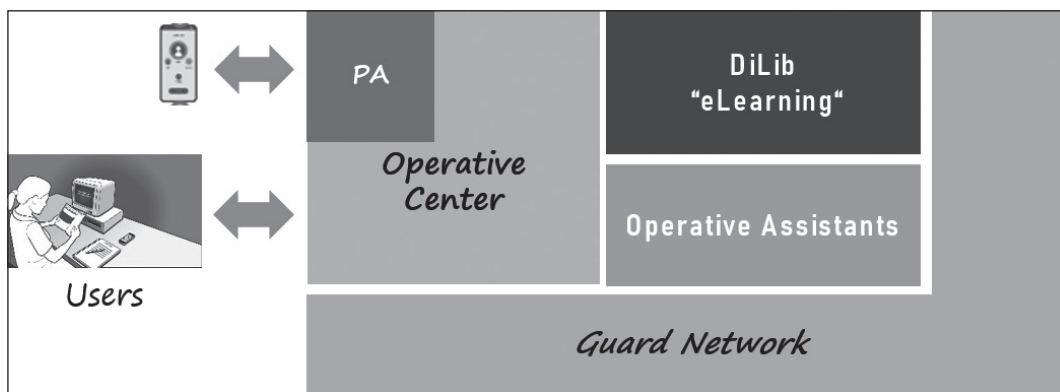


Fig. 2. The VES architecture

testing of students. Teachers prepare templates that the system uses to automatically generate individual tests in real-time during the exam. Each teacher can enrich the accessible repository of test questions in their academic discipline. The main tools supporting the testing are deployed in the DeLC 2.0 portal while the repositories (libraries) with teaching material are part of the VES Digital Library Subspace.

The VES portal provides an editor of questions, by means of which teachers can create, edit, delete, and search the questions in the database. The completed tests can be evaluated by the teachers manually or through using the system. The portal can automatically evaluate all question types other than open-ended ones. Partial evaluations of the system can be combined with assessments of open questions and a final evaluation is stored in the database. During an exam, when a test becomes valid in accordance with the rules set by the teacher, the portal generates individual tests from a test pattern that are accessible to particular users with the role of "student". After completing the test, the student receives the final result in his/her profile. In addition, the portal creates useful statistics for teachers (Figure 3).

3.2. Self-paced training

VES provides self-study training content in various formats such as .pdf, .doc, .html. However, the most

interesting format is the SCORM 2004 e-packages. The SCORM 2004 standard has been developed to assist in the creation, portable delivery, and use of reusable instructional content for application in computer-based self-study. SCORM (Sharable Content Object Reference Model) covers all the requirements of ISO/IEC 19796-1:2005. It is a part of the idea of ADL for the standardization of e-learning. SCORM is a referent model that defines the e-learning content, its naming, storage, and presentation in a distributed learning environment. The SCORM referent model is a set of interconnected technical standards, specifications, and guidelines designed to meet the high requirements on content and content management systems.

The DeLC 2.0 portal enables students to use the SCORM-textbook (Figure 4). Any student who has access to a particular academic discipline can start the learning process. Students can interrupt their work on the study material at any time since the SCORM Engine will retain its status and at a later time, the student can continue his/her training from where he/she has stopped. This enables everyone to learn at their own pace at a convenient time for them.

3.3. Lifelong learning

Lifelong learning (LLL) has been defined as all purposeful learning activity, undertaken on an ongoing basis with the aim of improving knowledge,

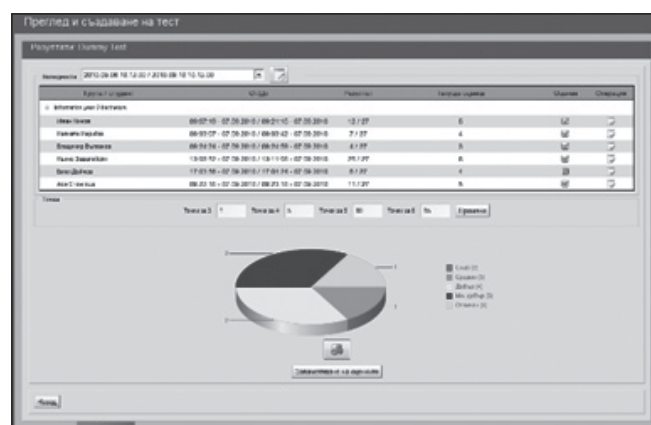
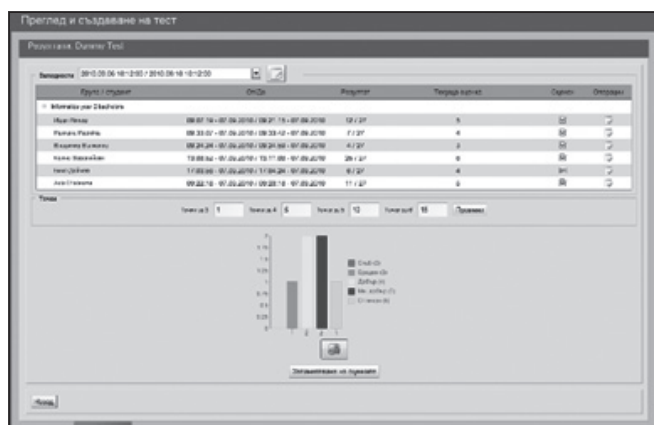


Fig. 3. Test results statistics

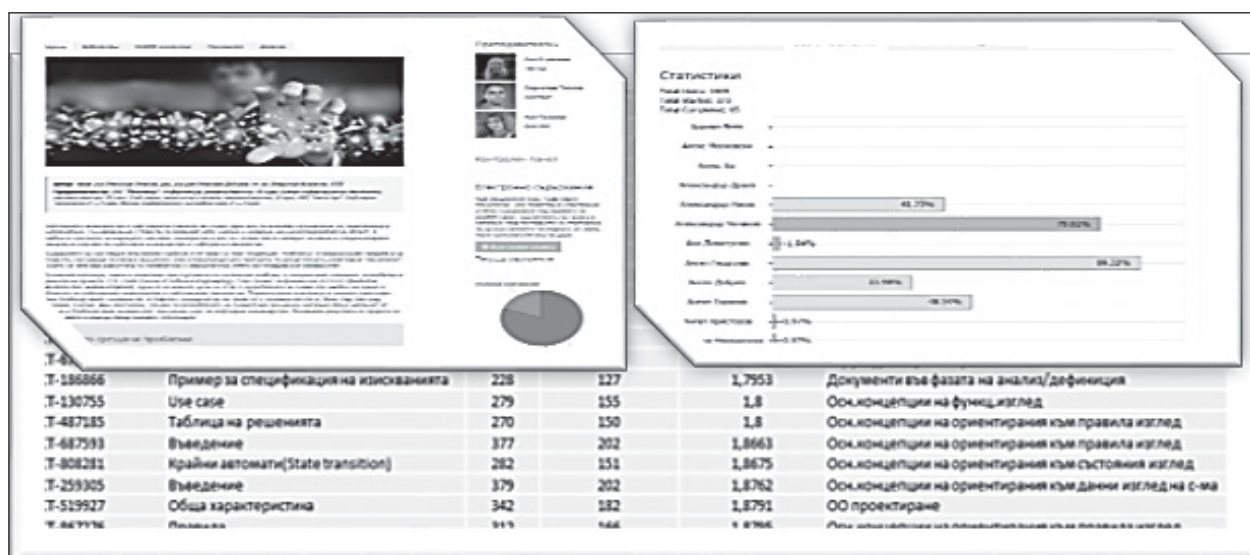


Fig. 4. SCORM-based self-paced learning

skills, and competence. According to the National and the European sustainable economy strategy [9], competences appropriate to the labor market have to be developed, which requires the acquisition of knowledge through the continuing forms of education. Lifelong learning technologies and systems are subject to intensive research and are increasingly being used to extend forms of study in universities and schools as well as in company training. The subjects of the learning content provided by such systems are expanding considerably. For example, [10] presents approaches and systems for lifelong learning. The approach suggested in VES to support lifelong learning consists of the following steps [11]:

- Presentation of topics to arouse interest in potential learners;
- Creation of a portfolio of each learner;
- Development of personalized education and training of students;
- Assessment of learners.

Three intelligent agents are modeled in VES — an internal educational agent (IEA), an external educational agent (EEA), and a career consultant (CC). The IEA will be trained to detect similarities between a user's profile and relevant courses available in the database of the space. The EEA will be trained to offer information about educational and training opportunities in addition to courses available. The career consultant will provide professional orientation to the user.

3.4. Inclusive education

Inclusive education requires a restructuring of the learning content and the learning environment so that everyone can learn and participate in the process together. It can only be successful when all learners feel that they are truly part of the educational community.

The ViPS adaptation for the secondary school has gone through several upgradeable systems. The

first one is the Distributed e-Learning Center (DeLC) education system that aims to provide e-learning resources and e-services to different user groups [12]. With the increase of the DeLC requirements and the need for a more flexible system to add even more functionality, the Virtual Education Space (VES) was created. VES integrates the DeLC functionality with the addition of a number of further services. This was made possible by the development of a system of intelligent components, on which VES was built.

Of particular importance for assisting the learning process in inclusive education are personal assistants that allow learners easy access to the space and the services that the system provides, regardless of their location in the physical world. The BLISS prototype presented here is an adaptation of ViPS for high school inclusive education [13]. BLISS is implemented as a multi-agent system, the core of which are personal assistants that interact with each other. The agent environment consists of two parts — an event-driven BLISS server and a blockchain-based school diary (Figure 5).

Teachers and learners interact in this space personally or through their personal agents that are constantly self-learning, reflecting, and serving the specific goals, interests, and desires of trainers and learners. The learning content and the learning process are dynamically adapted to the knowledge and specific characteristics of the individual students (Figure 6).

3.5. Game-based learning (GBL)

MATE (the Multi-Agent Testing Environment) is a GBL component supported in the ViPS space; it is a platform for training and testing of students in a game-based manner [14]. MATE is a set of autonomous agents, each one of which has responsibilities in the common architecture that arise from training and testing needs. In the current prototype, as shown in Figure 7, there are five active agents — two of them are client agents and three are server ones. At the

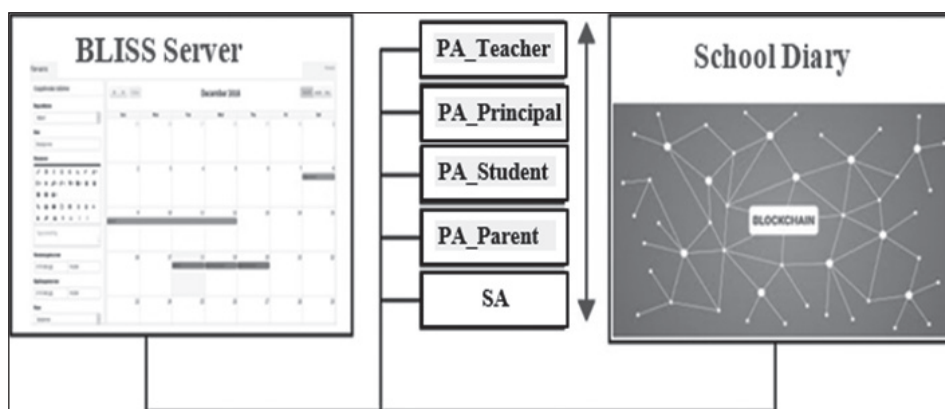


Fig. 5. The BLISS architecture

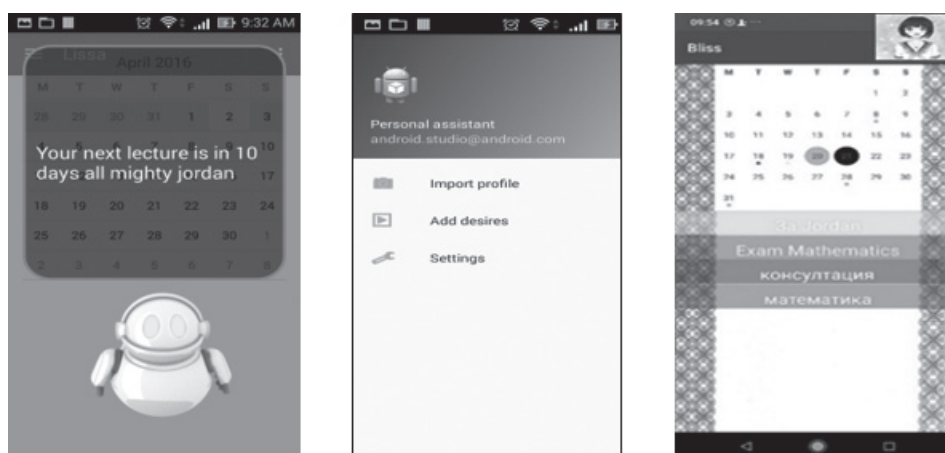


Fig. 6. Personal Assistants for different groups in the learning space – teachers, students, pupils

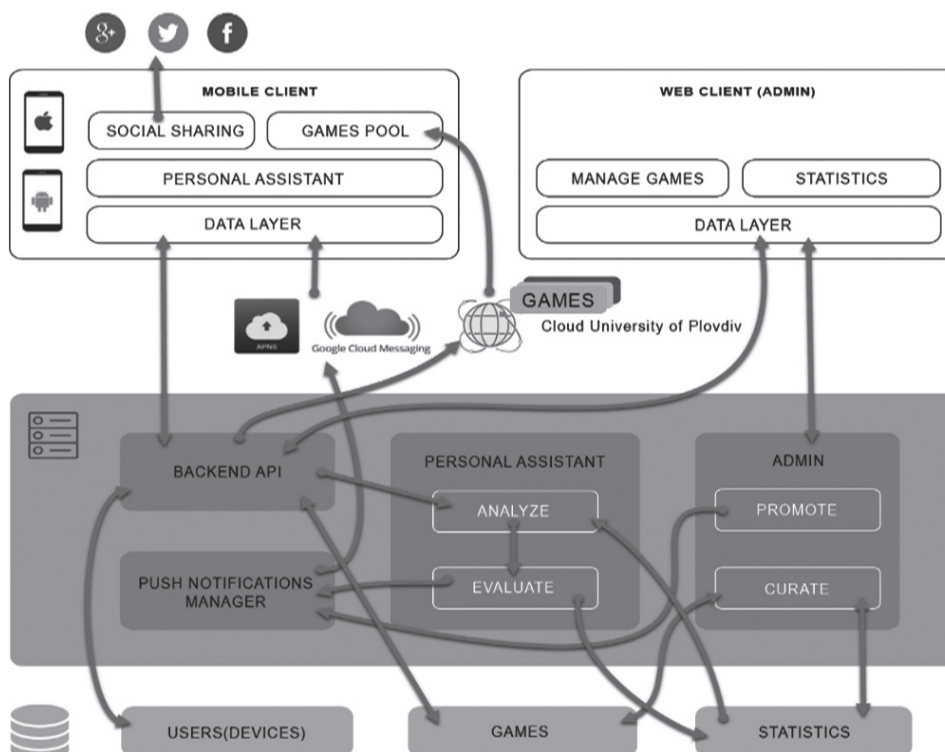


Fig. 7. The MATE architecture



Fig. 8. MATE adaptation for students with special educational needs

same time, the environment is sufficiently flexible and platform-independent, and the REST protocol of communication between the server and the client agents allows the creation of client agents on mobile phones and desktop computers in a set of programming languages.

An adaptation of MATE has been developed for the training of students with special educational needs and children from the autistic sector (Figure 8). The Student Personal Assistant (PPA) guides players to progress in educational games through voice and text messages. It builds an environment consisting of two parts: a game desk visible to the player and a game diary accessible only to the teacher.

4. Conclusions

As a CPSS space, VES introduces new approaches and scenarios to solve complex problems in the field of e-learning. By integrating different technologies for the development of VES, we expect increased commitment and interest of students to education in ways that were impossible before [15].

On the one hand, VES continues to evolve and improve as an intelligent e-learning environment, whereas, on the other hand, it is also as an experimental environment for solutions and prototype implementations related to the management of complex intelligent systems.

The applications running in VES were developed in different periods of time and their server parts are spread over different hardware configurations. Currently, a unified three-tier infrastructure is under construction, which will serve ViPS and its adaptations (including VES). The infrastructure consists of sensor networks on a low level, a cloud infrastructure on a high level, and an intermediate communication network.

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