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Evaluation of quality and personalisation of VR/AR/MR learning systems

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ABSTRACT
The paper aims to analyse the problem of quality evaluation and personalisation of virtual reality/augmented reality/mixed reality (VR/AR/MR). First of all, systematic review of relevant scientific literature on the research topic was conducted. After that, findings of the systematic review concerning evaluation of quality and personalisation of VR/AR/MR learning environments are presented. The author's VR/AR/MR learning systems/environments quality evaluation and personalisation framework is also presented in the paper. Evaluation of quality of VR/AR/MR platforms/environments should be based on (a) applying both expert-centred (top-down) and user-centred (bottom-up) quality evaluation methods and (b) separating 'internal quality' criteria, and 'quality in use' criteria in the set of quality criteria (model). Personalisation of VR/AR/MR platforms/environments should be based on learners' models/profiles using students' learning styles, intelligent technologies, and Semantic Web applications.

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Virtual reality; augmented reality; mixed reality; learning systems; evaluation of quality; personalisation

1. Introduction

The aim of the paper is twofold: first, to perform systematic literature review of virtual reality/augmented reality/mixed reality (VR/AR/MR) learning systems/platforms/environments and, second, to analyse and propose those systems' personalisation and quality evaluation framework.

Strides are being made in education, although much needs to be done. The possibilities of VR/AR/MR and education are endless and bring many advantages to pupils of all ages. Few are creating content that may be used for educational purposes, with most advances being made in the entertainment industry, but many understand and realise the future and the importance of education and VR/AR/MR.

The rest of the paper is organised as follows: systematic literature review on VR/AR/MR learning systems/platforms/environments is presented in Section 2, Section 3 presents findings of the systematic review, Section 4 presents the framework for evaluation of Quality of VR/AR/MR learning systems, Section 5 presents the framework for personalisation of VR/AR/MR learning systems using intelligent technologies and Semantic Web applications. Section 6 concludes the paper.

2. Systematic literature review

In order to identify scientific methods and possible results on evaluation of quality and personalisation of VR/AR/MR learning systems/platforms/environments, the systematic literature review method devised by Kitchenham (2004) has been used. The following research questions have been raised to perform systematic literature review:

- What are pros and contras of implementing VR/AR/MR in learning?
- What are the existing methods of evaluating the quality of VR/AR/MR learning systems/environments?
- What are the ways to personalise those systems according to learners' needs?

Systematic literature review was performed on 17 February 2016 in Thomson Reuters Web of Science database. The search history is as follows:

2.1. Search history

We see that during the last years (2014–2016), 236 papers were found according the topic (VR AND learning systems), including 136 articles (Figure 1).

After applying Kitchenham's (2004) systematic review methodology, in the last stage 33 suitable articles were identified to further detailed analysis. The analysis results are as follows:

According to Li et al. (2016), the navigation system developed in their study has a novel display mode capable of fusing endoscopic images to three-

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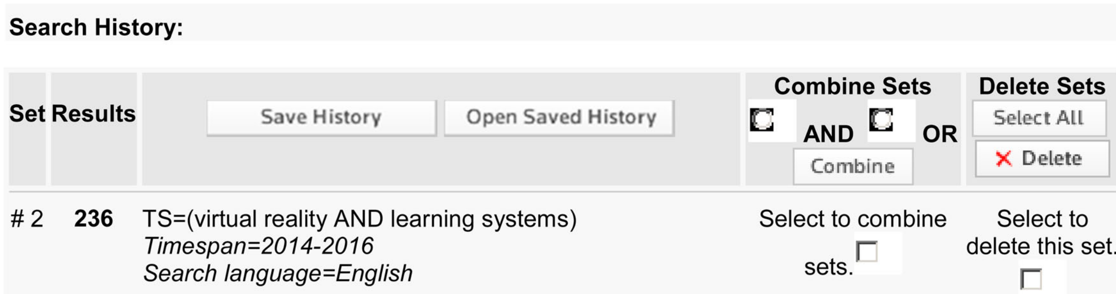

Figure 1. Search history in Thomson Reuters Web of Science.

dimensional virtual images. Compared with conventional navigation systems, the new system was more effective in terms of operation time and the mental workload of surgeons. However, the authors noted that the navigation system serves as an adjunct to a surgeon's skills and knowledge, not as a substitute.

Educational magic toys were developed with AR technology in the Yilmaz (2016) study. The author considers that this study revealed that teachers and children liked educational magic toys activity. In addition, children interactively played with these toys but did not have high cognitive attainment.

Petersen and Stricker (2015) revealed that although the concept of AR has already been proposed more than 20 years ago, most AR-applications are still limited to simple visualisation of virtual objects on spatially limited scenes. The authors highlighted that the developed systems did not pass the barrier of demonstration prototypes. One major reason, besides remaining ergonomic and hardware limitations, consists of the large effort required for creating the content of such virtual instructions and for building models allowing accurate tracking. In this paper, the authors presented a complete approach for creating AR content for procedural tasks from video examples, and then gave details about the presentation of such content at runtime. They showed that this new approach, in spite of its very challenging aspects, is scalable, and valuable from a practicable point of view.

Gavish et al.'s (2015) research results demonstrate that, in general, the VR and AR training groups required longer training time compared to the Control-VR and Control-AR groups, respectively. The results suggest that use of the AR platform for training industrial maintenance and assembly tasks should be encouraged and use of the VR platform for that purpose should be further evaluated.

In Tarng et al.'s (2015) study, the AR and mobile learning technologies have been used to develop a virtual butterfly ecological system by combining with campus host plants and virtual breeding activities. The authors argue that the virtual butterfly ecological system can increase the learning motivation and interest of students through virtual breeding and observation activities, so it is a suitable assistant tool for science education. A teaching experiment has been conducted by the authors to investigate students' learning effectiveness and attitudes after using the system, and the results show that using the virtual butterfly ecological system can improve their learning effectively.

The purpose of Cubillo et al.'s (2015) study was to investigate how an AR learning environment system (UNED ARLE) can be used by both teachers and students to add virtual content to educational resources and how can it serve as a tool for acquiring knowledge, motivating and encouraging students. In the study, UNED ARLE was used to add contextualised virtual content (3D objects, animated 3D objects, videos, sound files, and images) and the accompanying descriptions or narratives into printed material, thereby enriching existing content without any programming skills. The authors analyse UNED ARLE by examining the interaction between teachers and the system and by comparing the results of two groups of students. The study concludes that the students who used UNED ARLE show significantly better learning achievements compared to the traditional system.

Chen et al.'s (2015) research utilised VR to simulate the real situation of vehicles to evaluate product development and test. The questionnaire survey method was utilised as the method of evaluation. Also, after the operator utilised VR to simulate operation, the user-related information was collected as an important basis for improvement.

Sun et al. (2015) argue that technological advance in human-computer interaction has attracted increasing research attention, especially in the field of VR. Prior research has focused on examining the effects of VR on various outcomes, for example, learning and health. However, which factors affect the final outcomes? That is, what kind of VR system design will achieve higher usability? This question remains largely. Furthermore, when we look at VR system deployment from a human-computer interaction lens, does a user's attitude play a role in achieving the final outcome? Sun et al.'s (2015) survey data from 78 students in Taiwan indicated that promotion focus is positively related to a user's perceived efficiency, whereas involvement and promotion focus are positively related to a user's perceived effectiveness. The authors consider that promotion focus also predicts user satisfaction and overall usability perception.

Le, Pedro, and Park's (2015) study proposes an online social VR system framework which allows students to perform role-playing, dialogic learning, and social interaction for construction safety and health education. The system prototype was developed and evaluated with virtual scenarios derived from real safety cases to identify the system's benefits and limitations. The results concluded that the social/collaborative VR platform would improve construction safety and health education effectively.

Educational content visualisation in real environments was found to help students to evaluate and share their own-generated architectural proposals and improve their spatial skills. Riera, Redondo, and Fonseca's (2015) suggested method aims to improve access to 3D multimedia content on mobile devices and adapt it to all types of users and content.

According to Ragan et al. (2015), VR training systems are commonly used in a variety of domains, and it is important to understand how the realism of a training simulation influences training effectiveness. This study's results show that both field of view and visual complexity significantly affected target detection during training; higher field of view led to better performance and higher visual complexity worsened performance.

Freschi et al.'s (2015) evaluation study of the diagnostic module was performed by recruiting 36 novices and four experts. The performances of the hybrid versus physical simulator were compared. After the training session, each novice was required to visualise a particular target structure. The four experts completed a 5-point Likert scale questionnaire. The authors claim that the mean scores from the questionnaires were 5.00 for usefulness, 4.25 for ease of use, 4.75 for 3D perception, and 3.25 for phantom realism. According to the authors, the hybrid ultrasound training simulator provides ease of use and is effective as a hand-eye coordination teaching tool. MR can improve Ultrasound probe manipulation training.

In Hung and Young's (2015) research, both quantitative and qualitative data were collected from surveys, interviews, and observations. The results revealed that game-embedded handheld devices could increase the interdependence of the group and lead the learners into better immersion and interactions.

Chiu, DeJaegher, and Chao (2015) claim that the next generation science standards emphasise authentic scientific practices such as developing models and constructing explanations of phenomena. This study offers insights into how augmented virtual labs can be designed to enhance science learning and encourage scientific practices.

According to Wang and Lindeman (2015), despite the benefits of presence immersive VR is still too limiting and ineffective to be widely adopted in people's everyday lives. One important reason for this is its inability to handle highly diverse 3D interaction tasks, such as object manipulation from different scales, perspectives, reference frames, and dimensions.

In Shih, Jheng, and Tseng's (2015) research, questionnaire surveys were conducted to investigate the effects of the digital game. The results showed that the game can effectively enhance learners' cognitive growth, as well as cultural awareness in terms of the sense of existence of the environment, local culture, folk arts, faith and festivals, and architectural characteristics. The authors argue that it can be concluded that the three-dimensional simulated learning environment created in the digital game can successfully merge 'reality' and 'virtuality'.

According to Wei et al. (2015), student creativity is currently attracting considerable attention. An increasing number of high schools (in China) are trying to improve the learning motivation and creativity of students, as well as the teaching efficiency of creative design, by introducing AR technology into creative design courses. However, many teachers have only limited knowledge of AR, and software developers are not familiar with general creative design education, which makes it difficult to incorporate AR in such courses. The authors consider that the lack of relevant teaching facilities and creative design equipment means that the environment in which the technology curriculum is applied still has a long way to go to meet the real requirement of curriculum. Two teaching aids were introduced in Wei et al. (2015) to support this teaching scheme: 'AR Creative-Classroom', which explains the domain relevant knowledge of creative design, and 'AR Creative-Builder', which helps students to build actual AR scenes. The results of a pilot study show that the proposed teaching scheme significantly improves learning motivation, student creativity, and the teaching of creative design.

In Bertram, Moskaliuk, and Cress's (2015) study, the authors applied a virtual training environment to train police personnel for complex collaborative tasks. The virtual training group was compared to a group with standard training and to a control group. The data show that the standard training resulted in more motivation, perceived value of the training. and knowledge after the training session than virtual training. But with regard to the learning transfer measured by the behaviour in a real and complex situation, the virtual training was as good as the standard training.

In Le et al.'s (2015) research, mobile-based VR and AR for the experiential Construction safety education system prototype was developed and evaluated with case studies to identify the system's benefits and limitations. The results concluded that using mobile-based VR + AR would improve construction safety and health effectively.

According to Munoz-Cristobal et al. (2015), during the last decades, educational contexts have transformed into complex technological and social ecologies, with mobile devices expanding the scope of education beyond the traditional classroom, creating so-called Ubiquitous Learning Environments. The evaluation, following an interpretive research perspective, relied on a study where a pre-service teacher designed and enacted an authentic across-spaces learning situation in a primary school. The authors argue that the evaluation showed that the system created helped the teacher in the multiple aspects of orchestration, including implementation of his pedagogical ideas, adaptation in runtime, and sharing of orchestration load with students.

Velaz et al.'s (2015) paper focuses on the use of VR systems for teaching industrial assembly tasks and studies the influence of the interaction technology on the learning process. The experiment presented in the paper studies the efficiency and effectiveness of each interaction technology for learning the task, taking into consideration both quantitative measures (such as training time, real task performance, evolution from the virtual task to the real one) and qualitative data (user feedback from a questionnaire).

Aguirre et al. (2014) argue that the combination of VR interactive systems and educational technologies has been used in the training of procedural tasks, but there is a lack of research with regard to providing specific assistance for acquiring motor skills. In order to validate their work the authors generated a model for the diagnosis of tennis-related motor skills and conducted an experiment in which they interpreted and diagnosed tennis serves of several subjects and which shows promising results.

In Chiang, Yang, and Hwang's (2014) study, an AR-based mobile learning system was proposed for conducting inquiry-based learning activities. An experiment has been conducted to examine the effectiveness of the proposed approach in terms of learning achievements and motivations. The experimental results showed that the proposed approach is able to improve the students' learning achievements. Moreover, it was found that the students who learned with the AR-based mobile learning approach showed significantly higher motivations in the attention, confidence, and relevance dimensions than those who learned with the conventional inquiry-based mobile learning approach.

Dey and Sandor (2014) think that handheld devices like smartphones and tablets have emerged as one of the most promising platforms for AR. The authors argue that increased usage of these portable handheld devices has enabled handheld AR applications to reach the end-users; hence, it is timely and important to seriously consider the user experience of such applications.

Schomaker, van Bronkhorst, and Meeter (2014) investigated whether active spatial exploration of a novel compared to a previously familiarised virtual environment promotes performance on an unrelated word learning task. The authors show that ratings were higher for the novel compared to the familiar virtual environment, suggesting that novelty increased attention for the virtual rather than real environment; however, this did not explain the effect of novelty on recall.

According to Loup-Escande et al. (2014), the participation of users in the design process is recognised as a positive and a necessary element as artefacts suit their needs. The authors argue that two complementary approaches of users' involvement co-exist: the user-centred design and the participatory design. This study's results detail how the elicited needs are dealt with by designers, users, and/or project leaders: (1) the authors show a strong contribution of users in the design, compared to others stakeholders, (2) among the needs elicited by users, most have been validated by the designers, (3) some elicited needs could have been firstly rejected and finally validated and implemented.

In Chen et al.'s (2014) study, the authors propose a self-observation model that employs an instinctive interface for classroom active learning. Students can communicate with virtual avatars in the vertical screen and can react naturally according to the situation and tasks. The results show that the students' image in the vertical screen affected the students and the peer audience positively. Moreover, they positively perceived their competence and their enjoyment after they performed contextual learning activities through the body movement interface.

According to Yang and Chiu (2014), AR technology is capable of displaying virtual contents in real-life images. The authors proposed an AR-based note-taking system tailored for 3D curricular contents. The authors argue that note-taking using finger writing and hand gestures with 3D manoeuvre is better than other alternatives in terms of relevance, usefulness, intuition, and novelty.

Wang, Lin, and Liao's (2014) study's results provide important references for educators that a 3D situational learning environment is beneficial in improving students' ill-structured problem-solving ability.

According to Perez-Sanagustin et al. (2014), the right combination of AR and mobile technologies with computer-based educational tools such as Learning Management Systems drives this digital connection, leading to articulated blended learning activities across formal, non-formal, and informal settings.

Jia, Bhatti, and Nahavandi's (2014) study developed and tested a research model which examined the impact of user perceptions of self-efficacy and virtual environment efficacy on the effectiveness of virtual environment training systems. According to the authors, the model posits that user perceptions will have positive effects on task performance and memory.

A meta-analysis, conducted by Radu (2014), in addition to the benefits presented above, exposes such benefits of AR in education: the learning content is represented in novel ways; in multiple representations over space and time, the user is physically enacting the educational concepts (including the abstract ones) and 'record' tactile information, attention is directed to relevant content. This work has also pointed out some negative effects of AR application in education, including a student's attention tunnelling, usability difficulties, ineffective classroom integration, and learner differences.

Bacca et al. (2014) performed a systematic literature review on AR trends in education for the period of 2003-2013, and their findings of the analysis of 32 selected studies report that Science was the most frequent subject where AR was applied (40.6% of analysed studies). Most studies addressed Bachelor or equivalent target groups of students (34.38%). In the purpose of AR application dominated the explanation of a topic (43.75% of studies), augmentation of information (40.63%), and educational games (18.75%). Two types of AR dominated in the analysed studies: marker-based AR (59.38%) and location-based AR (21.88%). Regarding personalisation, the authors state that only 2 out of 32 studies report some kind of personalised process and 1 out of 32 considered a user modelling process. However, further analysis of these resources has shown that it was not clear whether they had a user model and whether the user model came from the user profile.

3. Findings of the systematic review

Systematic review reveals that the possibilities of VR/AR/MR and education are endless and bring many advantages to pupils of all ages. Few studies are creating content that may be used for educational purposes, with most advances being made in the entertainment industry, but many understand and realise the future and importance of education applying VR/AR/MR. Many studies report that their analysed VR/AR/MR-based systems were more effective in comparison with traditional ones, especially for situated, inquiry-based, and self-regulated learning. Teachers and students like learning activities based on VR/AR/MR systems – almost all studies mention improved students' motivation and satisfaction.

On the other hand, although the concept of VR/AR/MR has already been proposed more than 20 years ago, most applications are still limited to simple visualisation of virtual objects onto spatially limited scenes, and the developed systems did not pass the barrier of demonstration prototypes. The existing systems have little intelligence in terms of awareness about the current state of the scene and the user's context.

Out of all studies analysed in this paper, only one meta-analysis study (Bacca et al. 2014) directly addresses personalisation question of AR-based systems in education. This study has revealed that there were only two studies found, published in 2009 and 2013, addressing some aspects of VR/AR/MR system personalisation.

As reported in another meta-analysis work on the topic (Radu 2014), some studies on learner differences have shown that low and average achiever students showed learning gains through the AR experience, while high achieving students did not receive the same benefits. In fact, the high achieving students showed more learning gains in a traditional classroom where AR was not used. This is the possible area for further research on AR/VR learning systems and their personalisation.

In the majority of studies, VR/AR/MR learning systems were evaluated using experiments with small or medium research samples (e.g. one class of students).

No studies have proposed technologically and pedagogically sound frameworks to personalise VR/AR/MR learning systems or VR-/AR-/MR-based learning packages/scenarios.

Systematic review reveals that the majority of authors evaluated VR/AR/MR learning systems using case studies suitable for their created prototypes. Thus, the quality of already developed VR/AR/MR learning platforms was evaluated by the users only, and no studies have proposed technologically and pedagogically sound frameworks and methods to evaluate the quality and personalisation level of VR/AR/MR learning systems models/prototypes to be developed.

Many authors agree that use of the VR/AR/MR platforms for learning should be further evaluated.

4. Framework for evaluation of quality of VR/AR/MR learning systems

In this context, we should examine both the quality of (a) VR/AR/MR learning platform/environment developed and (b) its model/prototype to be developed.

According to Kurilovas, Serikoviene, and Vuorikari (2014), evaluation of quality means 'the systematic examination of the extent to which and entity (e.g. product or service) is capable of meeting specified requirements'. In our case, quality means VR/AR/MR learning platform/environment effectiveness and suitability to learners' personal needs.

In order to fully evaluate the quality of the learning platform/environment, both expert-centred (so-called top-down) and learner-centred (bottom-up) approaches should be applied (Kurilovas, Serikoviene, and Vuorikari 2014).

In the bottom-up approach, end-users should comment on the quality of the learning platform/environment according to each quality criterion, and, for example, use star-rating of the platform on each criterion in their reports. Application of the bottom-up approach means evaluation of the learning platform/environment by the end-users during, for example, case studies.

In the top-down approach, evaluation is performed by the external experts using multiple criteria decision analysis methods.

In both approaches, the first step should be development of the quality model (i.e. the set of the quality criteria) of the learning platform/environment against which evaluation should be performed.

A similar quality model should be used while evaluating VR/AR/MR learning systems. Since VR/AR/MR platforms/environments have additional features to be evaluated in comparison with, for example, Virtual Learning Environments (VLE) or full learning packages/scenarios, the VR/AR/MR quality model should be extended. Since VR is a computer technology that replicates an environment (real or imagined) and simulates a user's physical presence and environment to allow for user interaction, and VRs artificially create sensory experience, which can include sight, touch, hearing, and smell, corresponding additional quality criteria should be included in the model. These quality criteria should be interconnected with the type of VR/AR/MR under evaluation, for example, the level of visualisation, simulation quality of touch, hearing, smell, etc. This requirement implies involving the expert evaluators in particular type of VR/AR/MR systems according to the top-down evaluation approach, and organisation of appropriate case studies for end-users according to the bottom-up approach.

After evaluation performed according to both approaches, the results should be compared, and whether they should be similar, one could consider that the evaluation results are exact and valid.

On the other hand, according to Kurilovas, Vinogradova, and Kubilinskiene (2016), from a technological point of view, one could divide the learning platform/environment quality criteria into 'internal quality' criteria and 'quality-in-use' criteria. 'Internal quality' is a descriptive characteristic that defines the quality of software independently from any particular context of its use (e.g. interoperability, modular authentication, robustness, and stability) while the 'quality-in-use' is an evaluative characteristic of software obtained by making a judgement based on the criteria that determine the worthiness of software for particular users.

In Kurilovas and Dagiene's (2010) research, the authors have proposed an original set of VLE technological quality evaluation criteria combining general 'internal quality' and adaptation 'quality in use' evaluation criteria. This model has included 4 Adaptation criteria: Adaptability, Personalisation aspects, Extensibility, and Adaptivity. These quality criteria should be also applied to evaluating the quality of VR/AR/MR systems.

While implementing the top-down approach, sufficient number of external experts in the area (e.g. 9) should be invited to perform the evaluation of the platform. The experts should create the quality model, establish the weights of the quality criteria, and apply some evaluation method suitable in this case, for example, Fuzzy (Kurilovas, Serikoviene, and Vuorikari 2014) or AHP (Kurilovas and Zilinskiene 2013). The learning platform/environment could be considered 'suitable' if the final numerical value of the experts' utility function should be converted to linguistic variable 'excellent' or, for example, something between 'excellent' and 'good' (Kurilovas and Zilinskiene 2013; Kurilovas, Serikoviene, and Vuorikari 2014; Kurilovas, Vinogradova, and Kubilinskiene 2016). A similar approach is applicable for evaluating the quality of VR/AR/MR systems/environments taking into account the aforementioned additional requirements.

The learning system/platform/environment should include personalisation capabilities, for example, should be flexible enough to be easily adaptable to different learners' needs. Therefore, personalisation criterion/criteria should be implemented while performing evaluation of the VR/AR/MR learning platform/environment or learning scenario implemented in this kind of system (Kurilovas and Zilinskiene 2013).

In this way, the experts could evaluate not only the quality of learning platform/environment, but also the quality of personalised learning scenarios to be implemented using the platform.

5. Framework for personalisation of VR/AR/MR learning systems using intelligent technologies and Semantic Web applications

Research on learning personalisation and application of intelligent Semantic Web technologies has been very popular in scientific literature during the last years (Bobed et al. 2014; Ermilov, Khalili, and Auer 2014; Troussas, Virvou, and Alepis 2014; Wallden and Makinen 2014; Ignatova, Dagienė, and Kubilinskienė 2015; Spodniakova Pfefferova 2015).

According to Kurilovas, Kubilinskiene, and Dagiene (2014), learning software and all learning process should be personalised according to the main characteristics/needs of the learners. Learners have different needs and characteristics, that is, prior knowledge, intellectual level, interests, goals, cognitive traits (working memory capacity, inductive reasoning ability, and associative learning skills), learning behavioural type (according to his/her self-regulation level), and, finally, learning styles.

According to Kurilovas (2015), future education means personalisation plus intelligence. Learning personalisation means creating and implementing personalised learning packages/scenarios based on the recommender system suitable for particular learners according to their personal needs. Educational intelligence means application of intelligent (e.g. Semantic Web) technologies and methods enabling personalised learning to improve learning quality and efficiency (Kurilovas 2015).

In personalised learning, first of all, integrated learner profile (model) should be implemented. The author's approach to creating students' profiles is as follows:

- Selecting pedagogically and psychologically sound taxonomies (models) of learning styles.
- Creating an integrated learning style model which integrates characteristics from several models. Dedicated psychological questionnaires are applied here.
- Creating an open learning style model.
- Using an implicit (dynamic) learning style modelling method.
- Integrating the rest features in the student profile (cognitive traits, knowledge, interests, goals).

After that, interlinking of learning components (learning objects, activities, environments, tools, apps, etc.) with learners' profiles should be performed, and an ontologies-based personalised recommender system should be created to suggest learning components suitable to particular learners according to their profiles (Kurilovas, Kubilinskiene, and Dagiene 2014; Kurilovas 2015).

According to Kurilovas (2015), after the interlinking and ontologies creation stage, a recommender system should be created to link students' personal data in their profiles, relevant learning objects according to corresponding metadata fields, and learning activities and tools suitable to particular students according to their learning styles and other profiles' data.

Interlinking and ontologies creation should be based on the expert evaluation results. Experienced experts should evaluate learning components in terms of their suitability to particular learners according to their learning styles and other preferences/needs.

A recommender system should form the preference lists of the learning components according to the expert evaluation results. Probabilistic suitability indexes should be identified for all learning components in terms of their suitability level to particular learners. Probabilistic suitability indexes could be easily calculated for all learning components and all students if one should multiply learning components' suitability ratings (obtained while the expert is evaluating the suitability of the learning components to particular learning styles like in Jasute et al. (2016)) by probabilities of particular students' learning styles (like in Dorça et al. 2012). These suitability indexes should be included in the recommender system, and all learning components should be linked to particular students according to those suitability indexes. The higher the suitability indexes, the better the learning components fit the needs of particular learners.

Thus, personalised learning packages/scenarios (i.e. personalised methodological sequences of learning components) could be created for particular learners. An optimal learning package/scenario (i.e. learning package of the highest quality) for particular student means a methodological sequence of learning components having the highest suitability indexes.

A number of intelligent technologies should be applied to implement this approach, for example, ontologies, recommender systems, intelligent agents, decision support systems to evaluate quality and suitability of the learning components, personal learning environments, etc. (Kurilovas 2015).

This framework is suitable to be applied in blended learning (i.e. the convergence of online and face-to face learning). According to Watson (2008), this blended approach combines the best elements of online and face-to-face learning. It is likely to emerge as the predominant model of the future and to become far more common than either one alone.

The main advantages of this framework are analysis of interlinks between students' learning needs, for example, learning styles and suitable learning components based on using pedagogically sound vocabularies of learning components, experts' collective intelligence to evaluate suitability of learning components to particular learners' needs, and application of intelligent technologies.

This pedagogically sound VR/AR/MR-based learning packages/scenarios personalisation framework is aimed at improving learning quality and effectiveness. Learning package/scenario of the highest quality for particular student means a methodological sequence of learning components with the highest suitability indexes. The level of students' competences, that is, knowledge/understanding, skills and attitudes/values directly depends on the level of application of high-quality learning packages/scenarios in real pedagogical practice.

6. Conclusion

The problem of quality evaluation and personalisation of VR/AR/MR systems/environments is analysed in the paper. The study performed is twofold. First of all, systematic review of relevant scientific literature on the research topic was conducted. After that, findings of the systematic review concerning evaluation of quality and personalisation of VR/AR/MR learning environments are presented, and the author's VR/AR/MR learning systems/environments' quality evaluation and personalisation framework is presented in the paper.

Evaluation of quality of VR/AR/MR platforms/environments should be based on (a) applying both expert-centred (top-down) and user-centred (bottom-up) quality evaluation methods, and (b) separating 'internal quality' criteria, and 'quality in use' criteria in the set of quality criteria (model).

Personalisation of VR/AR/MR platforms/environments should be based on learners' models/profiles using students' learning styles, intelligent technologies, and Semantic Web applications. The VR/AR/MR learning system/environment should include personalisation capabilities, for example, should be flexible enough to be easily adaptable to different learners' needs. Flexible learning systems should match system Adaptation criteria, that is, Adaptability, Personalisation aspects, Extensibility, and Adaptivity.

Disclosure statement

No potential conflict of interest was reported by the author.

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