sciendo Acta Marisiensis - Seria Medica 2021;67(1):47-54 DOI: 10.2478/amma-2021-0003

RESEARCH ARTICLE

Educational design research, an innovative method to investigate virtual reality applications in disaster management training programs

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Educational design research is a form of experiment that combines the stages of development, design and testing of a researched paradigm in a way that all theese processes are conducted in real learning environment. The investigated educational dilemmas are continuously modified and readjusted throughout the research process, so that researchers can test and generate theories simultaneously within naturalistic educational contexts. Design-based research is defined as an adaptive, collaborative, contextual and flexible process, easily adapting to any research objective through the adjacent methodological complex. It differrs from other research methods by addressing practical and theoretical objectives with the same importance, the final contribution being, in general, a validated practical application and a set of new theoretical knowledge. The aim of this paper is to present the exceptional advantages of this research method and to provide a source of ideas for researchers interested in developing scientific works based on this methodology. Demonstratively, we include an example of a research protocol adapted to this methodological concept, which aimed to investigate the potential use and integration of virtual reality technology in disaster management related training programs. This protocol constituted the basis of a complex inquiry process led by our research team and which we consider to be a perfect model for demonstrating the adaptability of the method to instructional research objectives.

Keywords: design based research, educational design research, virtual reality, disaster management, simulation exercises

Received 15 December 2020 / Accepted 6 January 2021

Introduction

'Traditional' research methods, such as experiments, surveys, correlational analysis, descriptive studies, provide inadequately useful recommendations for design and developmental issues in education [1]. Often, research in education is based on theoretical investigations and applications under special conditions of supervision, which get drifted away from daily practice. This discrepancy has created the need to develop new research approaches in education, whereby the progress of theories is directly influenced by the confrontation with practical problems [2].

Educational design research is an innovative method of scientific research, developed to fill in these gaps in educational research. It is a form of a systematic study of the design, development, and evaluation of educational interventions, such as programs, strategies, and teaching-learning materials or innovative educational products and systems. This form of scientific inquiry is identified by its innovative, evidence-based, pragmatic character, connected to the basic sciences, and devotion to continuous improvement. It produces solutions to educational problems and also aims to advance our theoretical knowledge about the characteristics of these interventions in development and implementation [3,4].

The need to develop a scientific method that produces "usable knowledge" and addresses pragmatic solutions or at least understands real practical problems has long been expressed and has its origins in the research of social sciences and psychology [5]. Moreover, the need for a linking science, using empirical perspectives and theoretical advances to turn into initiatives to solve and improve problems in practice, was pronounced a century ago by Münsterberg (1899) and Dewey (1900), renowned professors in human psychology [6,7]. This vision was gradually taken over and developed in the education and social sciences, the next relevant step of maturation being the work of Robert Glaser (1976), about the basic elements of training in psychology, in which he concretely suggested this form of science as regards educational design research [8].

In 1992, two reference papers were published, which are often credited with launching educational design research as a specific genre of scientific investigation. The first paper discusses the tensions between educational innovations in-

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vestigated in laboratory conditions and challenges that occur when trying to integrate these innovations into a real educational environment [9]. The second paper argues why education should be regarded as a design science, unlike basic analytical sciences, pointing out that laboratory conditions could rarely be identical to real classroom settings [10].

As a result, several scientific debates have emerged, arguing the need to understand learning in its natural environment [11]. The importance of correlating educational theories with design processes and vice versa was emphasized [12] and, last but not least, the relevance of investigating practical interventions in a real educational environment and researching their implementation process in a dynamic and complex learning system [13,14].

The technological invasion of educational domain happened over the last decades has further accelerated the development and spread of the design research method in the educational research community. Numerous doctoral dissertations, research reports, and scientific papers in renowned journals of educational research have contributed to the capitalization of the methodology.

Currently, the educational research community have at their disposal a series of books published on this topic, focusing on conceptualization [15], methodological considerations [16], or practical applications based on research studies as regards this particular method [17]. Related volumes have been published in the areas of literacy [18] and instructional design [19].

Initially, educational design research was used predominantly in educational research for exact sciences such as technology, engineering, and mathematics. Subsequently to promotion through valuable educational results, the area of use of these experiments was extended to various educational fields, such as learning sciences, instructional design, curricular development, or educators' professional development.

The reference terminology used in the international literature is varied and deserves to be clarified, being an important aspect in defining a correct and suggestive term for the spread of the method in the educational research community in Romania. In the literature, we can find this method under several names, such as "design-based research" [20], "design experiments" [9], "development research" [1], "formative experiments" [18], 'formative research' [21] or merely 'design research' [16]. There are subtle differences in the way these terms are used by various researchers and which are reflected in variations in objectives and related methodological structuring. The term "educational design research" was introduced [15, 17, 22] in order to avoid confusion with design research used in many other specialities outside the educational field.

Another significant aspect to be elucidated is considered to be the difference between educational design-based research and educational design. Although both can be scientific disciplines and with a similar methodology, the educational design uses theoretical or empirical evidence to create educational interventions. Instead, educational design research investigates the process of development and implementation of educational interventions, producing useful theoretical knowledge while creating a validated practical application [17]. Some researchers also add as a third objective the contribution of the research process to the professional development of the participants [15].

As mentioned above, educational design research has emerged with the goal of fulfilling a form of connection between basic and applied scientific research. It is a way to reach new scientific theories by using data from applied practical testing through empirical and regulative research cycles. The scientific weight of thus obtained results is augmented due to bidirectional correlation between theory and practice.

In the same way that engineering design binds creative ideas with pragmatic understanding and follows the best available theoretical principles, educational design research is a complex effort that combines a wide range of research approaches. It cannot be identified with a rigorous research methodology, it is rather considered as a set of scientific research methods used flexibly and in various combinations depending on the proposed objectives. The differences in the educational problems addressed and the contexts in which the solutions are to be implemented require a whole repertoire of approaches, not just one. Thus, educational design research is easily modelled according to the areas of expertise, methodological preferences, specific experiences or traditions of the domains and researchers.

There are many purposes in which a postulate formulated through educational research can be used: descriptive, predictive, interpretive or developmental and action. In descriptive and interpretive goals, the authors offer descriptions and expounds of aspects of education. Studies with predictive aims concentrate on validating hypotheses linked to theories of teaching, learning, performance, assessment, social interaction, or instructional design. Researchers with development and action objectives carry out their studies by designing, developing, and testing interventions related to teaching, learning, and human performance issues as they seek mostly to improve professional practice in this field. Incorporating the search for theoretical understanding into the design and development of educational interventions differentiates design-based educational research from others [17]. It is a form of research oriented towards utility and focused on practical processes, carried out in an interactive, interventionist and transformative way, faithfully respecting the essential characters of fundamental research.

The development of an educational design research protocol can take two directions: a scientific inquiry carried out through interventions or on interventions. For the first orientation, the developed intervention serves more as a research context, a means for studying specific educational phenomena. Instead, design research conducted directly on interventions focuses explicitly on the characteristics of

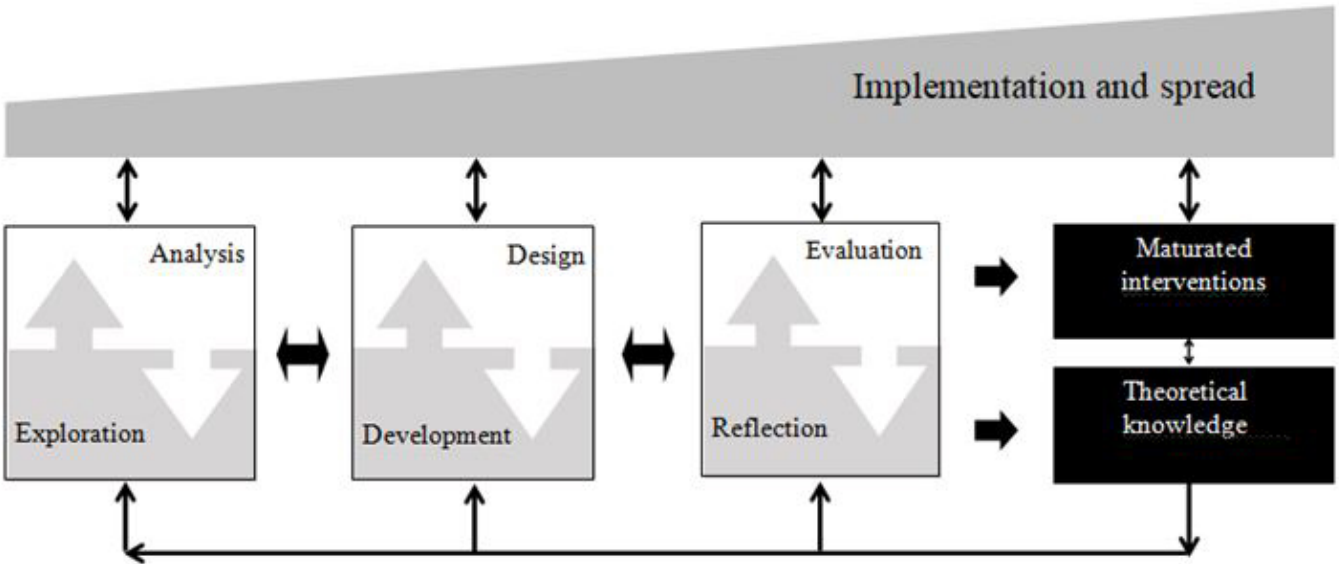


Fig. 1. The generic model of an educational design research protocol

designing and implementation of the educational product under development [17].

Based on these two fundamental directions, study protocols, built on the pattern of educational design research, are developed by combining various methods of research, testing, evaluation and data analysis, routinely used in the scientific world. Than the research process is organized in iterative cicles of design, implementation, evaluation and reflexion of practical applications until a valuable final product can be released.

A conceptual overview of educational design research methodology is demonstrated in Figure 1. The image was taken and adapted according to the generic model created by McKenney S. and Reeves T.C. This image perfectly demonstrates the integration of several scientific methods in a unique research process, each stage having a bidirectional relationship, reciprocity in the analysis and reflection of results, serving to develop practical educational products and useful theoretical knowledge [17].

In general, design based research consists of four major stages, which overlap over time and combine into objectives. Following the initial analysis of existing knowledge and gaps identified in the context of the researched subject, a set of ideas is formed in order to create prototypes of educational interventions appropriate to the topic. The second stage of design and development consists of the projection of practical configurations, which are afterwards tested and evaluated iteratively and adapted accordingly by reflecting the results after each application trial. This algorithm is repeated until they reach a fulfilled, usable form. New contextual knowledge is scientifically exploited by taking parallel advantage of these practical implementations in natural educational settings, enriching the succession of theories in the educational field.

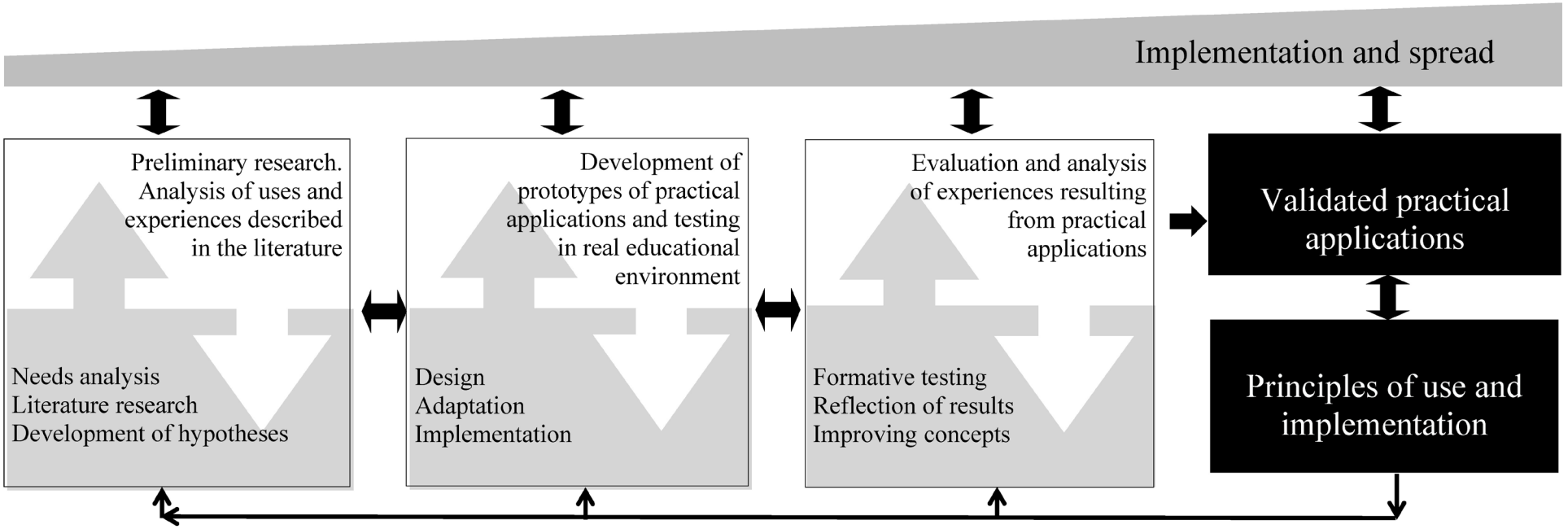
In order to demonstrate practically how to assimilate a scientific study protocol with the methodology of educational design research, we further present a research proceeding developed and led by our team of educational researchers. The main objective of this scientific inquiry is to explore the potentials of using and integrating virtual reality into disaster management training programs.

Virtual reality is an interactive, three-dimensional environment, generated by a computer, which allows the individual to explore the environment through visual, auditory and sometimes other natural senses, respectively manipulating objects or performing predetermined actions. The person or group „immersed" in this virtual environment can experience any dangerous, expensive or impractical situation in the real world. It represents a promising alternative to disaster management training programs, applicable at all stages of training. It allows the development of scenarios in all types of disasters, including exceptional situations, very difficult or impossible to achieve otherwise in real field exercises. Currently, it is more used for the training and individual evaluation of intervention staff or for case simulations in microgroups. This technique is less explored for the development of teamwork or for complex multidisciplinary simulations, with the involvement of several participants, similar to field exercises.

Within the National Emergency Simulation Center there is in use a virtual reality software (XVR software, www.xvrsim.com/en/) controlled by a team of experts, which deals with the design and organization of simulation exercises in virtual reality on the subject of disaster interventions. The close collaboration with this team of experts, respectively our experiences as instructors and designers of simulation exercises in various instructive-educational fields led to the formulation of this research protocol. Our observations have led to the conclusion that virtual reality is not being explored at its maximum capacity in this context. The need and passion to take advantage of virtual reality with all its potential in favor of optimizing training activities in disaster management have constituted the main motivation of the research process.

Educational design research has proven to be the most appropriate form of scientific inquiry to investigate the

Table. 1 Implementation of Virtual Reality in disaster management training programs. Research protocol.



Objectives: Mapping virtual reality forms and application models Development of the research protocol	Objectives: Identifying the potentials of using virtual reality Development of prototypes of practical applications based on virtual reality Integration of the method in existing programs	Objectives: Evaluation of the relevance, usefulness and validity of the technique in research Highlighting the political and cultural elements that influence the acceptance and compliance of users of innovation Determining the ways of integrating technique in complex field exercises	Objectives: Analysis of the determining factors in adaptation and adoption of the method Elaboration of the principles of use and integration in training programs for disaster management Description of the learning environment based on this technique
Methods Systematic review of the literature Comparative analysis Case study Interview Expert survey	Methods Contextual analysis Task analysis Design logs Case study Expert review Review by the target audience	Methods Usability testing Professional expertise Interview Formative evaluation Observation Semi-experimental studies	Methods Analysis of design logs Observation Interview Questionnaires Data extraction Correlation studies

proposed subject, the most attractive features of the method being flexibility and research on developing practical applications. Table 1 presents the construction of the research process in its complexity, developed on the methodological principles of educational design research. The research protocol is divided into four major stages, each stage covers a complex process of customized research to meet the target objectives and, at the same time, qualifies the main conceptual set of the study.

Analisys and exploration of the educational problem - *Evaluation of educational programs and exercises designed in Virtual Reality*

The first stage of the research project consisted of exploring the literature, experiences and scientifically documented observations, respectively in formulating the research objectives of the scientific investigation. In this respect, we have proposed a research of the specialized literature and the editing of a review article on this subject, rigorously respecting the scientific procedure of a systematic literature review. The aim of the study is to write a systematic analysis of the existing models of virtual reality used in disaster management training and to identify unexplored areas within this context.

The synthesis of the results obtained through this review, corroborated with our experiences and observations in this field, served to compose a set of ideas and recommendations for the next stages of the study. These ideas, already scientifically supported, represented the starting point for the development of prototypes of practical applications and for defining the methods of evaluation of these teaching activities. It has become clear that virtual reality is a promising and unexplored alternative for its full potential in supplementing practical workshops and complex, multidisciplinary field exercises in the disaster management training.

Development and design - *Development of prototypes of practical applications in Virtual Reality and their testing in real educational environment*

The second stage of the research protocol had extended over a period of 4 years, in which we had the opportunity to test several prototypes of practical applications in virtual reality, developed specifically for certain exercises and training projects for disaster management. Table 2 summarizes each prototype created, together with the program framework for which it has been designed, the way of its integration and usage in the program and the objectives pursued for each experiment.

The main purpose of these practical applications was to explore the potentials of using virtual reality for complex multidisciplinary and multilevel exercises, involving the entire operational system of such events. The first three

Table 2. Prototypes of practical applications designed in virtual reality

Program settings	Program description	Applications in virtual reality	Objectives
Digital exercise and seminar on civil-military cooperation in medical response to disasters EADRCC-NATO	Experimental digital disaster management training International exercise, Duration: 3 days	Carried out exclusively in virtual reality for 3 days, Command Post exercises Composed of 4-5 hour virtual reality simulation modules, with operational jump between them, but with continuity on the same situation of industrial catastrophe	Scalability of a national emergency system in case of a complex disaster, with multiple victims, and in organizing the mass evacuation of the population Civil-military cooperation Exploring the potential of using virtual reality within EADRCC-NATO exercises
„BOSNIA I HERCEGOVINA 2017" The 17th Disaster Consequence Management Exercise EADRCC-NATO	Large-scale, multidisciplinary, multilevel, multistrategic field exercise International exercise, Duration: 3 days	Command Post exercise for the purpose of preparing and testing the field exercise, "mini-ex" 4-5 hour virtual reality simulation module to supplement night field exercises	Testing the response of a national emergency system to a major natural disaster Multidisciplinary international cooperation Exploring the use of virtual reality during a large-scale field exercise
"SRBIJA 2018" The 18th Disaster Consequence Management Exercise EADRCC-NATO	Large-scale, multidisciplinary, multilevel, multistrategic field exercise International exercise, Duration: 3 days	Command Post exercise for the purpose of preparing and testing the field exercise, "mini-ex" Two modules of 4-5 hour virtual reality simulation, fully integrated into the field exercise, in two separate intervention locations	Testing the response of a national emergency system to a major natural disaster Multidisciplinary international cooperation Exploring the integration of virtual reality into the complex of a large-scale field exercise
Development project of a multinational level 3 field hospital "European Modular Field Hospital (EUMFH)"	Training program for the staff of an international level 3 field hospital, "EUMFH" type International training course, Duration: 5 days	Three practical workshops, based exclusively on 4-5 hour virtual reality: 1. Design of "EUMFH" type hospital models in virtual reality 2. Large-scale simulation exercise - practicing operational standards in a "EUMFH" type hospital created in the virtual environment 3. Large-scale simulation exercise - adapting operational standards in extreme conditions in the same "EUMFH" field hospital created in the virtual environment	Creating a development guide for a level 3 field hospital, type "EUMFH" Developing a training plan dedicated to "EUMFH" staff Development and validation of the curriculum and format of the basic training course Exploring the utilization potentials of virtual reality practical applications in this educational context

applications, essencially, meant large-scale simulation exercises, carried out through scenarios developed in the virtual environment. The series of these three instructional interventions was developed related to the international disaster management exercises, organized annually by the Euro-Atlantic Disaster Management Coordination Center (EADRCC) within the North Atlantic Alliance (NATO). The participants in the exercises were represented by various specialized intervention teams of the institutions for emergency situations.

Practical virtual reality applications have been gradually introduced in this instructive background. The first prototype is a large-scale simulation exercise, organized exclusively in virtual reality, which aimed to exploit the method in these series of EADRCC exercises. It has proven to be an effective and useful method for practicing the chain of command and communication channels, in the form of a command post exercise.

In the second experiment, the virtual reality scenarios were used in parallel with a large-scale field exercise in two formats. Before the start of the main field exercise, a Command Post exercise in virtual reality had been organized, similar to the first developed prototype. Thus, the participants in the field exercise had the opportunity to practice the command and control procedures, respectively communication means adapted to the situation, in form of a warm-up exercise. The second form of using virtual reality in this exercise was a scenario created for night interventions, which took place in parallel with the real night field actions. This virtual reality simulation aimed to supplement the night interventions and to provide practical activities for participants who had not qualified for field interventions in this regard.

In the third experiment, based on the experiences gained in this environment, we proposed the integration of virtual reality scenarios in the main field exercise. Once again the Command Post exercise was organised as a virtual reality warm up exercise, but the objectives were completed with the simultaneous testing of the command and control procedures of the exercise coordination team. In addition, we have developed two virtual reality simulation scenarios to complete the work sectors within the main field exercise, which required real resource allocation and special interventions. These virtual work sectors have been fully integrated into the command and control chain of the governing field exercise.

Experiments using virtual reality within the "EUMFH" project meant, again, the formulation of a series of simulation exercises through this technique. One of the objectives of the project was to develop a long-term and cost-effective training plan for the staff of a level 3 international field hospital. Within this context, the curriculum and format of a basic training course has been created, around which an educational plan has been built for the maintenance of skills and abilities needed in these working conditions. Within the basic training course, three virtual reality workshops have been organized, addressing various important objectives from a contextual point of view. The first workshop played two roles: participants were challenged to develop models of complex level 3 field hospitals in the virtual environment, and on the other hand, this workshop served to familiarize trainees with the technical part of simulations in the virtual environment. The other two practical workshops consisted of large-scale simulation exercises in the virtual environment, on scenarios developed specifically for this working set of a level 3 international field hospital. The curriculum and structure of the program were tested twice, consecutively, inviting participants from all key areas in this regard and with a real interest in participating in such missions. The main focus during these experimental sessions was to evaluate the course content and format. The survey of opinions and recommendations of the participants was done systematically for each training event, respectively the implementation of improvement ideas was accomplished immediately as far as possible. These experimental courses were exceptional in terms of the close collaboration between the researcher, instructors and participants, in developing a form of training that satisfies everyone's expectations.

The mental and physical immersion of the participants in the simulated scenario, facilitated by the virtual environment, offers an ideal educational environment for situational learning, the development of critical thinking and the ability to adapt, integrate and communicate in such extreme working conditions. The reproduction of important details, the interactivity and the real-time visualization of the consequences following the decisions taken faithfully reproduce the stress conditions specific to disaster situations. Simulation exercises in the virtual environment can be developed, carried out and controlled much more easily compared to large-scale field exercises and, at the same time, can satisfy the training efficiency for most instructional elements, safely and at a lower cost.

Evaluation and reflection of results - *Evaluation of prototypes of practical applications designed in Virtual Reality*

The appreciation of a training plan or new educational techniques involves a complex evaluation process, with increased attention to the elimination of biasis. As highlighted in Table no. 2, these prototypes of practical applications, developed in the virtual environment, were tested in real instructional backgrounds and integrated into the natural development of these training activities, without specific preparations or determining an experimentally controlled environment.

The main objectives of the evaluation of prototypes of practical applications in virtual reality were aimed at assessing in terms of adaptation, dissemination and adoption of technology in this professional educational environment. The influencing factors for the acceptance of virtual applications by this specific target audience and the ways of inte-

gration in the existing training programs were followed with increased attention. The main aim, this time, was to explore the usefulness and applicability of the method and not the educational efficiency in this instructional framework.

In order to obtain the most realistic and productive results, research methods triangulation has been proposed by combining several types of evaluation forms [23]. For each stage of the research study, a combination of evaluation techniques chosen from data collection methods (questionnaires, interview, expert opinion, observation, data extraction, documentation, etc.) and from data analysis and interpretation methods (scaling, factor analysis, comparisons, content analysis, formative evaluation, correlation studies, etc.) has been used. Table 1 also presents the evaluation methods chosen for each research pillar.

Maturation of developed interventions and contouration of new theoretical knowledge - *Reflection of results and generation of "design principles"*

The final target of the scientific inquiry represented the development of a good practice guidelines for the use and integration of virtual reality in disaster management related training programs, and the development of a methodology for designing large-scale, multidisciplinary, multilevel simulation exercises based on virtual environment.

Combining virtual environment training ground with the guidance of the professional instructor is a new form of training, which requires familiarization from both the candidate and the instructor as well. It is an innovative educational method, which provides an optimal environment for situational learning, for the development of non-technical skills, critical thinking and the ability to adapt to any extreme conditions.

The practical contribution of the research study is important due to these series of simulation exercises developed in virtual reality. The elaboration of these practical application prototipes has been developed in order to enhance large-scale field exercises. Each exercise ended with a reusable complex instruction package, which easily adapts to new curricular objectives.

These packages contain:

– the scenario developed in virtual reality in electronic form,
– description of the leading scenario and the exercise, in general, with objectives, the number of participants and the roles, the technical devices necessary to run the exercise,
– a table that includes in detail all the interventions of the instructors and technical operators for the guidance and control of the exercise, including the performance indicators for the final evaluation.

The theoretical contribution of our research represents the definition of the principles of design and development of large-scale simulation exercises in virtual environment, integrated in the instructive-educational activities of disaster management training. The abstraction of new knowledge, the reflection of the experiences resulting from the testing of the prototypes of practical applications has been carried out continuously, in all stages of the research, ending with the formulation of a good practice guideline for designing and implementing such a simulationala exercises.

Conclusion

In educational sciences, research paradigms that simply examine learning processes as isolated variables within a laboratory environment will necessarily lead to an incomplete understanding of their relevance to real practical conditions [9, 20]. Instead, the educational design research studies educational interventions or phenomena, produces evidence and new, useful theoretical knowledge, in parallel with the maturation of the developing educational product.

Educational design research involves a complex process of flexible and adaptable scientific inquiry, using several dependent variables, including capturing social interaction. Unlike the simple testing of hypotheses, the emphasis is on the development of an educational profile or theory, characteristic of their implementation. It is an interventionist method, focused on action, and involves close collaboration between instructors, the target audience and the researcher. It is an ideal method for introducing innovative educational tools and methods into training plans.

This study has been designed with the intention of promoting the adoption and dissemination of this research method in the scientific and educational community in Romania. The research protocol presented, as an example of adapting the methodology, illustrates how this type of research can serve as a powerful strategy for the implementation and scaling of educational innovations. This study report may also serve as a source of inspiration for new ideas for the conceptualization and application of educational design research and as a new directive for the adaptation of instructional research projects.

Author's contributions

ET, SET, MDP, EJ, CMB, JS, LA - Conceptualization, Data curation, Formal Analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing

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