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Digital Factory and Virtual Reality: Teaching Virtual Reality Principles with Game Engines

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Abstract

Virtual reality (VR) is widely used in various industrial applications. All leading industrial manufacturing companies today have a strategy called the 'concept of a digital factory' where all aspects of manufacturing are digitally verified on digital mock-ups prior to physical manufacturing. Other than that, it is a rapidly developing new medium and further development of VR and IT will open up new possibilities. The new concept of Industry 4.0 is based on using approaches like the Internet of Things, Cloud Computing, Cyber-Physical Systems and Virtual Reality. With the decreasing cost of VR devices, even smaller businesses are able to implement such technologies. It is therefore crucial that mechanical engineering graduates are familiar with these new technologies and trends. We had to use unconventional methods to educate mechanical engineering students in the latest trends in IT and VR. Back in 2010, there were almost no tools available for teaching how to create industry-themed VR environments, which did not require complicated coding, so we decided to make our own. To simplify the development, we used Source Engine as the core and enhanced it with a library of textures, models and scripts we called DigiTov. Although Source Engine is a game engine, the master logic of VR development is the same as for professional SW products. In autumn 2015, a group of 10 students modified the DigiTov for Unity3D, forming a team made up of different roles.

Keywords: Digital Factory, Source Engine, virtual reality, virtual reality education

1. Introduction

Leading industrial companies rely on virtual reality (VR) for the development of new products, which includes production planning, distribution, user experience and many other fields.

Virtual reality started to appear in the late 1980s, but it took about 30 years before it became available. Affordable devices like Oculus Rift, VR cases for mobile phones and augmented reality (AR) glasses have started to emerge in the last few years, creating the potential for use by small and medium businesses and home users.

Until recently, the prices of VR solutions had meant that they were only affordable for the automotive, shipbuilding and aviation industries and other big companies with very large production runs, or with smaller quantities of large and expensive products. For example, a decade ago, a Cave Automatic Virtual Environment (CAVE) device would have cost hundreds of thousands, if not millions, of euros. Today, consumer VR devices are available for thousands of euros at most.

Industrial uses of virtual reality are mainly in the automotive, aeronautical and shipbuilding industries. Many such industrial corporations have adapted their own concept of the Digital Factory (DF) [1]. Digital Factory, or 'Digitale Fabrik', is a German solution for shortening the product life cycle by taking advantage of data compatibility and real-time accessibility, simulation and visualization in virtual reality. Basically, a virtual counterpart of an actual production plant is used to virtually validate the production. This process eliminates errors and various problems without letting them occur in reality, lowering the costs and time demands and increasing the overall efficiency of the plant. The DF concept emerged in 2008 and has mainly been implemented by two leading companies: Siemens with their Tecnomatix software suite and the rival Dassault Systèmes Delmia software.

As seen in the Czech Republic, the next step from DF is the Industry 4.0 (I4) strategy. It was proposed in 2013 [2] by the German government, and thanks to the Czech Republic's close industrial ties with Germany, it is in the process of adaptation by the Czech Ministry of Industry and Trade under the Czech name 'Průmysl 4.0'. This strategy consists of smart factories with autonomous scheduling, material manipulation, simulation and the introduction of the Internet of Things paradigm into production. For further details, see [2]. In this concept, a virtual model of the production plant is also necessary. VR is defined as one of the cornerstones of this 'fourth industrial revolution'.

Other than these two major concepts, virtual reality also has its place in production. CAD models not only compute the durability for a particular load, they can also be viewed or validated in head-mounted displays (HMDs) or in CAVE devices in order to support decision-making, and for validation of the design and appearance of a product. In combination with a digital human model or an actual person, the product can be validated by VR-powered ergonomics analysis. This means we are able to check, for example, whether a driver will have a good view from the driving seat, whether a certain grip is comfortable, or whether workers can reach all the necessary surfaces during an assembly operation without the risk of injuring their backs through unsuitable movements. Subsequently, the whole production system is fine-tuned using a simulation model to optimize its throughput and minimize the production costs. Basically, the whole product life cycle today is supported by virtual reality.

According to Gartner and his Hype Cycle for Emerging Technologies for July 2015 [3], VR and AR technologies are entering the 'Slope of Enlightenment' part of the hype cycle, meaning that

usable solutions are slowly coming onto the market. Gartner estimates that it will take 5–10 years for such devices to create a new billion dollar market as Deloitte predicts [4].

This means the time is ripe for universities to consider education aimed at exploiting the advantages of VR devices and teaching the principles of virtual reality. Virtual reality is likely to become a new mass medium, potentially reaching numbers of users similar to those of other media such as TV or the internet. Students will need to understand the principles of using and creating VR. At the Faculty of Mechanical Engineering at the University of West Bohemia, we have been working with a CAVE-like device and other VR devices since 2009. Various projects and experiments have been carried out since then to make these devices accessible for students.

In 2009, there were very few possibilities for using virtual reality tools in an industrial environment. At that time, nobody knew how industrial virtual reality would evolve. We created a whole new subject which we called ‘Digital Factory and Virtual Reality’ (DFVR), which was designed to introduce virtual reality to fifth grade students at our faculty, and we needed a suitable tool for creating VR content for them in order to provide a practical experience. Industrial solutions were great, but too expensive, even with academic licences, and/or they were very hard to work with. We wanted an easy-to-use tool allowing students to focus on the content they would be creating.

Because of the lack of such a tool, we decided to design our own using a regular game engine. We created the DigiTov, a Source Engine–based library of assets and resources including 3D models of machines, workers, sounds, control logic, etc., so the engine could be used as a basis for creating industrial plant themed serious games. It was made available to students, and they enjoyed constructing their own virtual worlds in a very easy and understandable way.

Following the success of the DFVR subject, we decided to organize an annual workshop on virtual reality for secondary school students. We called it the Summer School of Virtual Reality (SSVR), which takes place at the beginning of July. Basically, it is a short version of the DFVR subject and more practically focused. As the Gartner Hype Cycle predicted, we have noticed an overall increase in the number of participants over the years, and participants have enjoyed the SSVR very much, claiming it was very interesting and useful.

Since 2009, there have been many changes and updates to these subjects. In this chapter, we would like to share the experiences and lessons learned from the DFVR and SSVR from a teacher’s perspective.

2. State of the art

There are many examples of virtual reality being used in industry. Existing solutions range from simple passive visualizations to complex interactive and collaborative solutions taking advantage of multiple instances of VR environments. There are many reasons for students at engineering schools to learn the principles of virtual reality.

Today, virtual reality is considered to be an immersive, computer-generated environment that lets its users interact with it, influence it and feel its feedback. This concept is very old, but it

has only become available in the last few years, mainly due to the high demand on the processing power of CPUs and GPUs. For example, the requirements for Oculus Rift or HTC Vive head-mounted displays (HMDs) are today's high-end gaming desktop computers. The processing power required for VR is high because of the stereoscopic 3D rendering in real time with a recommended minimum frame rate of 75 fps (frames per second). Another part of a VR system requiring high processing power is positional tracking, which requires the immediate transfer of the position of VR system elements to the computer. For example, when using a HMD, it is necessary to track its position in order for the computer to render the scene in the direction from the origin. All this must be processed at the desired 75 fps frame rate, leaving only 0.013 s to render one frame.



Figure 1. Augmented reality projection table. Touchscreen with black and white 'markers' is shot by a webcam. The marker-based 3D environment is generated and sent to a projector (original solution by Department of Industrial Engineering and Management, University of West Bohemia).

Other tracking issues arise with mixed reality (MR) systems. MR is a combination of a real and a virtual environment. For further information, see the details of the reality-virtuality continuum [5]. Augmented reality (AR) as a part of this continuum is basically the projection of 3D objects on to the user's field of view. The augmented scene is rendered on a screen, tablet, smartphone or a see-through HMD. This requires precision tracking in order to render the 3D objects in the correct position, rotation and size. Usually, this is provided by computer vision

algorithms that recognize the context of the scene or find positional markers. An example of an augmented reality system with marker-based tracking is shown in **Figure 1**.

As early as 2007, production system design and validation were carried out in an augmented reality environment. Back then, the objective was to check whether a product would collide with elements of the production system such as robotic manipulators, whether it would fit into the clamps flawlessly, or whether parts would be aligned properly before welding [6]. At that time, the limited power of portable computers did not allow visualization of such scenes in real time, on site at an actual production system. Therefore, the scene was photographed using a high-end camera and processed at a workstation, and the production system was then evaluated and validated.

Today, augmented reality has reached a much higher level. As for production line maintenance, an interesting study with a now discontinued version of the Google Glass HMD is described in [7]. A user wearing Google Glass is guided through the maintenance process of calibrating a driver assistance system testing bay. The results showed that using this AR system, the maintenance worker could calibrate it much more quickly.

As for AR systems depending on image recognition and marker tracking, it is possible to quickly evaluate a production layout design. Similar to **Figure 1**, the markers can be printed on paper cards and 3D models are laid over them, as described in [8]. It must be said that although this is a very fast, efficient and understandable method employable by everyone, such a simple system is better suited to creating a first concept than for a full evaluation of a production line. Another advantage lies in the fast preparation and creation of such a system.

A more advanced wearable AR system was presented in 2014 in [9], consisting of active video tracking via a webcam rigged to the user's HMD. The tracking algorithm contextually recognizes the video input and computes the position of the camera in space. This position is registered into a 3D model of the layout, allowing it to be rendered in the direction the user is looking. The user is able to create simple 3D models as envelopes of current elements of the production systems. These serve as so-called colliders—primitive 3D models used for collision computations. Then, the user can place 3D models of machines, workbenches, racks, etc., and evaluate collisions, safety distances and so on. Such tasks are normally performed at an office desk using production line documentation. However, this documentation is often found to be inaccurate, mostly because it is not updated after slight changes are made, or during continuous optimization. This new approach can bypass the need for documentation completely.

A VR platform can open up new opportunities in telecommunications. The concept of telepresence has evolved from videoconferences. It consists of transferring a user's 3D scan or model, making it possible to transmit gestures and expressions. Such a concept is very useful in collaborative problem solving, when participants are geographically distant. Experts can be brought to the site where the problem is without needing to travel, saving a lot of time and money.

Such advantages can be used in production systems planning. There are solutions that stem from distributed collaboration, such as Virtual Collaborative Arena (VirCA) [10], which is a platform for communication between CAVE devices. Users are represented by their avatars,

and the problem is modelled in 3D. Various experts can participate in the problem-solving process. VirCA's uses extend beyond production systems planning.

There are advantages in knowledge acquisition when using virtual reality. It has already been proven that VR can be used in various therapies, mainly in psychiatry. It is not that hard to fool human brains by exposure to a virtual environment. This feature is used, for example, in therapies trying to eliminate or at least moderate different phobias using virtual exposure therapy, and goes hand in hand with knowledge acquisition from virtual environments.

The understanding of a situation that is modelled in VR has been evaluated in many studies. There are differences in the kind of virtual reality projection and the quality of the VR hardware. For example, in [11] an Oculus Rift-based VR system is compared to an Nvis SX60 based one. The cost of these devices is very different, with the Oculus Rift being two orders of magnitude cheaper at that time. Although the display quality was better for the Nvis SX60, aimed at the professional market, users estimated lengths more accurately and did better in navigation tasks with the Oculus Rift, which is aimed at domestic use.

Study [12] found that a larger field of view provided by VR devices has a big effect on knowledge acceptance and navigation, even equalling the differences between men and women. In the study, Tan claims that men outperform women when using a VR device with a narrow field of view.

Study [13] compares input devices. In a study with 36 participants, it was found that users interacting with a virtual environment using gestures and touch control performed better than those using a mouse, although they took longer to train.

Study [14] is another interesting study. Participants were divided into three groups, and they were trained in a car service task. One group used a 3D environment on a desktop workstation, the other learned how to perform the task watching a video, and the last group learned by trial and error. After a period of time, they tried to perform the tasks they had learned. It was found that users who had been taught in the 3D virtual environment did better after 2–4 weeks.

Unfortunately, there are also some disadvantages when using virtual devices during training or for performing tasks. Users of VR devices are very prone to suffering from cyber sickness symptoms. Cyber sickness is a set of inconveniences caused by the discrepancy of acceleration perception. Basically, users see a movement but they do not feel it—exactly the opposite of what happens when travelling in a vehicle. Many articles have been written on the topic of cyber sickness and virtual reality. For example, AR can cause cyber sickness symptoms if users move their head faster than the model registration can be made: study [14] suggests a minimum 1 kHz frame rate for an object that is revolving at 1 revolution per second. This latency has been found to be a problem with AR devices in other studies, such as [15].

Virtual reality is used as a support tool in the education of software engineers. Rather than learning algorithms by calculating equations, students can learn them by designing situations in a virtual environment. Software development kits for various games can be used as platforms for such ideas. Study [16] shows the use of Source Engine (a game engine powering the Half-Life 2 computer game). Software engineers were taught the process of software

development by making levels for a Source Engine–based game. They worked in a team, and Dr. Emam, the author of this study, claims they learned how to set and accomplish goals in the process collaboratively.

It is clear that virtual reality will find a place in many fields as a novel tool for supporting data visualization, presentation, interaction and collaboration. Back in 2009, when we started to explore how to teach virtual reality at the Faculty of Mechanical Engineering, we found very little information about how to do it effectively. We had to find our own working approach, although we had the advantage of knowing the students and their skills. Searching for other educators' experiences is as difficult today as it was back then. Over the years, we have been refining our methodology for teaching virtual reality. In the following sections, we present the history and the future of our DFVR subject and the DigiTov project.

3. Digital Factory and Virtual Reality

Digital Factory and Virtual Reality, or DFVR, is our subject where we teach the basic principles of virtual reality to mechanical engineering students. Learning how to use this software is very specific because our students have very little or only a basic knowledge of programming, which needs to be brought up to the most basic level sufficient for creating virtual environments. Therefore, we present the DigiTov project and its use in DFVR.

4. DigiTov

Back in 2009, there was a lack of tools to support our virtual reality lessons. Some tools were too complicated, others too expensive, even in with an academic licence, or a combination of both. We needed a tool to enable the students to easily create their own virtual worlds.

We decided to make our own tool using a game engine with a game software developer's kit (SDK). The possibilities were many, although we quickly reduced them to only a few, such as CryEngine or Source Engine. We considered Source Engine the best choice because of the big community of hobbyists around it using the engine to make their computer games, meaning the engine would be simple enough to use.

We decided to use Half-Life 2: Episode Two as our starting point, as it was a modern game with good graphics, an optimized engine and easy to modify. The first step was to find out whether this approach was even possible.

We began by making a validation model. It consisted of a shop floor, which was designed in a Digital Factory project to be an assembly line for radio controlled (RC) car models. This production line's digital mock-up was made in Plavis VisTable[®] Touch software and balanced using a discrete simulation in Siemens Tecnomatix Plant Simulation programme. We use these tools commercially and we have a database of production line component models in Virtual Reality Modelling Language (VRML) files.

The VRML files were converted using AutoDesk 3ds MAX, where a consistent triangular mesh was made and textures were applied to the models. Using the SMExport plug-in, SMD files were generated as input for the final step in model conversion: building an MDL file, which can be directly used in a Source Engine game.

The models were built using Valve Hammer Editor (VHE), the official level-editor for Source Engine games—the tools the virtual worlds are created in. New textures and materials were made as we needed them, and the results can be seen in **Figure 2**.



Figure 2. The Half-Life 2 production line validation model. Above is an overall view of the building and parking place. Below is the redesigned production line.

The model was validated successfully. Although we had to overcome some engine limitations, we managed to make an interactive model of an assembly line. Workers play an animation when a part is passing them and the part can be picked up and returned to the conveyor.

This was the point when the DigiTov (abbreviation of the Czech words 'digitální továrna', or the Digital Factory) was founded. The work to make it a convenient and easy-to-use tool started. More models were converted for use in DigiTov, including machines, more conveyors, storage containers, office furniture, cars and so on. New sets of textures and materials were prepared, and functional blocks of control logic were made into prefabs to be easily deployed in the model and used directly. The final composition of DigiTov can be seen in **Figure 3**.



Figure 3. The composition of the DigiTov package.

The DigiTov package was created by a team of students. A total number of 12 authors contributed to making the assets and resources as well as an education e-book, which is a manual for creating models using DigiTov with the VHE level-editor.

In order for DigiTov to be easily used and deployed, a launcher was made in Visual Basic .NET to handle installation, uninstallation, downloading updates and launching models. Manual installation of DigiTov is possible, but it is error prone because the files are manually copied into the correct folders and the configuration files are modified.

Over the 5 years of using DigiTov in classes, new assets have been created by us or by the students. See examples of students' semester projects in **Figure 4**.

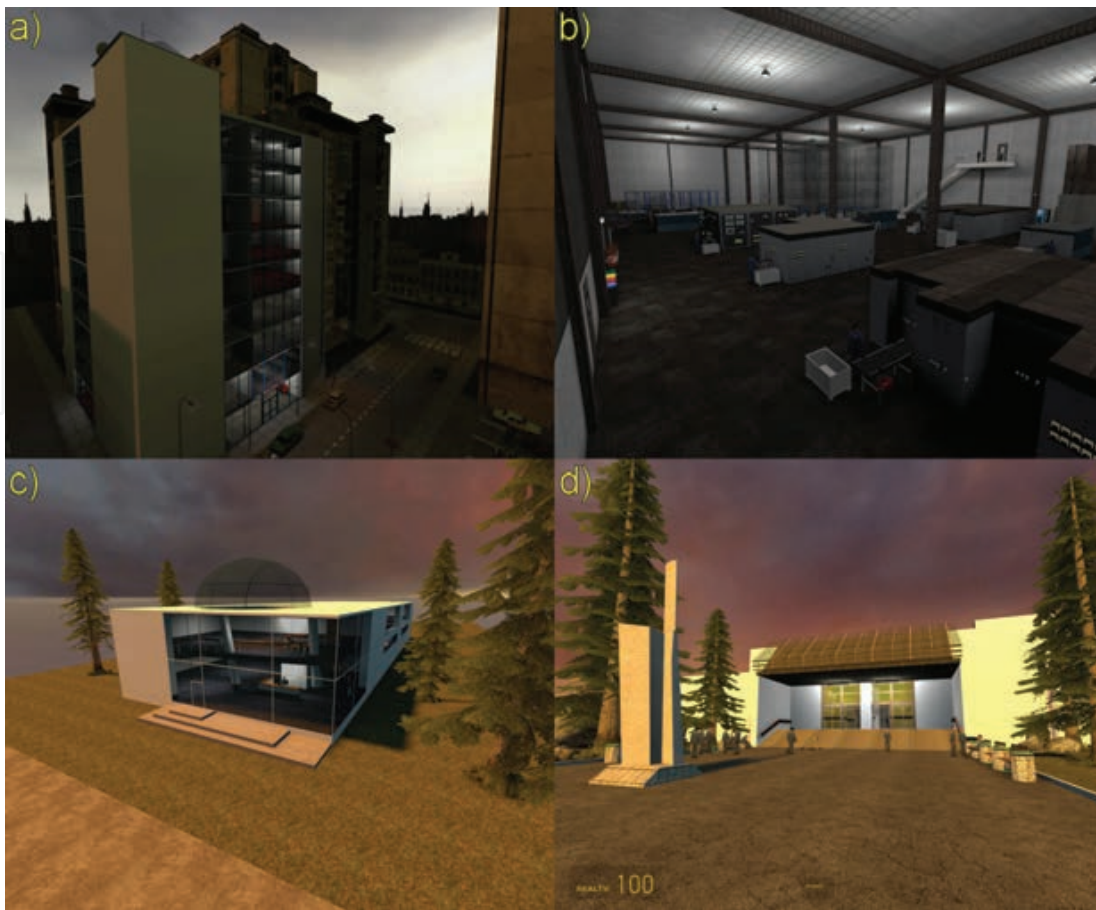


Figure 4. Examples of students' models made with DigiTov: (a) an administrative building inspired by an actual company building in Pilsen, Czech Republic; (b) a virtual reconstruction of an actual shop floor; (c) a fictional company producing automotive parts and (d) the entrance to our faculty.

We not only made an automatic installer and configurator for DigiTov, we also made an automatic converter from a conventional layout designing software product—Plavis VisTable. We encountered conversion problems in some 3D models, so right now the basic layout can be converted successfully, but the user has to check all the converted models manually and adjust lights and some textures.

5. Lectures in DFVR

Our course seems to be different from other VR courses around the world. These courses are still very rare; there are some provided, for example, by the University of Illinois, Stanford University [17] and Ecole de Lausanne [18], but they are all targeted towards IT experts. Our course targets mechanical engineering students who have only basic programming skills. We wanted to keep this programming part, but with lower demands on the students, and also we wanted to present how to work with VR and how it is used in practice. The main target of the subject is to introduce the possibilities of using modern technologies, software and hardware, mainly in the context of manufacturing management. The main paradigms are universal, so

the outcomes from these subjects can be used generally in other fields. We need to face the fact that all professionals will need to use virtual reality at least at user level. Some of the students will need to communicate with IT experts about this topic.

During the lectures, the students are familiarized with the developments that led to creating the digital factory, its definition and a short history. They learn the importance of topics like Product Lifecycle Management and Mechatronics and the basic benefits of a digital factory. Last but not least, the students are familiarized with software support in this field. Students are introduced to the historical development of the system and the basic technical principles of virtual reality. The possible uses of virtual reality in different fields are also demonstrated.

The first lecture is an introduction intended to raise students' motivation. We start with a discussion. Students usually have certain expectations about the subject, and it is very interesting to ask them for their basic definitions at this point. Each student has a slightly different view of VR at this stage, but at the very end of the discussion we clarify the definition. Students see the outputs of a selection of VR projects carried out at the department in recent years, and then, there is an excursion to the virtual reality laboratory.

The next main topics are:

- **Visualization and haptics.** Students learn about ways to trick basic human senses and how to connect all the aspects and build a CAVE. The last 'entertaining' part of the lecture is about filming stereoscopic movies.
- **Basics of 3D graphics.** This lecture provides a basic theoretical background for the practical part of the subject.
- **Digital factory and Industry 4.0.** Because the subject is part of the Mechanical Engineering programme, we need to have a special focus on modern manufacturing processes management and the use of visualization and virtualization. We explore the new trends which have led to Industry 4.0, such as the Internet of Things and services, Big data management, Simulation, etc. At the very end, we interconnect these aspects with virtual reality.
- **Hardware and motion capture.** Next, we present a little bit of historic, but mainly high end, hardware suitable for VR—starting with expensive solutions and ending with those which are widely available.
- **Augmented reality.** This term is not as widespread as the term virtual reality. The combination of real and virtual elements is now being used mainly for virtual training or as a warehouse management support tool. This lecture introduces the theoretical basis for constructing augmented reality and gives examples of many practical applications.

These are the main topics. We were also able to invite experts from industry to a hosted event, for instance:

- **Use of VR in practice.** This is the first hosted event. An expert who has in-depth experience in industry presents some case studies mainly from the automotive environment.
- **3D scanning.** An expert presents the possibilities of 3D scanning, describes the theory and guides students through the whole process of scanning: data acquisition in the field,

processing point clouds and methods for the acquisition of 3D models. Students can try the whole process on their own: we make a scan of the laboratory and then we process it. We count this activity as a 4 h lecture.

- **Use of virtual reality in psychiatry.** VR has been successfully used as a support treatment for different kinds of phobias and addictions. A doctor with experience from South Korea is the guest for this event.

Other topics have been presented over the 5 years of the course's existence, including Digital Factory and Logistics, Use of VR in Ergonomics with practical examples, and Serious Games.

For the summer school, lectures are simplified and extended using entertainment applications. Some of the lectures are presented not only on this course and SSVR, but as keynotes at the Mechanical Engineering Forum and Science in the Streets. An extended motivation lecture, Industry 4.0, Digital factory and PLM lectures are offered and presented at various high schools in the Czech Republic. Some of these lectures have also been presented at partner universities in Germany, Great Britain, Slovakia and Poland.

6. Practical classes in DFVR

We decided to base the teaching VR on the practical creation of the students' own virtual worlds. We want the students to try to make an interactive application for industry, although they can pick their own topic for their virtual environments.

Up to autumn 2014, we used Valve Hammer Editor (VHE) with DigiTov as the development environment, but we switched to Unity3D last year because, as it is based on Source Engine, DigiTov lacks some features which we would like the students to use.

With DigiTov, we start by carefully explaining the principles of making worlds in Source Engine. The students are taught that the world consists of primitive convex polyhedral solids with 3D models in MDL format. They gradually get to know the entities which carry interactive functions such as doors, lights, etc. and then learn how to use more complex prefabs containing new control logic which are used to make conveyor belts and similar objects found in real factories.

This usually takes half of the course, which is thirteen 90 min sessions. Depending on how fast they are, the basic course is usually completed by the seventh lesson. The rest of the classes are led as workshops—students work alone or in pairs on their projects and we are at their disposal in case they get stuck with anything. In the last lesson, students present their work in our VR lab using a stereoscopic projection wall.

Our university's information system has a module for evaluating courses, and students are asked on a voluntary basis to fill in a questionnaire. It consists of questions about quality that are answered as grades (one worst, five best) and they can also leave comments. Our subject regularly achieves very good scores, between 4.33 and 5.0, and the students very often say that they liked the subject very much because the topics are very current, up to date and interesting.

They especially appreciate that they have the freedom to choose their semester work topics and that the tool is simple and easy to use, allowing them to focus on the creation of content. There are not many subjects in our Faculty's study programme which are so highly encouraging and allow the students to use their own creativity. We believe that this is the main reason for the good feedback.

As we are trying to make the subject as up to date as possible, we felt that DigiTov was slowly ceasing to support current VR trends such as AR and interactive virtual manuals. Last year, we decided to try Unity3D as the IDE for the student projects.

In contrast to DigiTov, which did not allow any form of scripting by code, it is practically a necessity in Unity3D, except in some specialized cases where prefabs can be found on the Internet or the Unity Asset Store. This proved to be a major issue, because our students have only very basic programming skills in a different programming language—Unity3D uses its own proprietary JavaScript-based UnityScript or a standardized version of C#.

Last semester, we wanted all the students taking the course to form a big development team with different roles. There were coders, modellers, texture makers, sound makers, etc. We guided them in creating the project, but they were not good at coding. Other tasks like designing the virtual environment, getting and using textures and materials, even the sounds, were of good quality. The scripts did not work very well in the final presentation, because scripting is a hard task. The students stated in the questionnaires that they needed more classes explaining C# scripting.

We learned our lesson, and this autumn we are going to prepare the functionality of DigiTov prefabs into Unity3D to be used with as little coding as possible. Another change will be a return back to small teams (1–3 members) and to smaller projects. We are also going to dedicate some classes to augmented reality. We would like to exploit one advantage which mechanical engineering students have: the ability to make CAD models. Our students should be able to focus on creating the 3D models and then bring them to life as easily as possible.

7. Summer school of virtual reality

The Summer School of Virtual Reality (SSVR) is a 3–5 days workshop we organize every summer. Its purpose is to teach young people the principles of virtual reality in an enjoyable way. We began in July 2012, and the participants took lectures in various aspects and principles of virtual reality. We presented our case studies and real virtual projects which we had made. Then, participants were taught how to make their own virtual worlds using the DigiTov.

The students liked the event and we received very positive feedback from them. Following SSVR 2013, two high school students continued using DigiTov in a high school students' practical competition (SOČ), where they won first place at the regional level and seventh place in the European competition.

2016 saw a major innovation. We decided to switch to Unity3D, which is far more capable than DigiTov, although it requires at least basic programming skills.

There is quite a big difference between making a virtual environment in DigiTov and making it in Unity3D. Unity3D is much harder to start with, but practically anything can be programmed. On the other hand, DigiTov allows only a first person walkthrough with limited scripted scenes and interaction and does not allow scripting by writing code and using variables.

We taught the students how to make a virtual environment from the very beginning, from placing objects and writing simple scripts to making more complex models in SketchUp modelling software and importing them to Unity3D afterwards. On the second day, we continued making simple walkthrough games and tried to port them to the Oculus Rift DK2 head set, which unfortunately was unsuccessful, probably due to the incompatibility of the version.

On the third day, we taught the use of prewritten scripts and showed examples of codes we had written for other projects: state machines, controllers, animations, etc. In the afternoon, we let students work alone on their own projects and we were at their disposal in case they got stuck with any technical problems.

At the end of each day, participants were asked to fill in a questionnaire. There were a few questions to evaluate what they had liked the most and the least, what they had learned, etc. The results are shown in the graphs in the following figures.

Among other questions that were answered very positively, these two shown in the graphs are the most important for us. Unity3D is very hard to begin with, and 3 days (8 h each day) is hardly sufficient to teach the basics. Overall, the grades dropped on the second day (see **Figure 5**), which we believe was due to the failure of the Oculus Rift porting and that the portion of things taught had to increase rapidly. The last day was a success, and most of the students managed to make a 3D platform or maze game. We are pleased with **Figure 6**—it is proof that we managed to teach the participants of SSVR the principles of virtual reality. All of them now consider themselves to be lower intermediate level.

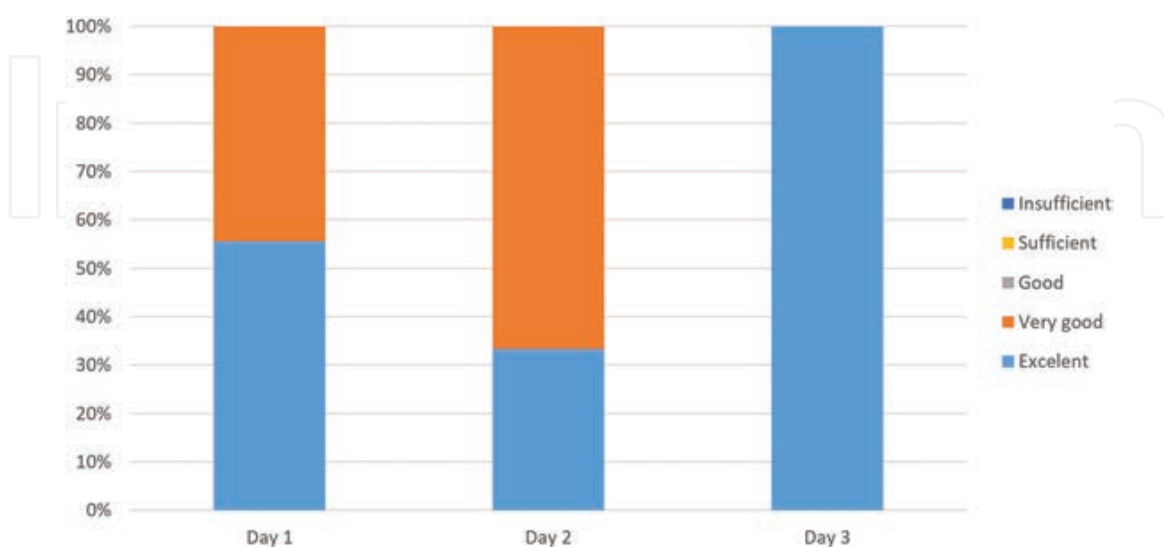


Figure 5. Answers from the questionnaire: 'How would you evaluate this day? Use grades, like at school.'

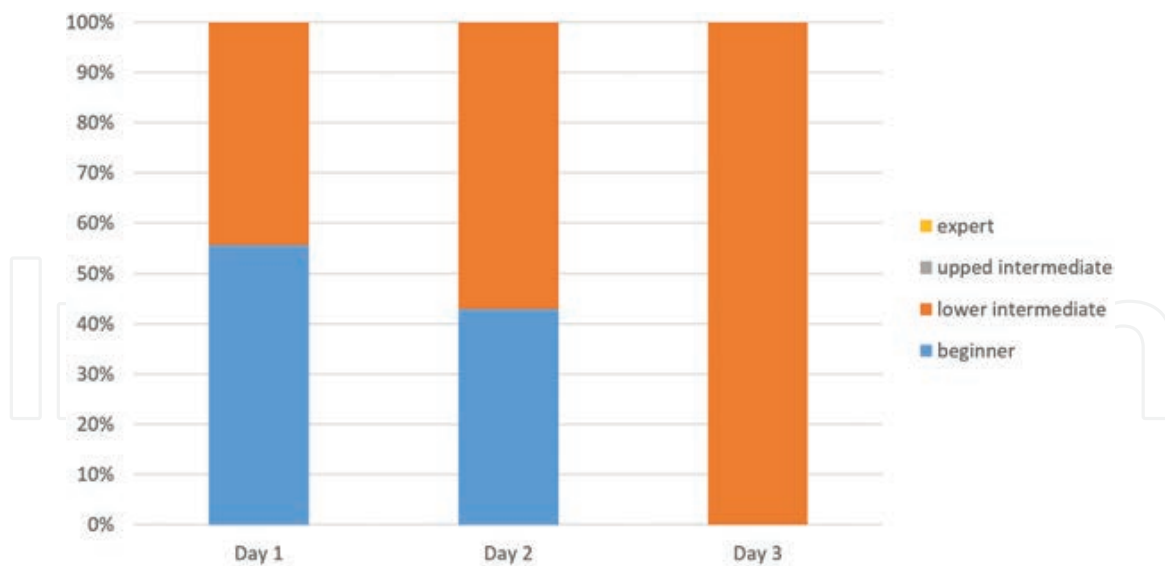


Figure 6. Answers from the questionnaire: 'How experienced do you consider yourself in virtual reality?'

We wrote code snippets on the projector, but the students claimed it was too hard and too fast for them to catch. In the future, we are definitely going to prepare more complicated scripts and explain them rather than write the scripts in front of them. Some students even suggested such approach.

Looking back at the SSVR, the approach of teaching VR in Unity3D is a good idea, but Unity3D is not an easy tool to start with. A slower approach would be better, and we will provide the students with prewritten scripts which they can use simply, assign variables and directly try the results. This was an event for engaged enthusiasts, and they were always delighted when they saw their virtual worlds working.

8. Other outputs

DigiTov is not the only unique output from DFVR. Other interesting studies arising from the subject included special semestral work and a start-up for a collaboration with particular students (for a thesis in most cases). Students also helped and participated in a study exploring knowledge acquisition and cyber sickness, published in [19].

Figure 7 shows some outputs from selected projects and studies made in collaboration with students.

- a. **Minnesota Dexterity Test (MDT) comparative study.** Some companies use tests at assessment centres when hiring new staff. One of these is the MDT test for jobs where manual speed and accuracy are required. We made a virtual version of this test and compared our results with results from a conventional test.
- b. **Virtual workshop.** This is a serious game which is currently used as a support SW tool for learning the basics of manufacturing.

- c. **Augmented reality for training.** We developed a system where a worker receives complete instructions for assembly on a monitor accompanied by a real-time video feed (published in [20]).
- d. **Game—training in industrial engineering methods.** This is a full-scale 2D computer game. The gamer/student plays the role of manager for the first day, and the task is to solve a range of manufacturing problems using industrial engineering methods such as KANBAN, JIT, 5WHYS, etc.

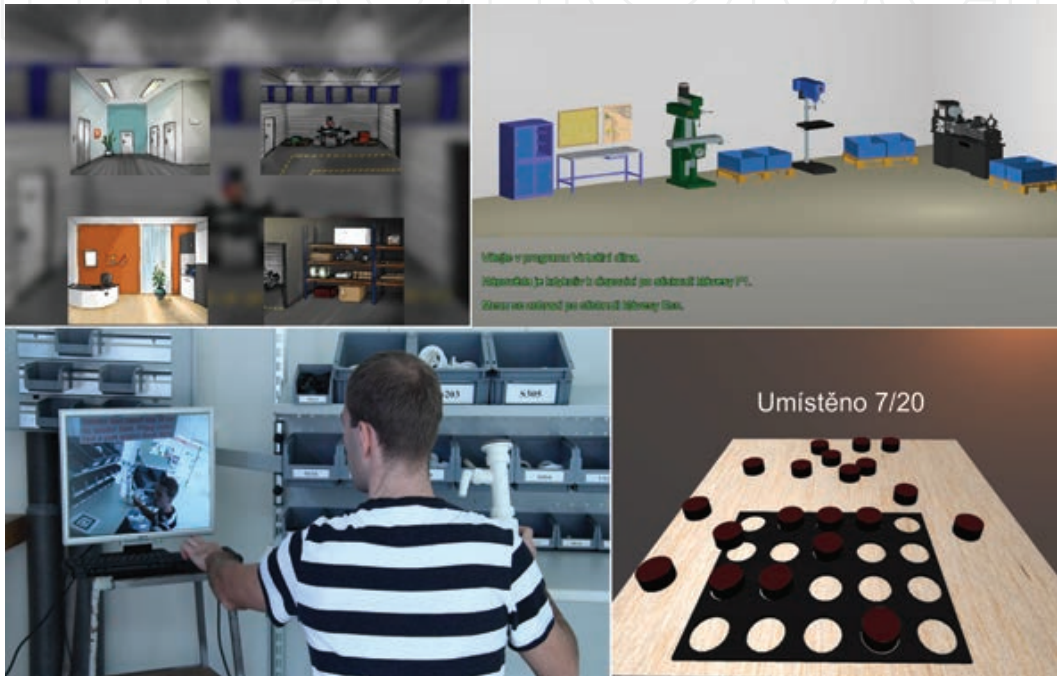


Figure 7. Other case studies and projects.

9. Conclusion

Bringing DFVR to life has been a long process. It took 2 years of intensive work to prepare, during which we created a basic version of DigiTov, and this was later extended by another 3 years. We launched a website for this subject and also developed two interactive e-learning books. The first book provides direct support for the lectures and contains more than 80 videos, 400 illustrations and 200 pages of text. The second is a multimedia e-book for working with DigiTov (200 pages). Students can also download all the lecture presentations (5 GBs) and further examples of finished models.

We also used this approach for the summer school of virtual reality which is primarily targeted at high-school students. Last year (10 days in 2015), students made their very own 3D game (using DigiTov) and also a 2D adventure game. This year (2016) students made their very own outdoor game with their own 3D models and level design. The results were ported to CAVE and Oculus Rift.

The completed student models are presented to basic schools, high schools and universities. We have also used the outputs at different events such as Science on The Streets, Popular Project (presentations and lectures at high schools), Education Expo, etc.

The evaluation process was carried out each year, the course receiving positive feedback from students. They primarily appreciate the topicality of the subject, the interconnection between theory and practice and the possibility to immerse themselves in their own virtual reality.

In the future, we would like to stick to a given concept with a few changes. We have recently started to use Unity3D, which offers more possibilities, but using it is more challenging. Students will have total freedom of creativity with all options open to them. For instance, Unity3D allows multiplatforming, which means, for example, development for iOS and Android.

After applying this approach, we found that some students who have only one or two semesters of programming had difficulties in event-driven real-time programming, which is essential for virtual reality development. This time we assigned these students the roles of graphic designers, sound editors and designers. In the future, we would like all of them to try basic virtual world development as in previous courses. To this end, we started to develop the port of DigiTov into Unity3D. This time we 'translated' more models from DigiTov, some of them are now 'intelligent' and have more action scripts included, which can be user controlled, combined and triggered (see **Figure 8**).

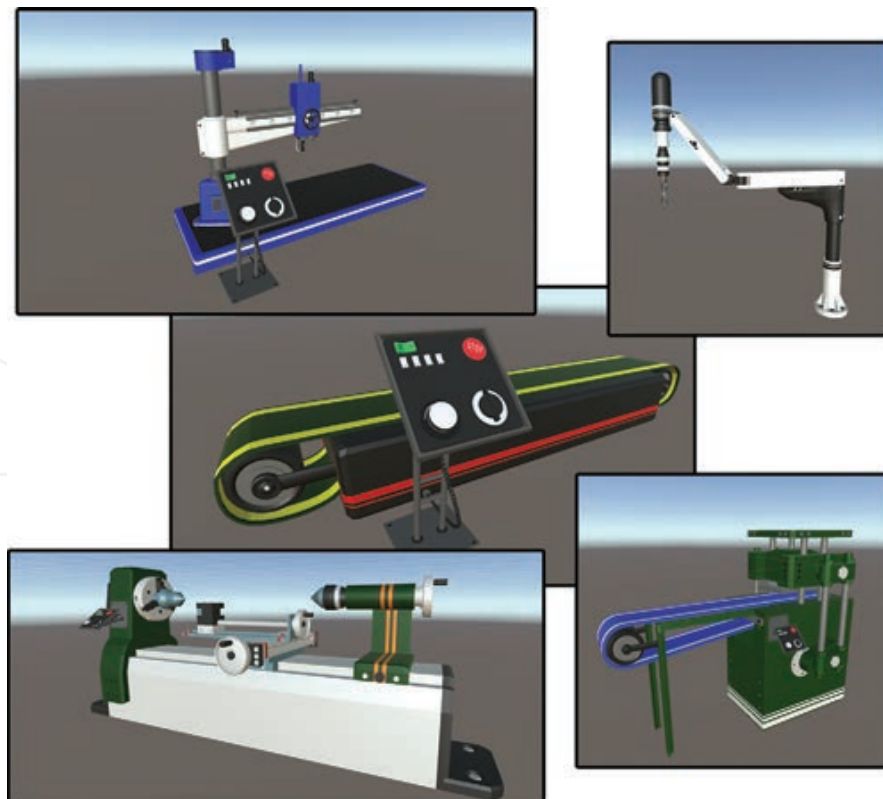


Figure 8. New 'smart' machines.

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