A Design-based Approach to Enhancing Technical Drawing Skills in Design and Engineering Education using VR and AR Tools

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Abstract: There are concerns from higher education (HE) institutions and industry about the decline in standards of technical drawings (TDs) due to the lack of understanding of basic geometric construction and the conventions of drafting skills that underpin the best practices. There is growing evidence that simulations/animations along with augmented and virtual reality (AR/VR) technologies can improve learners' engagement, competence, and skills; especially when compared to traditional didactic methods. However, this approach to teaching and learning (T&L) is difficult when studied at distance, or without access to the appropriate technologies to carry out the suggested activities. Leading to the need to develop appropriate methods and content that suit this pedagogical problem.

This paper describes the development of an AR/VR application to support the T&L of design and engineering students in education and industry. Using a multi-disciplinary design-based research methodology, this European (UK, Bulgaria, Turkey) funded research project combines pedagogy and technology to approach TDs education problems; and to develop an AR/VR education solution to address learning difficulties within the different critical TDs categories identified.

This development is based on findings from an international study in three different categories covering the perception of TDs education, assessing of TDs knowledge and ability, and expectations of TDs education. This research project also covers the difficulties and good practices of multi-disciplinary teams for developing TDs and AR/VR contents where the approaches to T&L may differ between practices.

1 INTRODUCTION

TDs are an essential part of the curriculum for engineers and product designers. They are a vital way of communicating the technical product specifications (TPS) for manufacturing. TPS may include: material, size, shape, tolerances, etc. Concerns about the decline in standards due to the lack of understanding of basic geometric construction and the conventions of drafting skills that underpin these practices have challenged the traditional teaching strategies (McLaren 2008). Despite engineering and product design students being known to prefer visual, sensing, inductive, and active learning styles; most engineering education has relied on auditory, abstract, deductive, passive, and sequential teaching styles (Felder and Silverman 1988).

TDs have evolved significantly as a result of the introduction and broadening of 3D tools as a key teaching component in the design process (Meyers 2000, Unver, E. 2006). However, the need to develop instruments to make qualifications comparable and help skills to be better recognised has already been identified (Azevedo 2009). HE institutions are left with the challenge of developing new T&L tools and methods to ensure students are equipped with knowledge and understanding of TD skills to meet the demands of both academia and industry (Garland 2017).

Although AR/VR technologies are not new, their potential in areas of education in which students find learning challenging have been studied by many researchers. Many educators have incorporated desktop-based virtual reality technologies into their teaching to actively engage in realistic activities that stimulate learning, to teach abstract concepts, (Merchant et al., 2012), to teach scientific inquiry

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(Galas and Ketelhut, 2006; Lee et al., 2010) and engineering subjects (Coller and Shernoff, 2009).

AR/VR offers HE institutions and design students an efficient way to improve their knowledge and skills; especially on complex theories, principles, or mechanisms of systems or machinery (CONNECT, 2007; CREATE 2004 and ARiSE, 2008). Complex and difficult theories/concepts can be accepted and understood by students with contextually enriched interaction using AR technology (Liarokapis, et al. 2004). Animations have shown to provide more enthusiasm for the learning activity, better performance in understanding the appearances and features of objects, and improve the spatial visualisation capabilities (Wu and Chiang, 2013). Simulations allow learners to early test their hypotheses and the effects of input variables on the outcomes (De Jong, 1991; Lee, 1999; Tobias and Fletcher, 2010). Games, as a special category of simulation (Tobias and Fletcher, 2010), promote learning by providing students a sense of autonomy, identity, and interactivity (Gee, 2003, 2007). However, as these technologies will continue to evolve and become highly advanced and expansive; new and more efficient methods to help design students to improve their TD skills are needed.

The creation of these methods and tools should aim to bring a well-balanced use of AR/VR technologies and consider students at the core during the design and development of content (i.e. human-centred design) (Rouse, W. B., and Rouse, W. B. 1991, and Oviatt 2006), in order to make education of critical and complex TD subjects more interactive, productive and engaging (Kuş, et al., 2018).

The design of AR/VR applications for T&L should consider three main circles of interaction (Cuendet et al., 2013). The first circle of interaction includes individual constraints such as the student's previous experience and cognitive load (Dillenbourg et al., 2011). The second circle of interaction considers multiple users interacting with each other; where the usability is measured by factors such as the quality of conversations, the richness of deictic gestures, and the smoothness of turn taking. Finally, the constraints given by the learning environment define the third circle of usability; here the effort necessary for the teacher to conduct learning activities should be considered as a real-time management of a multi-plane pedagogical scenario (i.e. Vygotsky's social development theory) (Vygotsky, 1978) that can maximize T&L experience. AR/VR applications for pedagogical approaches used in the classroom should consider integrating individual, team and plenary activities into a coherent learning environment.

An AR/VR application can be designed for individual use, the integration of this system in a classroom will require embedding the individual work within a scenario that often includes teamwork and class-wide activities. The design and development of an AR/VR must, therefore, anticipate the probable T&L scenarios in order to improve the student learning experience. In these scenarios, as the technology continues to evolve, the pedagogical activities (Bernardes, 2009) will continue to stretch beyond the individual, team, and classrooms, to include the classroom periphery. Hence, the importance of good interaction and usability, either individual or in teams, and the smooth integration within the learning environment in the classroom workflow that considers the notion of classroom usability.

In this paper, the authors present the initial stages of a 3D interactive AR/VR teaching system developed from a design-based method to help engineering and product design students improve on critical and complex topics related to TD skills according to an international survey (Kuş, et al. 2018) and as part of a broader European funded research project. This work shows that design-based methods and human-centred approaches can improve the understanding of students needs and facilitate the development of AR/VR technology applications for T&L within an international and multidisciplinary team. As a result, these approaches for the development of AR/VR applications for T&L could anticipate the pedagogic requirements and constraints involved in the delivery of such subjects.

2 DEVELOPMENT OF AR/VR AND ANIMATIONS

TDs are one of the most important aspects of the engineering and manufacturing process. However, TDs can be quite difficult for students to understand and for the tutors to explain. When traditional teaching methods are used alongside AR and VR, students have a much higher engagement rate and perform significantly better on tests (Bodekaer, 2015).

This paper addresses the use of low-cost mobile based AR/VR tools developed with the support of animation and simulation tools alongside text-based teaching methods. Having several approaches to teaching would give students a variety of options when learning technical contents. Individual students may require different support as the concentration and abilities of the students may change due to personal circumstances, environment, age, among other factors.

The first stage of this research carried out an analysis to identify the area of TDs that may require support from AR/VR technologies in order to overcome T&L issues. 320 people from UK, Bulgaria and Turkey, from different industrial and educational background (engineering/design, student, instructor/lecturer, manufacturing sector employee, vocational college student, high school/university student, and teacher/trainer), participated in a survey where their TD perception, knowledge and skill levels and expectation of TD education were questioned. From the results, it was concluded that current teaching methods have led to a deficit in the quality of TDs and that using up to date AR/VR and animation technologies could help. The program identified six aspects of engineering drawings which were separated into modules to improve the learning experience. From the analysis, the following module areas were selected for developing AR/VR content and animations (Kuş et al., 2018)

- 1 – Dimensioning and Tolerances
- 2 – Sectioning, Projections and Perspective Drawings
- 3 – Dimensional Tolerances, Edge Tolerances, Shaft and Hole Tolerances
- 4 – Geometric Tolerance/Form-Position Tolerances
- 5 – Surface Treatment Markings/Surface Roughness
- 6 – Production and Assembly Drawings

2.1 The Use of Animations in TD: Dimensioning and Tolerances Case Study

Animation is an effective medium for communication due to the use of different styles of text, colours, audio and video that can be shown to the students. Ismail, et al., (2017) stated that the use of animation in T&L increase the rate of acceptance by more than 30% when compared to traditional teaching methods. The use of video animations can help the student with imagination and visualisation whilst increasing their motivation and engagement. The design phase for animation and AR/VR content started with the development of storyboards for each of the 6 modules. Figure 1 shows the planning phase of module 5 and how the work could be developed by the relevant research partners. During this phase, the team had regular video meetings where each partner demonstrated their progress and constructive feedback was given. Screen sharing was found to be a useful tool

to demonstrate the proposed work. Progress meetings every quarter were crucial for successfully running the project, where specific deadlines and targets had to be met in the first phase of this international collaboration project

Figure 1: Storyboard for module 5.

Figure 2 shows the process used for creating animations where storyboarding is an important aspect of the project. It gives a clear development path/route indicating the elements required for every module. Technical content development research is then carried out to understand the requirements of the module at which point a script is created. When animating, the script could be adjusted depending on the time assigned for the particular content, skill level required and importance of content. Constant feedback from the relevant team members has been used as an input in this iterative development process.

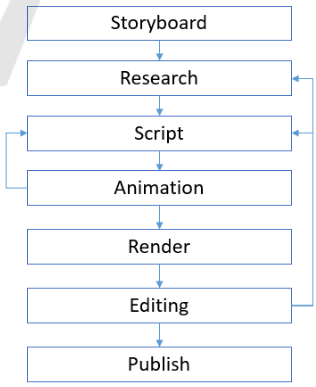

Figure 2: Animation and AR/VR Process.

The team decided to use a Formula Student Race Car (IME, 2017) as the centrepiece of the project. This car is developed by the engineering students at the Technical University of Sofia which has been designed (i.e. CAD) and physically manufactured.

This car model gave a wide range of different components to be used within AR/VR and animation. Context/environment for each part was assigned in AR/VR and animations to help the student understand the component and to give a more real-world experience.

Several software packages were used to achieve the required output including the Adobe suite (Photoshop, Illustrator, and InDesign) to create the storyboards, and graphics. For 3D content generation, SolidWorks was used to model the car, which was then imported into 3D Studio Max to start the animation process. The model was converted to polygonal data (low for AR/VR and high for animation). Appropriate textures were then applied to the model, and various animation methods were utilised to create the content, including camera and object movement (Figure 3).

The animation was then exported to KeyShot software for adding the appropriate materials for the animation before rendering. Adobe Premiere software was used for editing the animation (timing, text, sound, and effects). The research and storyboard was constantly referred to during this process. Two animations were created for each module to be integrated into the training package as part of AR/VR content.

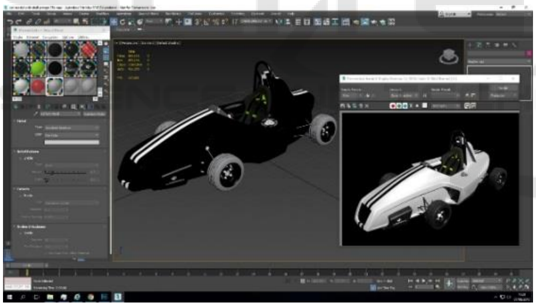

Figure 3: CAD modelling and rendering from an animation available at: https://www.youtube.com/watch?v=0TbrWxJebTE.

Unity was used to create interactive AR/VR applications with ARCore for building the AR experience. In this phase, multi-disciplinary knowledge and skills help to effectively create the content that would be visually rich to be used by students and industry to engage in the modules. Interactivity is key when creating an engaging experience. Not only should the user be able to look around the environment, but they should also be able to interact with components and complete objectives. A multi-disciplinary approach allows the effective and appropriate use of individual skills within software, programming and design.

The development of AR/VR and animation requires hardware considerations before the development phase. The requirements for the student/teacher for this project would be:

- VR headset
- Competency of modelling Solidworks or equivalent
- Design for manufacture experience, experience in TD details
- Some experience using AR and VR
- Mobile Phone (Android 7.0+)
- Powerful computer

2.1.1 Geometric Dimensioning and Tolerancing (GD and T) Case Study 1

GD and T is the use of symbols and standards designed and used by designers, engineers and manufacturers to describe a product and facilitate communication between users. Knowledge of creating a well-structured GD and T will improve communication from designers to engineers to manufactures including technical team for quality control.

TDs from the wheel component have been chosen to demonstrate requirements of standards for TDs. During the research phase of the animation, standards including BS, ISO and DIN were reviewed to meet the requirements.

Figure 4 shows the teaching of good practices of dimensioning in TDs. Here, students are shown how this could be solved and improved. Every detail of geometric dimensioning and tolerancing wasn't shown here but further requirements are added in the video training material through sound, images, text and video; including baseline dimensioning, line types, leaders, scale, methods to show rounded end shapes, fillets, tapers, chamfers, angles, dimensioning of screws and threads.

Well-designed and executed animations can improve the engagement and T&L experience. Therefore, colour theory and cinematography were always kept in mind when designing animations and related experiences. The rule of thirds was used to make the animations more dynamic while colour theory was used to create a memorable experience. Application of appropriate colour, font size, timing of text and how the information is communicated to the user has been planned for effective communication.

Figure 5 shows the use of paper size and how TDs can be scaled to cover the appropriate paper size for an effective layout. This section also covers the use of information in the title box and describes the use of coordinates to locate specific features in TDs. Fur-

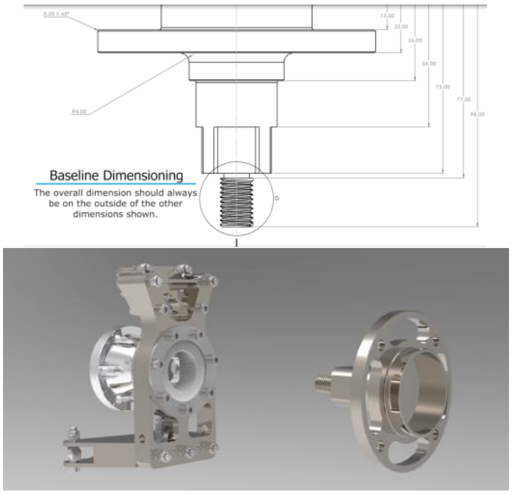

Figure 4: Dimensioning animation showing best practices.

ther animations were created for projection views, European "ISO E" (1st angle) and American ANSI "ISO A" (3rd angle) projection standard.

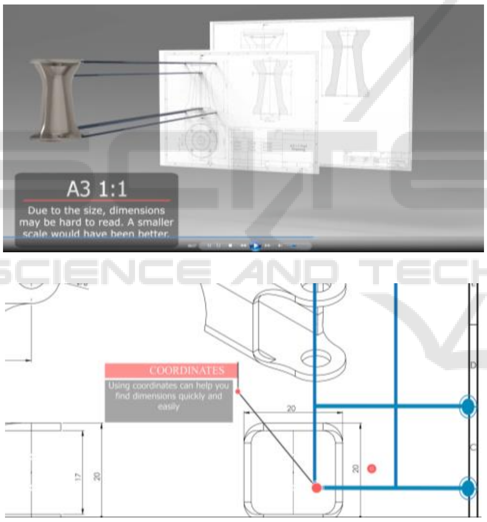

Figure 5: Paper size and scale.

2.2 AR/VR Case Study: Tolerances in Technical Drawings

VR has been growing in popularity especially over the last few years. With the release of the Oculus Rift and the HTC vive, many more people have been exposed to VR with it being implemented into education and industry. Creating a completely new virtual environment leads to endless possibilities. With its use in the medical industry where students can be placed into an operating theatre to do a certain procedure, to the military where they can train for dangerous situations, virtual reality has paved the path for a new way to learn.

Augmented reality is not a new concept. A virtual object would be superimposed over a live view from the device's camera. Tracking, animation, and depth perception among many other things have improved the quality of augmented reality. The development of technologies such as the Microsoft HoloLens, powerful integrations of tablets and mobile phones for augmented reality application has meant that virtual objects are more realistic within the environment. It has allowed for more interaction between the object and the user. The requirements for using basic augmented reality may include just a mobile phone. A user would be able to view virtual objects easily. However, for improved functionality, more advanced software and hardware may be required. The use of ARCore can only work with newer mobile phones that have Android 7.0. ARKit, or can be used for Apple devices if they are iOS 11.0 or later. These tools enable developers to add advanced functionality and ease of use to their AR application. Some AR applications require a certain code to be read which could be a QR code or a unique image. ARCore would allow the user to scan the surface on which a model could be placed.

The technology and accessibility of AR/VR have improved drastically while the cost has decreased. These technologies are easier for students and staff due to the increase in functionality and should be further developed so as to improve the quality of work that is produced.

2.2.1 AR/VR in Tolerancing Case Study 2

Several AR applications have been developed for improving student understanding of tolerances. Tolerancing is defined as an extension of dimensioning of TDs. It specifies a range of accuracy for the shape, size, and position of components so that when they are manufactured all parts can fit and function properly when assembled. Currently, tolerances covering form (straightness, flatness, circularity and cylindricity), orientation (angularity, perpendicularity and parallelism), location (position and concentricity) and runout (symmetry, circular runout and total runout) have been completed. Figure 6 shows angularity tolerances in AR with surface parameters. Also shown is an AR game where the car can be driven using the onscreen controls on a floor defined in AR environment on Android.

The vehicle has been rendered with panoramic and stereoscopic cameras to be viewed in a Samsung Gear

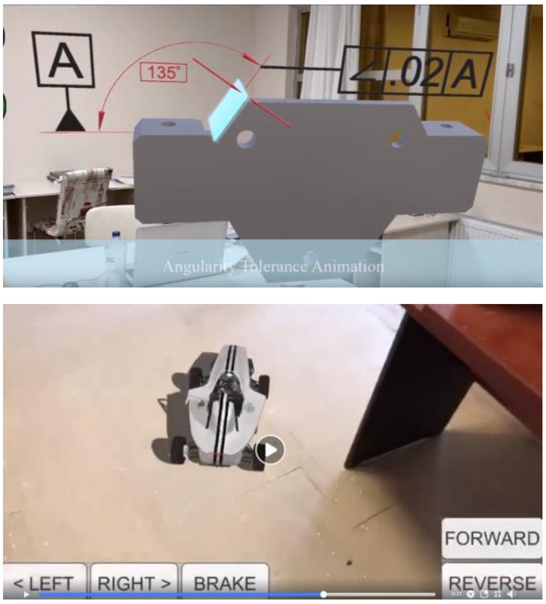

Figure 6: AR Applications.

VR. The VR device is a more user-friendly experience and is more comfortable than the Google Cardboard. This VR device has better optics with a decent field of view and good head tracking due to the sensors. The controller can be used to navigate and interact with the scene. The disadvantage of this device is that it only works with the latest Samsung phones and has a relatively low level of immersion which would be good enough for this type of T&L activity. VR development includes the creation of 3d content and the programming of interaction. Depending on the desired level of both realism and interactivity, either high-level programming languages may be used; but these required extensive knowledge of programming or game engines such as Unity, Unreal or similar.

Unity was chosen due to its popularity for video game development. Its flexible graphics engine offers a wide range of resources. Projects can be exported to both mobile (Android, IOS) and desktop operating systems.

3 DISCUSSION AND CONCLUSIONS

The use of AR/VR in education is promising and useful in T and L. A multi-disciplinary approach is crucial. This approach brings a different perspective to T&L methods and content development which results in a better experience for students. Individuals from different backgrounds (engineering and design) can offer their expertise in the content development and application of software. Running international projects require the use of methods and tools to facilitate the communication of content. Storyboarding helps to alleviate this problem. The research and material development can be communicated well through storyboarding and can give a visual representation of the project. Changes and feedback can be easily represented into the storyboard due to the development process not being linear. The process of creating the AR/VR content is time-consuming if not developed using effective design and visualisation methods. Students are more accustomed to using 3D games with a high level of visual detail where a substantial amount of investment may have been available for commercial projects. Therefore, a careful consideration of end-user requirements and expectations is needed to engage students. Interactivity is essential when creating AR/VR content. While animations may not have any interactivity, it would provide a visually pleasing platform to communicate the information. However, large file sizes may limit its use as it would require high internet speeds to download the animation content which could be hosted on a website, however, many educational institutions have fast and free internet available. Software use for AR/VR traditionally requires low-polygon modelling techniques but on multidisciplinary projects, teams normally use their daily-use software to generate 3D content which may limit the level of interactivity as optimisation between software would reduce performance and increase file size of any developed media. The use of VR hardware can cause

Figure 7: Testing of AR/VR content.

health issues such as motion sickness and fatigue. Several headsets and mobile phones (Android 7.0+) would also be required to give each student the experience. For this reason, several platforms have been developed to ensure that all students would have an experience with each T&L method. Projecting the view of the VR user onto a screen may also be a solution to this problem. Positive feedback was received from the initial pilot study where selected students used the developed AR/VR and animation content. Further work includes the development of an AR/VR application to other operating systems to reach a wider market. Students would be able to choose a method tailored to their needs. These didactic resources should be easy to use and must be developed with a good level of educational usefulness.

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