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The Application of Virtual Tools in Teaching Dynamics in Engineering

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Abstract: Student success in Dynamics, a core subject in Mechanical Engineering courses, requires conceptual understanding of complex systems. Dynamics covers motion of particles and objects, and usually relies on 2 dimensional images and/or written descriptions to explain models and problems. This paper explores the value of visual representation of Dynamics problems with an assumption that it would facilitate student understanding of the content. Two approaches were applied for representation of Dynamics problems with the premise of Bring Your Own Device (BYOD): used with augmented reality and web animation activities. Responses from students and reflection from lecturers were collected and reviewed in relation to the applicability and the ease of use. Students and lecturers both appreciated the benefits of visual representation of complex models, and the possibility of manipulating with virtual objects. Lecturers also appreciated the easy access and use of tools during the class.

Keywords: augmented reality; engineering education; problem solving; virtual tools; visualisation

1 INTRODUCTION

Animated digital models enable the visual representation of systems easily accessible to different audiences, including learners new to a subject area. In engineering, complex problems with data and formulas can be visually presented in an animated 3D models, showing dimensions, forces, and movement. These types of animations are often used when engineers are sharing details about complex models with colleagues or clients, but are not commonly used with students. Likewise, augmented reality (AR) has been used in the engineering field, but not as commonly with students. AR overlays virtual objects, static or moving, on the real world and may utilise a range of advanced hardware and software systems [1] such as smartphones or specialised headsets. Use of digital representation like virtual reality (VR) and AR in engineering include engineering drawing and machine elements, electrical and civil examples [2-9]. AR has also been utilised in other fields including of higher education [10-15].

The need to better visualise technical models strongly relates to technical subjects such as engineering, particularly where real-life demonstration may not be possible: for example, a satellite in space. Driven by the commitment for improvement in student engagement and outcomes, in this paper different visualisation methods were trialled to ascertain their suitability and effectiveness.

Engineering Dynamics is a core subject in Mechanical Engineering undergraduate courses and often has students struggling to comprehend an array of complex systems that relate to motion of objects. With digital tools and online content offerings a standard in education today, the next step of inclusion of animated visualisations is a logical one. For example, with over 70% of students at Charles Darwin University (CDU) learning in a blended or fully online mode, it is important for suitable online tools to optimise student learning.

So far, most of the problems in Dynamics we represented through textbooks as 2 dimensional images. With this preliminary research, appropriateness of development and use of own digital representations of problems in Dynamics is explored as well as their use in classroom environment.

1.1 Visualisation Tools

With blended learning approaches leveraging online applications and innovative approaches, visualisation tools have gained increasing popularity to support student learning. Animated models have been shown to offer opportunity to challenge misconceptions [16] and see complex systems at work. It is also contemporary engineering work practice to utilise visualisations for project planning and presentations, and this practice should be modelled with students as part of authentic learning and assessment practices. In this era of digital information and Internet of Things prevalence, there is a growing significance of animation as a link between virtual and physical world [17].

AR has achieved a sufficient level of development for it to be considered as a relatively common application in many aspects of higher education as well as research [18-20]. However, the cost of development can be a significant challenge. Nevertheless, in recent years technology enhances and better accessibility has made it more achievable to create models and introduce them it into teaching environments. There are also requirements for enabling visualisations visibility on different devices with possibly minimising download or streaming requirements. Despite these challenges, there are undeniable benefits of implementing digital visualisation techniques [13, 21]. Being able to view a problem or model in motion, at different angles and take a closer look at specific components offers potential for better understanding and processing into cognitive schema, and improvement of the transfer of learning [22].

While developing effective visualisations for learning one should be aware of to the limitation of cognitive architecture, taking into consideration level of learner expertise. Moreover, visualisation needs to be constructed to maximise learning, and minimise confusion by incorporating principles of good multimedia design, using contemporary learning practice, approaches and research [23-25]. This includes presenting information in a scaffolded way and allowing for accessibility. Further preferences on device/hardware use need to be accommodated: i.e., while some students prefer to use smaller handheld devices for learning, others prefer a desktop computer.

This paper explains visualisation tools used, and the specific educational approaches explored, at Charles Darwin University in Australia and University North in Croatia. Taking into consideration lecturer reflection and students' attitudes, this paper also discusses the benefits of visualisation tools and future opportunities.

Part of this research explored the value proposition for developing different types of visualisations. That is, we wanted to look at the time and cost involved, and weigh this against the benefit that would be received by a learner.

The visualisation tools included animated models accessed directly online and others via AR. The different approaches were trialled with students in 2 different locations: Australia and Croatia, and explored benefits including engagement, outcomes, and timeliness, as well as accessibility and re-usability of different objects. Each of the models gave a digital representation of the changes in time and space and allowed learner interactivity with the model being able to be viewed from different angles.

2 MODEL DEVELOPMENT

The selection and development of three models for trialling the usability of visualisation were based on the following requirements:

- Selected problems represent typical Dynamics examples (i.e., curvilinear motion of particles or rigid bodies),
- Problems (with copyright permission) are taken from Textbook used in class: J. L. Meriam, L. G. Kraige: Dynamics (Seventh edition) [26]

Two approaches were then selected for exploration with the models: application of an animated digital model that opened as a web page; and an AR model that required the use of mobile phone to open and manipulate with models. Both approaches were offered to students and presented in class (for face-to-face delivery) as well as made available (with accompanying explanations) on Learning Management Systems for external students.

2.1 Development of Digital Visualisations

Development of the visualisations used 3D modelling and open-source web and AR applications was based on the following assumptions and requirements accommodated in the development of the visualisations:

Assumptions:

- The platform for AR will have no cost to students.
- On campus students will have access to smart phones during classes to access the AR
- Online (and on campus) students will be able to access the same 3D models through a web browser.

Functional requirements:

- Where necessary the application will clearly demonstrate angles and motion in the exercises
- The application will engage students through attractive models and AR functionality
- Users will be able to scan a target or QR code using a free application.

Usability requirements:

- Users can scan a target and link with a 3D model
- Users can interact with the model, looking at different angles and rotating the model.

Accessibility requirements:

- Navigation:
    - No established patterns
    - Work for everyone; keyboard, mouse and touchscreens should all work.
- Clarity:
    - Too much motion may be confusing
    - Complex background may distract from the model
    - Insufficient contrast may make it difficult to some users to identify key features
- Users can manipulate and navigate models using keyboard, mouse or touch screen controls.
- The exception to this is AR where models must be navigated using location and orientation controls to maintain the AR illusion
- Users should be able to pause animation or motion to avoid confusion
- Models should have a strong contrast with their background. Text should target an AA rating according to WCAG 2.0 guidelines 1.4.3 where possible.
- Attached text should explain key details of the models

The development process used an agile approach, with iterations tested with users and feedback used to direct improvements in design and functionality.

2.2 Animated Digital Models Accessed Directly Online

Three problem examples were prepared as online animated models.

Example 1: Model of an airplane flying on a circular path. This first example is related to curvilinear motion of particles [26]. The aim of this exercise is to present Free Body Diagram and the use of normal and tangential coordinate system to calculate the force value. Students were asked to calculate the force exerted on the pilot at particular points. This example contained animation without accompanying problem text (Fig.1).

Example 2: Model of spacecraft (satellite) rotating about its z-axis. This example is related to rotation of rigid body [26]. Students were supposed to determine the angular velocity of the body after the panels are rotated to a particular position. The aim of animation is to show students how the change of geometry (in this case rotation of the solar panels) can influence mass moment of inertia (and rotational speed).

In this example problem text was placed on a page with the model (Fig. 2).

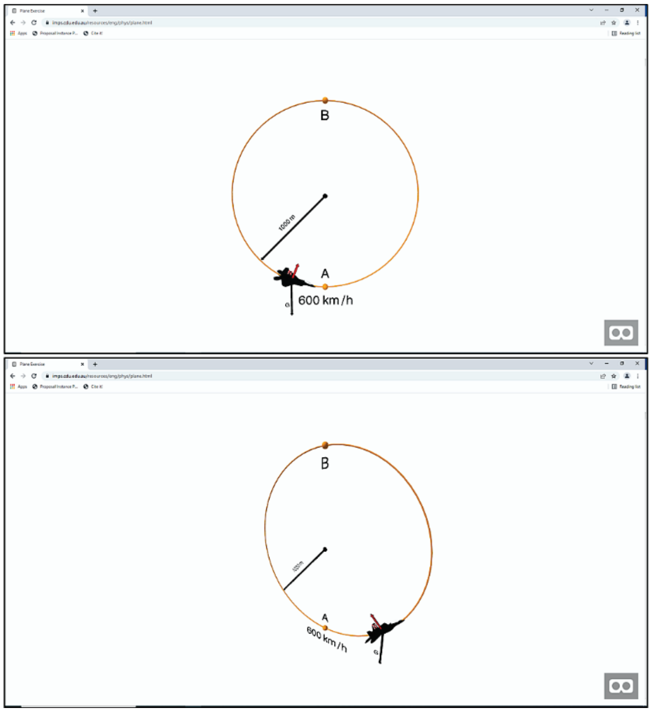

Figure 1 Curvilinear motion of the airplane and forces acting presented in online animation

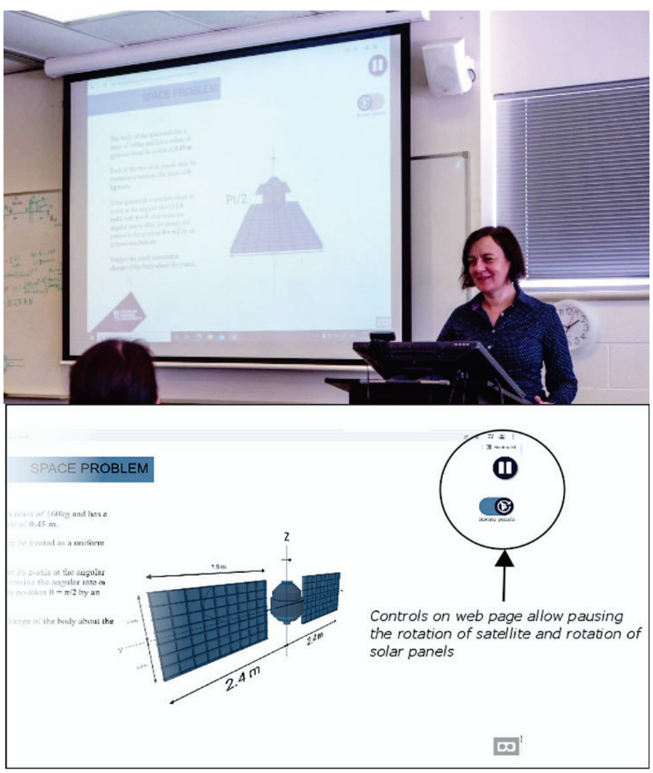

Figure 2 Conservation of Momentum example (use of the model in the classroom and controls on web model)

Example 3: Model of diver leaving a diving platform. This was another example related to dynamics of rigid body (impulse - momentum equations) [26]. The aim was to show students how the change of geometry influences the change of mass moment of inertia and how geometry of the complex bodies can be represented with more simple geometrical shapes (cylinder and sphere – Fig. 3). Students then estimate the angular velocity when the diver has assumed the tuck position (sphere shape).

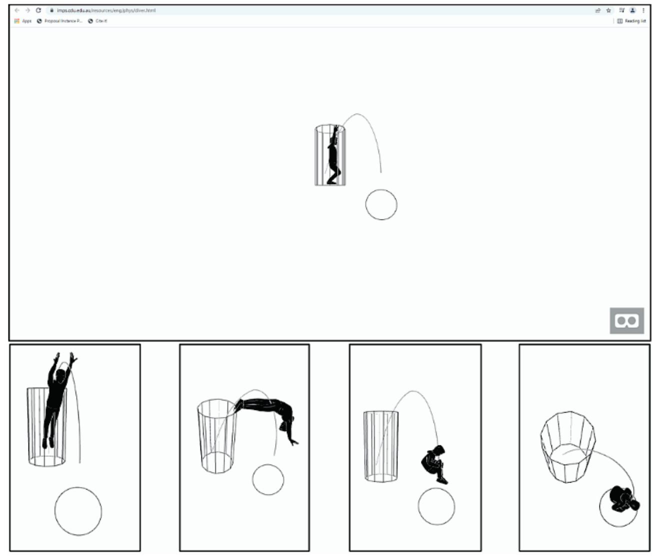

Figure 3 Second conservation of Momentum example

2.3 Augmented Reality

Examples 1 and 3 were also prepared as AR models that students could access from their mobile phones (Figs. 4 and 5) via QR code links. Printouts of the QR code were given to students during the class and published online for external students.

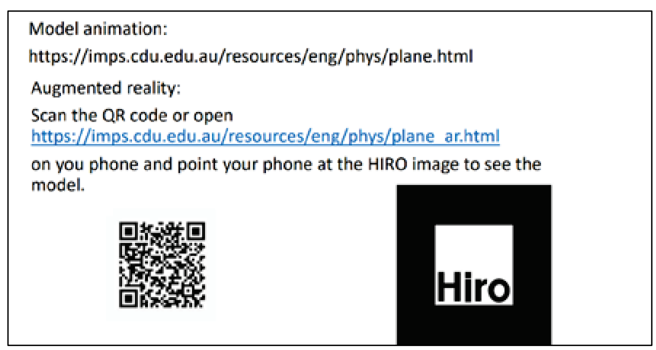
Model animation:
https://imps.cdu.edu.au/resources/eng/phys/plane.html
Augmented reality:
Scan the QR code or open
https://imps.cdu.edu.au/resources/eng/phys/plane_ar.html
on you phone and point your phone at the HIRO image to see the model.

Figure 4 QR code and links for web and AR plane model

3 EXPERIENCE REVIEW

3.1 Students' Attitude towards Used Models

Two groups of participants (with classes run by two lecturers) took part in the trial of animated digital models via webpage and AR; students studying engineering at Charles Darwin University, Australia and students studying engineering at University North, Varaždin, Croatia.

Students completed activities that used the models as part of classroom work with lecturers present. Also, students were free to choose and interact with the animated digital models at their own pace, to solve specific questions. Students were encouraged to view the models from different angles and manipulate them.

After the subject delivery, a short survey was conducted (at this stage only with internal students) to find out student's attitude towards the use of visualisation tools as well as to gauge their preferences regarding the use of web pages/AR models, as well as if there are any suggestions for improvements or innovative ideas.

While both student groups interacted with the models in class, the analysis of the survey was only based on 19 responses from students of University North, Croatia. This was due to the very small number of responses from Charles Darwin University students.

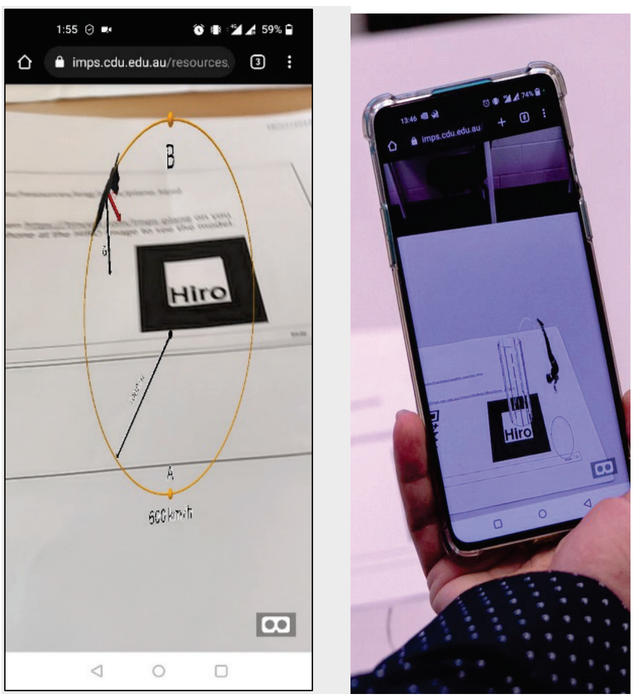

Figure 5 Augmented reality models opened on a mobile phone

The survey consisted of 6 questions:

1. How useful do you find digital models and animations to visualise Dynamics problems?
2. Did the use of digital models and animations help you to better understand the mechanics principles and solve problems?
3. To what extent you agree with this statement: "The implementation of augmented reality could help me feel more engaged in my study"?
4. If you had to choose between viewing an animated digital model either on a web page or via an augmented reality layered image, which would you choose?
5. Does the use of digital models and augmented reality encourage critical thinking and devising what-if scenarios?
6. Please give your thoughts and suggestions about use of digital models and augmented reality in Engineering.

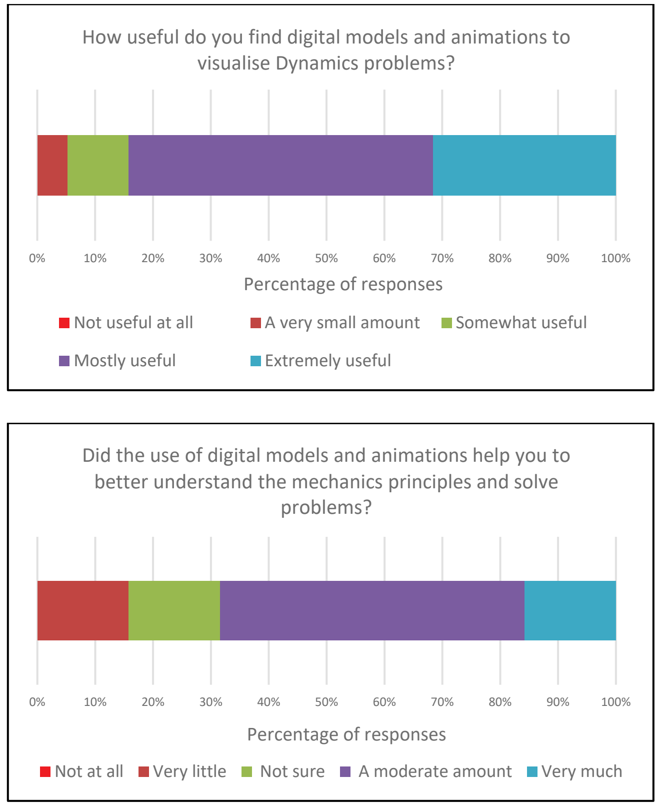

Figure 6 Students' responses related to usefulness of digital models (Survey questions 1 and 2)

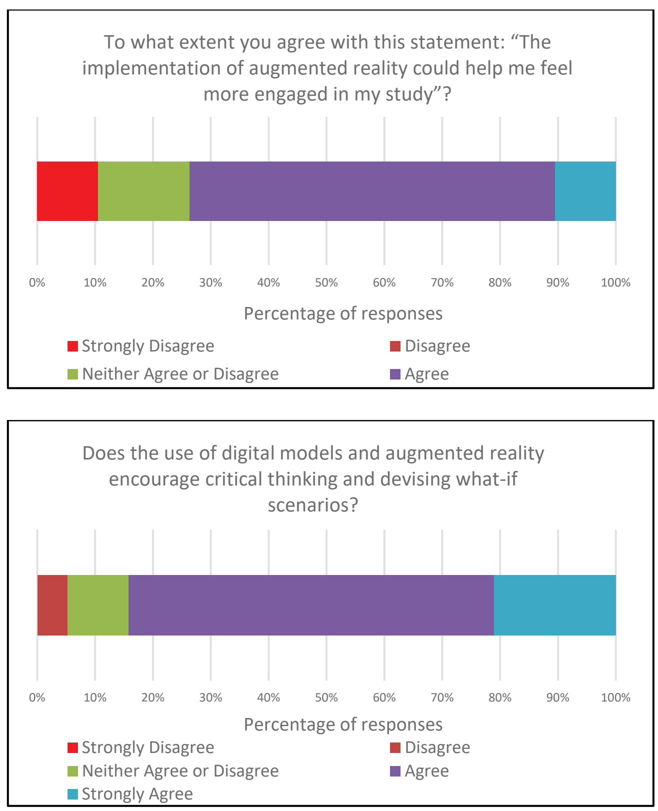

Figure 7 Students' agreement related to engagement and critical thinking (Survey questions 3 and 5)

Student's attitude to the visualisation models from the survey questions is presented in Figs. 6-8. Based on the analysis it is evident that student's attitude toward these innovative approaches and refreshment in content delivery is positive, and majority of students agree that these approaches could encourage critical thinking and engagement, as well as improve understanding of complex problems. Also, in their answers, students tend to appreciate AR examples more than web-based representation of the problems. However, it is important to take into consideration low survey sample size.

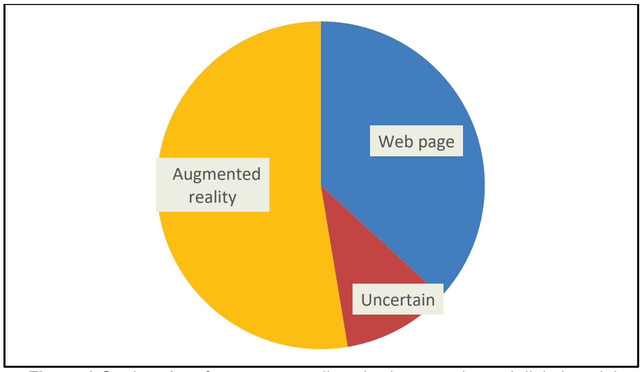

Figure 8 Students' preferences regarding viewing an animated digital model (Survey question 4)

3.2 Lecturers' View and Discussion

From the lecturers' perspective these tools did allow better presentation of dynamics problems, allowing observing forces or movement of segments in 3D space. For teaching face to face (in classrooms) web pages proved to be more efficient as opening and manipulating with 3D object was possible in a quick way with added text and all details that were easy to present (Fig. 2).

Introducing AR models during class time did provide full engagement of students, however setting up devices and opening models on their mobile phones took some of their time and attention away from the actual Dynamics problems. This time impost would be reduced with future use, as students gain familiarity with the use of the tools and how to access the models.

Further there was a significant development time for each of the examples. While there is a value in reuse of visualisations, the initial build of a small suite of visualisation models required significant time (and development cost). Investment in improvements that lead to greater engagement and learning success are worth pursuing, but the number of examples developed would need to be rationalised against budget, timeframes and priorities of other learning approach improvements. However, with continuing advancement with technology there could be modelling applications that make development much quicker and easier.

4 CONCLUSION

The aim of this case study was to develop digital representation of a few typical examples of Dynamics problems and observe their appropriateness in teaching and learning. The trial with 3 different Dynamics models included evaluating efficiency of their development, their effectives in classroom as well as lecturer and students' attitudes toward them. While 2 different groups of students were involved in the study, only the results from one of the groups was of sufficient number to include in the analysis.

The scope of this study was primarily with students studying in internal mode (models were used in classroom). For the future research it would be useful to review students' preferences (web or AR) for purely online deliveries and/or for individual study.

This study shows the positive impact of digital visualisations and virtual tools on student engagement and learning. While only a relatively small study it adds to a larger body of work being done with online tools and AR. The potential and options for AR and visualisations in education are rapidly involving and look play an important role in future approaches. The use of AR and web models for visualisations also prepares students for work beyond their studies by using relevant contemporary technologies utilised in industry.

Acknowledgment

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5 REFERENCES

[1] Ko, S. H. & Rogers, J. (2021). Functional Materials and Devices for XR (VR/AR/MR) Applications. *Advanced Functional Materials, 31*(39), 2106546. https://doi.org/10.1002/adfm.202106546

[2] Haspinger, F. (2022). *How Augmented Reality Is Changing Engineering*. IEN Europe. Retrieved from https://www.ien.eu/article/how-augmented-reality-is-changing-engineering/

[3] Scaravetti, D. & François, R. (2021). Implementation of Augmented Reality in a Mechanical Engineering Training Context. *Computers, 10*(12), 163. https://doi.org/10.3390/computers10120163

[4] Gazzotti, S., Ferlay, F., Meunier, L., Viudes, P., Huc, K., Derkazarian, A., Friconneau, J-P., Peluso, B., & Martins, J-P. (2021). Virtual and Augmented Reality Use Cases for Fusion Design Engineering. *Fusion Engineering and Design*, 172, 112780. https://doi.org/10.1016/j.fusengdes.2021.112780

[5] Vlah, D., Čok, V., & Urbas, U. (2021). VR as a 3D Modelling Tool in Engineering Design Applications. *Applied Sciences, 11*(16), 7570. https://doi.org/10.3390/app11167570

[6] Ivanov, Pavlenko, I., Liaposhchenko, O., Gusak, O., & Pavlenko, V. (2019). Determination of contact points between workpiece and fixture elements as a tool for augmented reality in fixture design. *Wireless Networks*, *27*(3), 1657-1664. https://doi.org/10.1007/s11276-019-02026-2

[7] Ong, S. K., Yuan, M. L., & Nee, A. Y. C. (2008) Augmented reality applications in manufacturing: a survey, *International Journal of Production Research, 46*(10), 2707-2742. https://doi.org/10.1080/00207540601064773

[8] Opriş, I., Costinaş, S., Ionescu, C. S., & Nistoran, D. E. G. (2017). Towards augmented reality in power engineering. *The 10th International Symposium on Advanced Topics in Electrical Engineering (ATEE), 3*9-44. https://doi.org/10.1109/ATEE.2017.7905160

[9] Souza, E. (2019). *9 Augmented Reality Technologies for Architecture and Construction.* ArchDaily. https://www.archdaily.com/914501/9-augmented-reality-technologies-for-architecture-and-construction

[10] Aveleyra, E. E., Racero, D. A., & Toba, G. G. (2018). The Didactic Potential of AR in Teaching Physics. *2018 IEEE World Engineering Education Conference (EDUNINE),* 1-3. https://doi.org/10.1109/EDUNINE.2018.8451000

[11] Sırakaya, M. & Sırakaya, D.A. (2018). Trends in Educational Augmented Reality Studies: A Systematic Review. *Malaysian Online Journal of Educational Technology*, 6, 60-74. https://doi.org/10.17220/mojet.2018.02.005

[12] Onime, C., Uhomoibhi, J., Austin, R., & McNair, V. (2017). Smart technologies and applications for visualisation in higher science and Engineering education: Issues of knowledge integration and virtual experimentation. *2017 IEEE Global Engineering Education Conference (EDUCON)*, 1070-1077. https://doi.org/10.1109/EDUCON.2017.7942981

[13] Rizov, T. & Rizova, E. (2015). Augmented reality as a teaching tool in higher education. *International Journal of Cognitive Research in Science, Engineering & Education (IJCRSEE), 3*(1), 7-16. https://doi.org/10.23947/2334-8496-2015-3-1-7-15

[14] Krüger, J.M., Palzer, K., & Bodemer, D. (2022). Learning with augmented reality: Impact of dimensionality and spatial abilities, *Computers and Education Open*, 3, 100065, https://doi.org/10.1016/j.caeo.2021.100065

[15] Yoo, H., Jang, J., Oh, H., & Park, I. (2022). The potentials and trends of holography in education: A scoping review, *Computers & Education*, 186, 104533, https://doi.org/10.1016/j.compedu.2022.104533

[16] Berthoud, L. & Walsh, J. (2020). Using visualisations to develop skills in astrodynamics, *European Journal of Engineering Education, 45*(6), 900-916. https://doi.org/10.1080/03043797.2020.1742664

[17] Digital Engineering (2022, February 21). The New Age of Engineering Animation. Retrieved from https://www.digitalengineering247.com/article/the-new-age-of-engineering-animation/engineering-resource-center

[18] Abulrub, A.-H. G., Attridge, A., & Williams, M. A. (2011). Virtual Reality in Engineering Education: The Future of Creative Learning. *International Journal of Emerging Technologies in Learning (iJET), 6*(4), 4-11. https://doi.org/10.3991/ijet.v6i4.1766

[19] Ariso. (2017). *Augmented reality: reflections on its contribution to knowledge formation*. De Gruyter. https://doi.org/10.1515/9783110497656

[20] Kaur, D.P. Mantri, & A., Horan, B. (2020). Enhancing student motivation with use of augmented reality for interactive learning in engineering education. *Procedia Computer Science*, 172, 881-885. https://doi.org/10.1016/j.procs.2020.05.127

[21] Jaziar Radianti, J., Majchrzak, T. A., Fromm, J., & Wohlgenannt, I. (2020). A systematic review of immersive virtual reality applications for higher education: Design elements, lessons learned, and research agenda. *Computers & Education*, 147, 103778. https://doi.org/10.1016/j.compedu.2019.103778

[22] Cree, V., & Macaulay, C. (2000). *Transfer of learning in professional and vocational education*. Routledge. https://doi.org/10.4324/9780203134511

[23] Khalil, M. K., Paas, F., Johnson, T. E., & Payer, A. F. (2005). Interactive and dynamic visualizations in teaching and learning of anatomy: A cognitive load perspective. *Anat Rec B New Anat*, *286B*(1), 8-14. https://doi.org/10.1002/ar.b.20077

[24] Forde, C. & Obrien, A. (2022). A Literature Review of Barriers and Opportunities Presented by Digitally Enhanced Practical Skill Teaching and Learning in Health Science Education. *Medical Education Online, 27*(1), https://doi.org/10.1080/10872981.2022.2068210

[25] Rudolph, M. (2017). Cognitive Theory of Multimedia Learning. *Journal of Online Higher Education, 1*(2)

[26] Meriam, J. L. & Kraige, L. G. (2013). *Engineering Mechanics, Volume 2, Dynamics (Seventh edition)*, Jhon Wiley & Sons.

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