TPACK INSTRUCTIONAL DESIGN MODEL IN VIRTUAL REALITY FOR DEEPER LEARNING IN SCIENCE AND HIGHER EDUCATION: FROM “APATHY” TO “EMPATHY”

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Abstract

Deeper learning is associated with increased retention, intrinsic motivation, the durability of knowledge and a solid understanding of the underlying principles of studied phenomena. It advocates learning beyond rote content knowledge accumulation using student-centred instructional strategies such as case-based learning, simulations, collaborative learning, self-directed learning and learning for transfer. Science education in Higher Education is crucial for the social, scientific and economic progress of both advanced and developing countries. Desktop Virtual Reality is a technological medium that can be utilized to facilitate deep learning instructional strategies in science education. Desktop Virtual Reality features pervasive, computer-generated 3D virtual immersive environments where users interact through digital agents or avatars. In this paper, we explore if three learning scenarios from the fields of Biology, Earth Sciences (Geology) and Physics are updating the traditional transfer of knowledge. Passive, teacher-centred approaches often cause a sentiment of “apathy” to students while interactive student-centred approaches for Deeper Learning in Virtual Reality environments evoke feelings of “empathy”. More specific, we inquire to what extent does the TPACK instructional design model in Virtual Reality support Deeper Learning. Results indicate that academic teachers were able to enrich their teaching paradigm by integrating learning activities in virtual reality that evoke students’ interest, motivation and autonomy. Moreover, and after discussing the research results, we propose recommendations that instructional designers need to take in consideration to promote Deeper Learning in blended distance e-learning settings using social VR. The TPACK Learning Scenarios were developed in Palestinian Higher Education Institutes (HEIs) in the context of the capacity building Erasmus+ KA2 project “Virtual Reality as an Innovative and Immersive Tool for HEIs in Palestine (TESLA)”. Keywords: virtual reality, deeper learning, instructional design, science education, STEM, higher education

1 INTRODUCTION

Science education in Higher Education is crucial for the social, scientific and economic progress of both advanced and developing countries [1]. Despite high unemployment rates in many countries, there are notable records of persisting skills’ shortage in Science, Technology, Engineering and Mathematics (STEM) fields [2]. As a result, several initiatives are launched at international, national and institutional policy levels to encourage STEM careers and increase qualifications’ supply in the labour market. In Higher Education, policies depend on the quality of teaching and learning practices as curricula are live experiences [3]. Passive teacher-centred approaches relying on knowledge transmission often diminish motivation and interest in science [4] up to the point of ‘apathy’. Low levels of affective involvement have in turn a detrimental effect on students’ self-efficacy to identify themselves with STEM professions. In contrast, active, constructivist student-centred approaches have the potential to impact positively students’ engagement and achievement [5]. High teaching quality leads to meaningful learning and in depth understanding of the studied topic [6]. One model that can guide technology-enhanced instructional design is Technological Pedagogical Content Knowledge (TPACK) [7]. Desktop Virtual Reality (VR) is a technological medium that can be utilized to facilitate Deeper Learning instructional strategies in science education. Especially in STEM subjects, immersion in VR environments helps
students, particularly women, debunk stereotypes, build empathy with positive role-models and aspire to become scientists [8]. The current study seeks to inquire to what extend the application of the TPACK instructional design model in Virtual Reality supports Deeper Learning in Higher Education settings.

2 CONCEPTUAL AND THEORETICAL FRAMEWORK

2.1 Deeper Learning

Deeper learning is associated with increased retention, intrinsic motivation, the durability of knowledge and a solid understanding of the underlying principles of studied concepts and phenomena [9]. It advocates learning beyond rote content knowledge accumulation that focuses on six competencies: (i) mastery of core academic content; (ii) critical thinking and complex problem solving skills; (iii) collaboration; (iv) effective communication; (v) life-long learning; (vi) academic mindset development. To facilitate Deeper Learning competencies, faculty members are advised to apply active, student-centred teaching and learning strategies that are presented in Table 1 [9], [10].

Table 1. Learning Strategies for Deeper Learning

<table>
<thead>
<tr>
<th>Learning Strategy</th>
<th>Purpose &amp; Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Case-based learning</td>
<td>Study of real-world topics/problems and projects that are relevant to the learners for abstract concept and skill mastery</td>
</tr>
<tr>
<td>2 Multiple representations</td>
<td>Alternative demonstrations of complex of concepts and ideas</td>
</tr>
<tr>
<td>3 Collaborative learning</td>
<td>Group analysis of complex situations utilizing individual members’ strengths</td>
</tr>
<tr>
<td>4 Apprenticeships</td>
<td>Mastery through trial and error, guidance and mentoring</td>
</tr>
<tr>
<td>5 Self-directed, life-wide, open-ended learning</td>
<td>Free, informal subject exploration and engagement according to students’ interests and values</td>
</tr>
<tr>
<td>6 Learning for transfer</td>
<td>Knowledge &amp; competences application outside of the classroom</td>
</tr>
<tr>
<td>7 Interdisciplinary studies</td>
<td>Exploration of richer world perspectives though links across multiple scientific fields</td>
</tr>
<tr>
<td>8 Personalized learning</td>
<td>Content &amp; learning adaptation to accommodate student needs</td>
</tr>
<tr>
<td>9 Connected learning</td>
<td>Bridging knowledge with real-world challenges and chances outside traditional, formal education settings</td>
</tr>
<tr>
<td>10 Diagnostic assessments</td>
<td>Student needs detection to ensure learning alignment with their aspirations, needs and culture’s differentiations</td>
</tr>
</tbody>
</table>

2.2 Virtual Reality

Desktop Virtual Reality (VR) features pervasive, computer-generated 3D virtual immersive environments where users interact through digital agents or avatars. Social VR environments such as virtual worlds offer a series of affordances for learning including enhanced spatial knowledge representation through contextualized, experiential learning [11]. As a result, learning experiences in virtual spaces support empathy creation [12] and embodied cognition [13] that lead to episodic, autobiographical memory of events within specific spatiotemporal context rather than semantic, abstract memory [14]. VR can be used both for formal and informal interventions [15] to support declarative and procedural knowledge [16]. Educational programmes and HE courses can take place exclusively remotely in virtual worlds for distance learning [17] or be combined with face-to-face teaching [18]. Pedagogical scenarios in Virtual Reality can enhance both classroom instruction [19] and distance education [20] in higher education and vocational education [21].

2.3 TPACK Instructional Design Model

The TPACK Model features a complex interplay of three primary forms of knowledge: Content Knowledge (CK), Pedagogy Knowledge (PK), and Technology Knowledge (TK) [22]. To achieve high quality of learning in a VR environment, learners’ knowledge about the subject matter (CK), and
knowledge about specific ways of thinking and acting with VR tools and resources (TK) need to be coupled with the pedagogical understanding why learners learn, what they learn and how they can use it (PK). The TPACK Instructional Design Model in Virtual Reality adds a critical thinking component in teaching by specifying the basic elements of the pedagogy, the content, the technology and their combinations, within a layered, multifaceted, multi-factorial approach that emphasizes “why” and “how” beyond “what” [23]. Knowledge of what makes concepts difficult or easy to learn and how technological affordances can help teachers readdress some of the difficulties that students face and knowledge of how VR technology can be exploited to construct new epistemologies or enhance old ones [22]. Effective application of the TPACK model requires developing sensitivity to the dynamic, transactional relationship between these components of knowledge situated in unique contexts.

3 METHODOLOGY

The current study addresses the following research question: Does the instructional design of a virtual world support Deeper Learning in Higher Education? More specific, we explore if the instructional design of three virtual learning scenarios following the TPACK model support Deeper Learning. It employs a qualitative research approach using content analysis of all design documents and transcripts of communications as a basis of inference and explanation [24]. Examining the afore-mentioned ten criteria for Deeper Learning, we code and categorize systematically data.

Three learning scenarios were developed in the fields of Biology, Earth Sciences (Geology) and Physics in the free open source virtual worlds’ platform OpenSimulator. The learning scenarios were developed in Palestinian Higher Education Institutes (HEIs) in the context of the capacity building Erasmus+ KA2 project “Virtual Reality as an Innovative and Immersive Tool for HEIs in Palestine” (TESLA).

4 RESULTS

The analysis of all three learning scenarios is tabulated in Table 2.

<table>
<thead>
<tr>
<th>Learning Scenario</th>
<th>Subject</th>
<th>Learning Activities in VR</th>
<th>Deeper Learning Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Topography</td>
<td>Geology</td>
<td>Visualization, Exploration, Experience, Group Discussion, Games</td>
<td>1, 2, 3, 5, 6, 9</td>
</tr>
<tr>
<td>DNA</td>
<td>Biology</td>
<td>Exploration, Simulation, Group Discussion, Problem-based learning</td>
<td>1, 2, 3, 4, 5, 6, 8</td>
</tr>
<tr>
<td>Newton’s Laws</td>
<td>Physics</td>
<td>Exploration, Simulation, Game-based learning</td>
<td>1, 2, 4, 5, 6, 8</td>
</tr>
</tbody>
</table>

4.1 Scenario 1: Topography of Jericho and Dead Sea

The general purpose of the scenario is to educate students about topography, earth’s surface, and the impact of human activities on the environment. The learning outcomes are to understand the topography and calculate elevation of the area below the mean sea level, to evaluate the problem of Dead Sea receding, to analyze the hydrological cycle in the area, and to synthesize optimal solutions and a strategic plan.

The philosophy of this scenario, developed by the Palestine Polytechnic University and the Arab American University in Palestine, is infused from Critical Dialectic Interest [25]. Students will extend the notion of “understanding” a situation to forming a “critical consciousness” and to “action” in order to solve critical presented problems, aim for liberation and release from such situations targeting in environmental phenomena and changes [26].

It applies activity-based and authentic learning approaches. Activity learning enhances students’ engagement by delivering powerful new experiences they may not have encountered before by using
the VR to present the reality of the topography surface and to highlight the problems in the area. In addition, the scenario sparks new interest in the subject matter, providing a shared experience for better classroom discussion, and improve overall engagement by sharing knowledge representations, theories and calculations. Moreover, the scenario provides unique and fresh learning moments that attract students as they actively explore and exercise their curiosity. So, it provides opportunities for the students to experience typically boring or low appealing geographic and topographic subjects in an innovative way. Authentic learning is intended to help students value the genuine subject importance and relevancy, which may lead to higher motivation and engagement in finding the solution for topographic and geologic problems in the study area, ensuring also open-ended and self-directed learning. Authentic and multi-sensory VR experiences make the subject area become alive, especially in geographic and geological topics, were reality can help the student to understand and imagine the involved topics.

In the scenario, the activities present analytical problems and encourage the student to suggest solutions by calculating and planning geometric and mathematical concepts and values. Also short games were set to motivate the student to interact and collaborate.

4.2 Scenario 2: Crime scene investigation & DNA Technology

In this scenario, students learn how DNA analysis is changing the fight against crime. Students have to solve problems around a crime to discover the offender. Initially they explore the use of DNA fingerprinting in criminal investigations. They have to follow a problem-solving process of defining the problem, gathered information/data, organize and analyze it, synthesize evidence so as to reach a solution. Then they have to present this solution and propose ways of facing similar problems/crimes.

This course, developed at Al-Istiqlal University, includes topics in forensic DNA profiling, sample collection, DNA extraction, DNA quantization and amplification. The process of DNA analysis places emphasis on PCR technology. After participating in the scenario, students will able to:

- understand the scientific concepts related to biological forensic evidence;
- deal with the crime scene and identifying its components and how to maintain it properly;
- explore criminal evidence in the scene, collect and analyze it in the lab and read its results correctly;
- explain and interpret all DNA laboratory analyzes to solve a crime.

![Figure 1. Investigation of the crime scene (activity from the Forensic Biology scenario).](image)

Students assume the role of a forensics expert and arrive in an urban area to investigate a crime scene area where a father laments on this son’s dead body and asks for help. Students are urged to reflect in teams on the following questions and formulate a course of action: “How we can help the father solve the crime? Who is the perpetrator of this crime, and how we can determine him, to be brought to court? What evidence can be gathered from this crime scene? What can we do with this evidence after it is transferred to the forensic laboratory? After collecting relevant evidence, students’ avatars travel by car to the molecular biology forensic lab. There they learn to wear properly their avatar laboratory clothing and equipment and interact with the lab manager and technicians who perform the processes of DNA extraction and amplification analyze, evaluate and present the results in their quest to solve the crime.
4.3 Scenario 3: Carry my stuff!

The core aim of this scenario is the enhancement of students’ critical thinking while analyzing and solving problems using Newton’s laws of motion. The main learning outcomes of the scenario are to understand Newton’s first law by experience, to discover the relation between mass and acceleration by applying Newton’s second law, and to understand the relation between action and reaction forces (Newton’s third law).

The learning scenario, developed by Al-Quds Open University, is organized as a game with two levels. In the first level, student avatars arrive a wide quarter with many apartment buildings surrounded by a green land with the mission to carry their furniture (e.g. table, carpet, and cabinet) to his/her apartment located at third floor of the building. Unfortunately, the building’s elevator is not working, and the furniture is too heavy to be transported by climbing the stairs. Instead to proceed in the game they have to find a solution; exploring the surroundings and asking neighboring non-player characters (NPCs), they can discover a way to raise the furniture by using traditional methods, a pulley and a rope using appropriate mass.

In the second level, students proceed to a local business to procure the appropriate blocks to raise the furniture. To calculate their mass, they have to undertake a challenge of lifting a block hanging with a rope in the water bowl on a table using a pulley, a frictionless rope, and different masses. If they succeed, they get the blocks, move the furniture and celebrate with their friends.

5 DISCUSSION

The data analysis of three learning scenarios indicate that academic teachers were able to enrich their teaching paradigm by integrating learning activities in virtual reality that evoke students’ interest, engagement, motivation and autonomy towards Deeper Learning. More specific, all of them have incorporated at least six (6) related strategies. Four strategies were the most commonly coded and observed: (1) Case-based learning, (2) Multiple, varied representations, (5) Self-directed, life-wide, open-ended learning and (6) Learning for transfer. Indeed, all learning scenarios feature representations of authentic, realistic virtual worlds and simulated procedures that students are encouraged to experience and undertake so as to construct procedural knowledge transferable to the physical world. In these experiences they have the option to expand upon planned, structured activities and engage in peer discussions and related, informal activities. Instead of merely reading and seeing, students are immersed in virtual indoor and outdoor environments of varying scale of visualization to formulate hypotheses, experiment, discuss, reflect and learn by doing.

On the contrary, two strategies where totally absent, (7) Interdisciplinary studies and (10) Diagnostic assessments. Given the fact that these scenarios are developed within the constraints of specific academic courses, they lack the element of interdisciplinarity. Similarly, diagnostic assessment wasn’t foreseen however it can be part of the holistic course design.

Another notable element is that the scenarios were of increasing level of design and development complexity. The first scenario relied more on collaborative exploration of 3D environments and objects of high representational fidelity and the experience of geographical phenomena such as the receding of the Dead Sea. The second scenario featured a story-driven, problem-based simulation in multiple locations to immerse students in the role and tasks of a forensic scientist both in the field and in the laboratory. The third scenario was designed in the form of a structured realistic game with three levels with simulated activities linked to each of Newton’s laws. Finally, all of them were facilitated by NPCs in the role of guides that support the experience by providing information and tips. NPCs have playful forms such as Sir Isaac Newton and Mano, the dog detective. Hence, their design is suitable for dual, flexible implementation, either in a physical laboratory with the physical presence of teachers and students or remotely via synchronous e-learning.

6 IMPLICATIONS FOR PRACTICE

After discussing the research results from the instructional design of the TESLA learning scenarios, we propose a list of recommendations and emerging characteristics that instructional designers need to take in consideration in order to promote Deeper Learning in blended distance e-learning settings using social VR:
Aim deep early, keep your eyes high: Critical success indicators were incorporated in all design templates developed by University of Patras researchers. Educators appreciated that they were prompted in all stages of the immersive instructional design process to reflect on the impact of their course design decisions and avoid reverting to practices that aren't linked with the intended learning outcomes;

Break the conventional student – teacher stereotypes: In academic settings, usually the students are expected to assume the role of a novice who follow the instructions of the expert, namely the teacher. In complex technologically VR environments this dynamic can be inverted. To the extent that millennials are digital natives or residents, they can be active contributors to more aspects of course design, development and implementation towards a harmonic creation of sustainable virtual Community of Practice [27].

Unleash student creativity and initiative: Virtual Worlds are open environments where students can assume responsibility and undertake their own projects in line with Deeper Learning principles following their passions. Educators are advised to facilitate spaces, time, methods, and even intrinsic incentives for informal peer interactions even outside the strict course boundaries.

7 CONCLUSION

Based on research results, we deduce that a critical-reflective instructional design of authentic virtual worlds could support Deeper Learning in Higher Education. Specifically, the TPACK instructional design model in Virtual Reality, when it is infused with a critical-reflective philosophy, state of the art Technology Enhanced Learning theories, and emerging collaborative and problem solving methodologies can be well aligned with Deeper learning principles. Passive, teacher-centred approaches in Science Education often cause a sentiment of “apathy” to students. Active and critical-reflective simulated and collaborative student-centred approaches for Deeper Learning in VR environments can evoke feelings of “empathy” towards scientific roles and practices, through dynamic simulated experiences, thus enhancing learning quality, critical spirit and STEM career prospects.

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REFERENCES


