didacticum

Zeitschrift für (Fach)Didaktik in Forschung und Unterricht
der Pädagogischen Hochschule Steiermark

WERNER ALEXANDER ISOP

# Acceptance Evaluation of a Digital Extended Reality Teaching and Learning Tool to Support Constructivist-Oriented Teaching Methods in Engineering Education


## Abstract

*In den vergangenen Jahren war ein verstärkter Einsatz von digitalen Lehr- und Lerntools in der Berufsbildung zu verzeichnen, nicht zuletzt aufgrund der herausfordernden Covid-19-Situation. Gebräuchliche Lehr- und Lerntools basieren typischerweise auf zweidimensionalen Benutzeroberflächen und konzentrieren sich hauptsächlich auf unterrichtsorganisatorische Aufgaben. In diesem Artikel wird ein unterstützendes, digitales Extended Reality Tool vorgestellt, welches für gängige konstruktivistisch orientierte Lehrmethoden in der Berufsbildung konzipiert ist, die durch eine dreidimensionale virtuelle Lernumgebung erweitert werden. Das übergeordnete Ziel besteht darin, gängige Lehrmethoden, durch die gezielte Anwendung von Interaktionen, interaktiver und lebendiger zu gestalten. Darüber hinaus wird, mit Fokus auf Nachhaltigkeit, ein verantwortungsvoller Umgang mit dem Tool betont. Einerseits beinhaltet das Tool virtuelle Lehrende und Lernende, andererseits betont das Tool deren gleichzeitige physische Präsenz. Durch die Darstellung beispielhafter Anwendungsfälle des Tools werden die entsprechenden Designaspekte mit konstruktivistischen Lerntheorien verknüpft. Dadurch wird der Erhalt von natürlicher menschlicher Präsenz unterstrichen, welcher eine nachhaltige Grundlage für das Lehren und Lernen im Bereich Bildung darstellt. Um die Akzeptanz des Tools zu untersuchen, wurden in der Folge fünf Umfragen mit insgesamt neunzig Lernenden, zwischen der zehnten und zwölften Schulstufe an der berufsbildenden höheren Schule, durchgeführt. Unter Verwendung von Likert-Skala Items mit Fokus auf fünf Kategorien werden Mittelwert, Standardabweichung und Konfidenzintervalle angegeben und zwischen den Umfragen verglichen. Im Detail wurde, im Rahmen der Umfragen, untersucht, ob die Lernenden das Tool im Vergleich zu gebräuchlichen/bekannten Lehrmethoden, mit denen sie vertraut waren, als immersiver, verständlicher und interaktiver empfanden. Darüber hinaus wurde die Akzeptanz des Tools als unterstützende Methode und die Akzeptanz bezüglich des Fernunterrichts untersucht. Zusätzlich zu einer Reflektion des insgesamt überwiegend positiven Ergebnisses hinsichtlich der Akzeptanz des Tools geht dieser Artikel auch auf Einschränkungen der Umfragen ein und zeigt dadurch Verbesserungspotenzial und mögliche zukünftige Schritte auf.*

## Keywords

*Digitales Lehr- und Lerntool, Nachhaltigkeit, natürliche menschliche Präsenz, Extended Reality, Konstruktivismus*


## Motivation

Due to the challenging COVID-19 crisis, a significantly increased use of digital teaching and learning tools was recently noticeable (Tengler et al., 2020). Tools that were used for distance learning during that time and are nowadays still common for either dislocated lessons or face-to-face lessons, are often two-dimensional (Gatzke, 2021) and put a strong focus on learning management (Schulmeister, 2017). On the one hand, they can effectively support organizational tasks for educators and learners (Stockreiter, 2021). On the other hand, in the sense of common constructivist learning theories, they very often lack maintaining a lively teaching and learning experience (Reich, 2012). Especially during distance learning, one issue is a reduced presence of educators and learners, being connected via two-dimensional conferencing tools. Despite this does not cover the full spectrum of available tools, typical representatives, also commonly used in engineering, education may be "Microsoft Teams" (Hai-Jew, 2020), "Moodle" (Athaya et al., 2021), "LMS" (Bradley, 2021), "Zoom" (Stefanile, 2020), "Blackboard Learn", "Docebo" or "Open LMS" (Turner & De Muro, 2022). During either face-to-face or distance learning lessons, such tools typically provide a basic set of available interactions between educators, learners and related (virtual) teaching and learning content, also affecting usability (Al-Qora'n et al., 2022). To improve the afore-discussed aspects, this article presents a digital eXtended Reality (XR) teaching and learning tool, created in 2019. Considering XR as an umbrella term for methods and displays from more specific realities, like "Augmented Reality" (AR) and "Virtual Reality" (VR) (Milgram et al., 1995), the presented tool mainly focuses on techniques from VR. However, since it is also augmenting educational virtual content with real content, utilizing different types of displays (classical computer screens, smartphones, or VR-headsets), it is also capable of moving along the XR continuum (Herur-Raman et al., 2021). Originally designed as a presentation tool for science, the purpose was to make scientific talks or supplementary material livelier and more interactive. While the basic concept of the tool itself did not change over the years, the presented contents steadily evolved. Based on valuable feedback from the learners, the contents were adopted and improved over time. Addressing a reduced two-dimensional presence of educators and learners with common tools in dislocated settings, the tool suggests combining a three-dimensional virtual learning environment (VLE) with the virtual representation of educators and learners. By extending simple two-dimensional video-livestreams and learning sequences to fully 3D-rendered virtual content, one major goal is to increase the perception of presence (Figure 1).

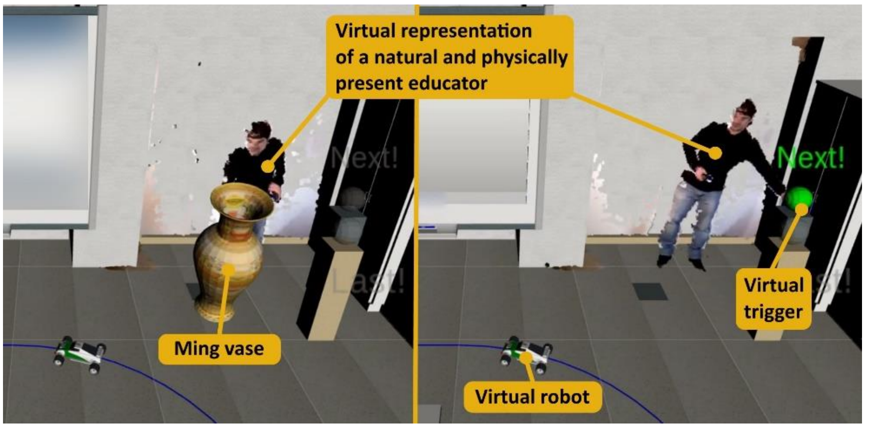


*Figure 1: The virtual representation of a natural and physically present educator is interacting with the virtual learning environment (Isop, 2019). (left) The educator pushes a virtual Ming vase. (right) The educator activates a virtual trigger.*

Another advantage of a VLE, also during face-to-face lessons, is to make contents even accessible to the learners, if not being available in a physical sense. Furthermore, the VLE facilitates advanced interactions between educators, learners, and the virtual environment itself. Following the idea of constructivist-oriented teaching, the interactions are designed to fuel a more lively and more interactive learning experience, compared to typical lessons the learners are already familiar with. Moreover, addressing a core sustainable aspect of the presented tool, this article emphasizes a responsible use for teaching in engineering education. On the one hand, state of the art methods from visualization and artificial intelligence are capable of mimicking natural educators and learners. In contrast, besides including the virtual representations, the tool strictly underlines the necessity of natural physical presence at the same time. According use cases are presented during face-to-face lessons or distance learning lessons. Being essential for the whole complex of education, the goal is to highlight a conservation of the natural physical educator's and learner's presence. Finally, this article reflects on the acceptance of the presented digital XR tool, seen from the learner's perspective. An overall of five different surveys with a total of 90 learners was conducted in engineering education at technical school. Reflecting an overall acceptance, the perceived "Immersiveness", "Comprehensibility", "Interactivity", the acceptance as a "supporting tool for common teaching methods" and the acceptance as a "supporting tool for distance learning" is examined. The examination is followed by a discussion of the results. Finally, potential shortcomings, room for improvement and potential future steps are discussed.

## Focus of the Evaluation and Hypothesis

Substantial long-term goals of the presented digital XR teaching and learning tool are to make common and established teaching methods in engineering education more comprehensive, interactive, and lively. This is to be achieved by using a three-dimensional VLE, incorporating dedicated interactions in XR. As this article presents results of a general acceptance evaluation, it does not investigate the detailed effects of each visualization and interaction metaphor or evaluation of any task performance. In particular, the preliminary interest was on if the learners even perceive the XR tool as useful support regarding their overall learning experience towards a significant positive or negative trend. Furthermore, the evaluation avoided a downgrading of other teaching and learning tools, also posing a valuable support for common teaching. Consequently, a comparison against "the common/well known teaching methods the learners were familiar with" was chosen as a baseline. The according hypothesis of the acceptance evaluation is formulated as the following: The presented XR teaching and learning tool has a significant positive effect on the overall learning experience of the learners, compared to common/well known teaching methods the learners were familiar with.

In a first step, the evaluation focuses on the XR tool's overall acceptance towards a pro-or-con response for constructivist-oriented frontal teaching during common face-to-face lessons. Moreover, parts of the surveys also examined the support of more advanced methods like cooperative learning (Seitz, 2020). Complementary, one survey was conducted for constructivist-oriented frontal teaching, however online, during a distance learning lesson. In this context, it must be noted that all evaluations were conducted so that learners participated in the lessons without any additional dedicated client application. This means that during face-to-face lessons, the XR teaching and learning content was delivered directly via a projector in a typical classroom setting. In addition, to evaluate on the acceptance during distance learning, the according lesson was live-streamed with a commonly used conferencing tool in engineering education (Hai-Jew, 2020).

## Related Learning Theories

To substantiate the interaction design of the presented XR tool, the focus of this section is to highlight essential principles from constructivist learning theories. Constructivism in the context of learning is not only a cognitive process of knowledge transfer. A constructivist method could be rather considered as an approach to learning where learners "actively construct or make their own knowledge and that reality is determined by the experiences of the learners" (Elliott et al., 2000, p. 256). If learning is considered as a process, the interaction between constructivism and didactics can be described as a form of teaching that has become increasingly "established in teaching practice" in recent years (Reich, 2005, p. 5). In this context, constructivism is also used as a learning concept, meaning the "democracy-oriented and plural reference of constructivist critique of knowledge" (Reich, 2005, p. 5). Interestingly, part of modern constructivism is also understood to be a co-development of the lesson, also adapted to the age of the learner. In addition, Reich also emphasizes a more action-oriented approach that complements a pure cognitive transfer of any teaching content. Rather, modern constructivism should develop in the direction of a jointly exploring method, but also with corresponding responsibility. The focus is also on an approach that is adapted to the learners. Above all, an increase in social skills and competencies for more efficient learning is also understood as part of modern constructivism. Constructivism should therefore promote the learning process as "learner-effective" as possible. Furthermore, the focus should be on an action orientation. The associated constructivist-oriented methods underline the effectiveness of the learning process, which is achieved through three elementary perspectives.

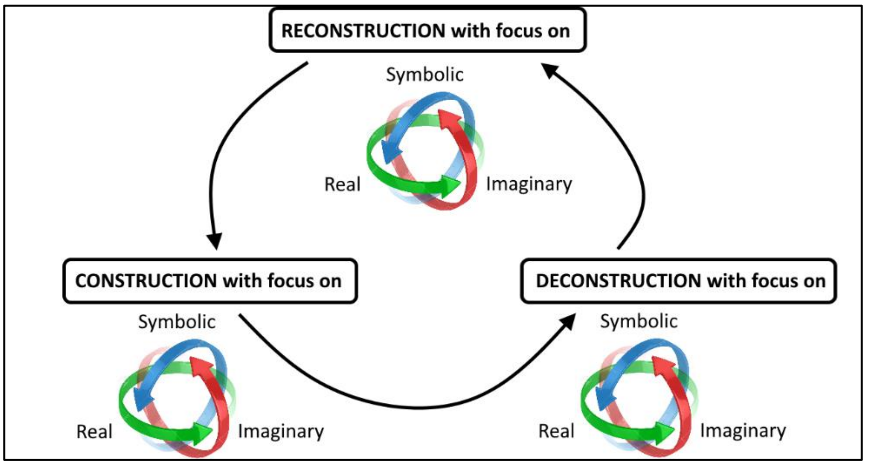


*Figure 2: Didactic cycle with three core dimensions "construction", "reconstruction", and "deconstruction" (Jank & Meyer, 2014).*

Following these perspectives, the learning process results in an essential "didactic cycle", which also includes three elementary dimensions (Jank & Meyer, 2014). The didactic cycle is shown in Figure 2. As "construction", "reconstruction", and "deconstruction" are considered as elementary perspectives of constructivism, supplementary teaching methods together with constructivism are discussed more detailed in the following.

In recent years, classical frontal teaching, as a method that supplements the holistic didactic concept, has increasingly fallen into disrepute. A strong anti-participatory character and, due to declining attention, the according reduction in learning success are contradictory to the practice-relevant teaching efficiency and low complexity of the method itself. This is probably one of the reasons why frontal teaching has become very well established. Still being widely used, in combination with learner-activating phases, it can at least partially compensate for the disadvantages of classic lessons (Westerholz, 2019). As a further consequence, the broadest and most diverse expansion possible through constructivist methods can also generally be regarded as a worthwhile goal. This aspect would probably be understood as the core of a nevertheless solid teaching basis. In addition to a still widespread application in the field of education, frontal teaching as a fundamental method in engineering education can also be found in other areas of our modern society. The pure transfer of knowledge "in plenary session", which is very one-sided in its classical form, is also very popular in the areas of research (scientific talks), industry (product presentations) or politics (press conferences). Particularly, if information is to be presented and communicated in an efficient manner. Even if the purely one-sided form of frontal teaching is to be avoided in modern, enlightened didactics, at least supplementary frontal teaching phases cannot be completely excluded from a holistic teaching concept. The following fact is also important at this point: “New things cannot be learned effectively without instruction” (Wellenreuther, 2009). For example, to prepare the learners adequately for a new type of action-oriented teaching method, short introductory frontal phases or short immediate supplementary frontal elements become most obvious for such teaching and learning scenarios. The remaining phases of the lesson can, nevertheless, be designed to be more participatory and action-oriented, so that the overall didactic concept does not contradict constructivism in its basic features. In addition, recent research has shown that combinations of frontal teaching and open forms of teaching and learning can demonstrably increase the quality of teaching (Seitz, 2020). Frontal teaching as an organizational form is also linked to the term “plenum”. While “plenary” means “the whole” in Latin, or “the group” in the context of the teaching form, it is also associated with ordinary classroom teaching (Junghans & Meyer, 2021). Moreover, the teaching in the group reflects the social form. Despite of the fact that all learners construct their knowledge individually, attempts are made to deliver the content to all learners at the same time and, thus, as effectively as possible. Benefits of frontal teaching might also include controlling or monitoring the learning or the organization of other constructive teaching methods through an active and dialogue-based setting of additional impulses. According to Meyer, classic frontal teaching can be described as:

> Mostly thematically oriented and language-mediated teaching, in which the learning group is taught together and in which the educator – at least according to the claim – defines the work, interaction and controls and monitors communication processes. (Meyer, 1987, pp. 181–224)

This organizational form of teaching has its origins in the direction of communication and the impulses to trigger interactions. The Latin word “Frons” means “forehead”, whereas the essential processes mentioned in frontal teaching can be controlled and evaluated by the educator “from the front”. While pure frontal teaching with a completely educator-dominated one-sided communication is hardly used nowadays, modern frontal teaching aims to take at least two essential aspects into account. On the one hand, more lively communication and, on the other hand, the inclusion of as many interactions as possible are essential. This can be achieved through verbal and non-verbal cues (correct use of body language, modulation of voice, targeted use of eye contact, etc.). An important prerequisite, however, is the acquisition and development of a so-called “Culture of Conversation”. Other important components that influence an increased interactivity or liveliness of frontal teaching are group dynamics and emotions (e.g., enthusiasm or joy in the newly learned contents). It is mentionable that, in the context of constructivist-oriented teaching, the afore-discussed aspects played an essential role in the design of the presented XR tool.

### Related Learning Tools

Digital teaching and learning technologies certainly open a wide range of applications for modern teaching and learning nowadays, but also in the future. If used in a purposeful and, above all, responsible manner, such tools could significantly contribute to an overall increased quality of teaching and learning. In the context of digital educational technologies, the term "virtual teaching and learning tool" in general describes an online platform for digital teaching and learning at dedicated institutions. Modern virtual teaching and learning tools offer activities and interactions along with the necessary digital resources during a lesson or lecture. However, they typically use two-dimensional teaching and learning content, without incorporating a three-dimensional VLE. Such tools may focus on organizational tasks like the assessment of learners, learner attendance or offer connections to other teaching and learning tools via cross-linking digital content. As an extension to common two-dimensional virtual teaching and learning tools, more recent solutions focus on the use of three-dimensional VLEs, namely principles from VR. Commercial tools, like "VReddo" (VReddo, 2023), "Class VR" (Avantis Systems Ltd., 2023), "Virtual Education" (Nextech AR Solutions Inc., 2023) or "Google Expeditions" (Shapovalov et al., 2018), but also free simulators like "Electronics Circuits Simulator" (Tuovinen et al., 2017) or online-multimedia platforms like "Second Life" (Jarmon et al., 2009), are widely available to educators and learners. Following the principles of constructivism as "most often utilized learning theory/method" (Marougkas et al., 2023), the focus of typical VR tools (Chau et al., 2013) lies on enriching teaching and learning content. Above all, the goal is to improve the teaching and learning experience. However, such solutions typically utilize purely virtual representations or avatars of educators and learners, and do not focus on a conservation of natural, physically present, educators and learners in a three-dimensional VLE. Despite, they do not pursue the goal of providing a fully transparent open-source solution, backed by a large community. Complementary, the goal of the presented tool is to reproduce, extend and enrich classical constructivist-oriented teaching and learning experiences, including a close to real representation of the involved educators and learners. Thus, a purposeful and responsible use of the tool underlines sustainable teaching and learning in the context of education. Moreover, the focus is on widely accessible open-source solutions, originated from a broad community in the fields of robotics and human robot interaction (Quigley et al., 2009).

### Design for Basic Principles of Constructivism

The design of the presented XR tool includes a rich set of visualization and interaction methods. Despite of the fact that a reflection on all methods would exceed the limits of this article, however, core principles are described and connected to the according principles of constructivist learning theories. Noteworthy, these methods were also utilized during the five surveys of the evaluation to improve the overall learning experience. An expressive summary of constructivist paradigms for teaching and learning is outlined by Bada and Olusegun (2015). Whilst such concepts played an important role for the design of the presented XR tool, the core goals are listed in the following (Tam, 2000; Honebein, 1996):

1) (Characteristics) **Knowledge will be shared** between educators and students.
2) (Characteristics) Teachers and students will **share authority**.
3) (Characteristics) The teacher's role is one of a **facilitator** or guide.
4) (Goals) To **provide experience** with the knowledge construction process (students determine how they will learn).
5) (Goals) To provide experience in and appreciation for **multiple perspectives** (evaluation of alternative solutions).
6) (Goals) To embed learning in **realistic contexts** (**authentic tasks**).
7) (Goals) To encourage the use of **multiple modes of representation** (video, audio text, etc.).

In the following the listed core characteristics and goals of constructivist learning theories are connected to the basic methods of the presented XR tool. As a summary of these connections is given in Table 1, use cases of the according methods are visually expressed in the according Figures.

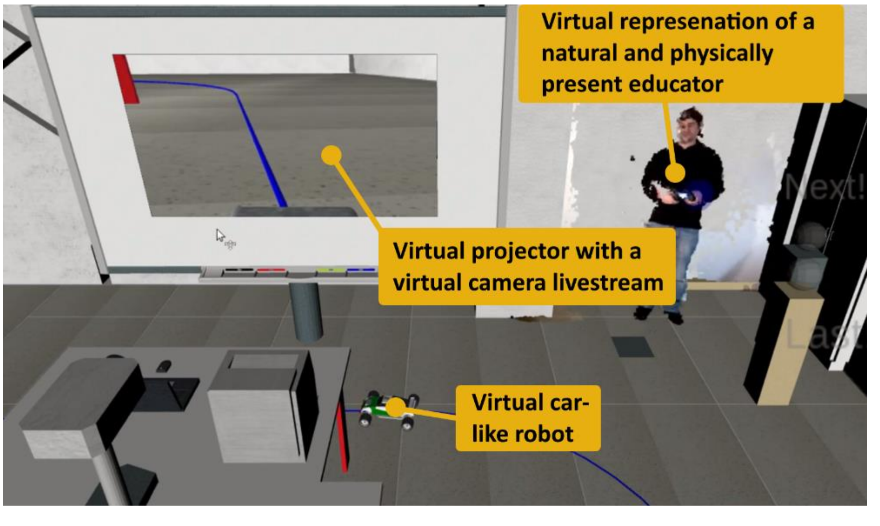


*Figure 3: Exemplary use case for the VLE of the presented XR tool. Contents include a virtual car-like robot with a camera livestream visualized on a virtual projector. The VLE's contents may be hard to reach or are unavailable for teaching otherwise.*

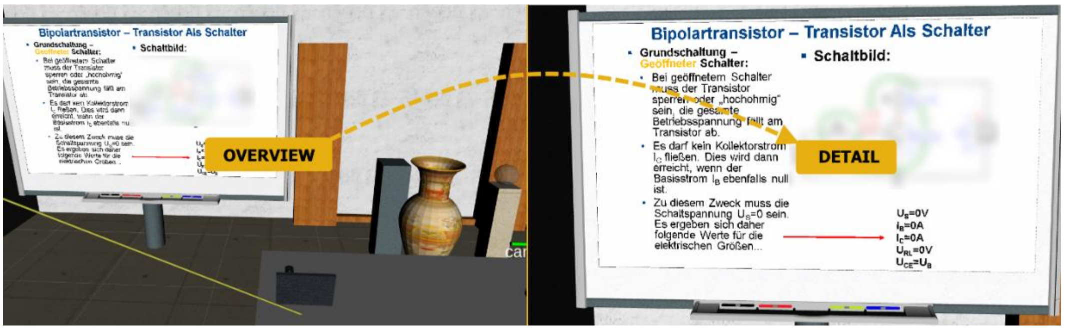


*Figure 4: Exemplary use case of the XR tools virtual camera for a common "overview-and-detail" method (Tory & Swindells, 2002).*

| Methods utilized in the presented XR tool | Common basic methods from XR | Characteristics and goals of constructivism |
|---|---|---|
| *Virtual Learning Environment (also refer to* Figure 3*):* | | |
| The virtual learning environment facilitates more realistic visualization of otherwise non available or hard to reach physical real content. | A fully 3D-rendered virtual scene, including purely virtual teaching and learning contents and/or virtual representations (Dillenbourg et al., 2002). | (6) The goal is to embed learning in realistic contexts and to provide realistic tasks. |
| *Virtual Camera (also refer to* Figure 4*):* | | |
| The virtual camera is a powerful tool to share specific content between educators and learners. Moreover, during distance learning the goal is to share authority. Ultimately, it can provide a multi-perspective experience of the presented teaching contents. | The virtual camera encapsulates the "third person view" concept, facilitating flexible and seamless switching of viewpoints. Thus, educators and learners can get a better overview of the VLE or move closer to interesting details of the teaching content (Boy, 2010). | (1) Knowledge will be shared between teachers and students.<br>(2) Teachers and students will share authority.<br>(5) To provide experience in and appreciation for multiple perspectives (evaluation of alternative solutions) |
| *Virtual Projector (also refer to* Figure 3*):* | | |
| The virtual projector poses a common basis for sharing teaching content between educators and learners. While it is capable of projecting typical content like slides, it also supports the educator with real or virtual live-streams, videos and other multimedia formats. | The virtual projector (also called "virtual beamer") is a virtual projection wall implemented inside any VLE. It is typically used to project audio or video streams and moreover supports experiencing a more realistic virtual environment (Bischoff, 2004). | (1) Knowledge will be shared between teachers and students.<br>(3) The teacher's role is one of a facilitator or guide.<br>(6) The goal is to embed learning in realistic contexts and to provide realistic tasks<br>(7) To encourage the use of multiple modes of representation (video, audio text, etc.) |

| | | |
|---|---|---|
| *Virtual Hand (also refer to* Figure 5*):* | | |
| The virtual hand pointer extends the physical reach of the educator inside the VLE. Besides, the goal is to enrich the experience of educators and learners by pointing towards and emphasizing specific teaching content. Moreover, this interaction method can bring content closer to the learners. | Virtual hands are typically based on spatial inputs and enable object manipulation inside the VLE. This may include grabbing, changing pose or respawning of objects in "mid-air" (Mendes et al., 2019). | (4) To provide experience with the knowledge construction process (students determine how they will learn). |

*Table 1: Basic methods of the presented XR tool, connected to core principles from XR and constructivism.*

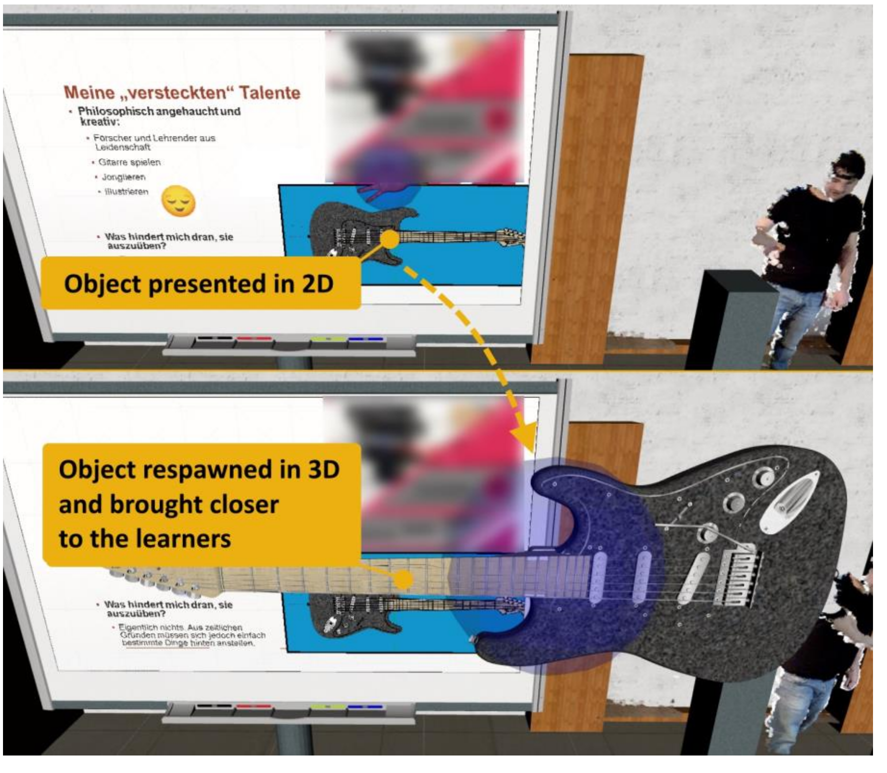


*Figure 5: Exemplary use case of the virtual hand. The educator respawns an object presented in 2D into a 3D object and brings it closer to the learners by using the virtual hand.*

### Use Cases Emphasizing Sustainability

In addition to utilizing common and established methods from constructivist learning theories and XR, the presented tool also underlines sustainable aspects. Since the tool is essentially based on overwhelmingly virtual teaching and learning contents, the more it is necessary to emphasize the natural human educators and learners as fundamental elements in the process of teaching. Digital virtual content can certainly enrich teaching and learning experiences in VLEs, also towards a sustainable development of digital skills (Rybalkin, 2022). Nevertheless, it may be more prone to being exploited or misused (Skulmowski, 2023). Especially regarding natural human presence, state of the art technology has no difficulty mimicking according virtual, and moreover artificially intelligent, content. Examples like virtual and artificial intelligent news speakers (China Xinhua News, 2018) or virtual humans for animation (Achenbach et al., 2017) demonstrate that today's technology is actually capable of reproducing natural human presence in VLEs for years now. On one hand, the virtual and artificially intelligent representation of teaching and learning material seems promising and could potentially also increase the flexibility of the presented XR tool. On the other hand, there is clearly the danger of losing natural human presence as a fundamental instrument for imparting knowledge and, thus, also the danger of a literal loss of humanity. The design of the presented XR tool tries to address related issues, promoting a sustainable use of digital XR teaching and learning tools in education. In this context, one major goal is to support, supplement and selectively extend the transfer of knowledge by at the same time natural and physically present educators and learners. Under no circumstances natural human presence and all associated teaching and learning processes, interactions and related aspects may be replaced by purely virtual artificially intelligent content. Typical use-cases of the XR tool require any form of realistic natural human presence of educators and learners being mandatory to even interact with the VLE. Educators and learners may be visualized by common 2D-camera livestreams or projected as a point cloud or mesh, captured by a 3D-camera (Figure 6). For example, once the educator's presence inside the VLE is fully disabled, it is not possible to proceed with the teaching content or interact with supporting artificially intelligent systems or robots.

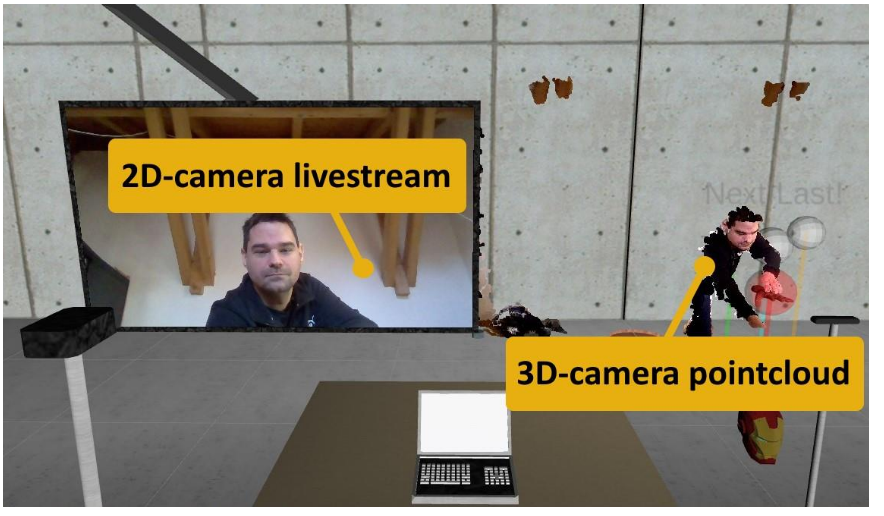


*Figure 6: Typical modes of presence in the VLE of the XR tool. (left) A common 2D-camera livestream visualizes a natural and physically present educator via the virtual projector. (right) A 3D-rendered point cloud representation of the same physical educator.*

## Evaluation

To investigate the overall acceptance of the presented XR tool, an evaluation was conducted. The evaluation consisted of five different teaching and learning sequences, whereas the presented XR tool was used to extend and enrich the common and familiar learning experience of in total 90 learners. The lessons differed with regards to the teaching and learning content, however the method itself (XR tool as supporting method) remained constant over all five lessons. Further, there were five different groups of learners, resulting in five different lessons and surveys with custom questionnaires. Despite, in each lesson all learners were working with the same learning content. Accordingly, the learning experience was measured with five similar questionnaires, whereas the items of the questionnaire were adapted to the lesson's contents. Consequently, the items of all questionnaires were formulated towards the same five categories, namely "Immersiveness", "Comprehensibility", "Interactivity", "Acceptance as supporting method" and "Acceptance for distance learning". Moreover, the overwhelming part of the evaluation, including four surveys with a total of 64 responses, was conducted face-to-face (FTF), during common constructivist-oriented frontal teaching. Additionally, one survey with a total of 26 responses investigated the acceptance online, during distance learning (DL). For a detailed overview of the conditions of the five different surveys, please refer to Table 2. Noteworthy, the learner's participation in the surveys was explicitly voluntary. The learners were informed and instructed about their participation, evaluation procedure and the questionnaires of the surveys before the evaluation.

| # Survey | Teaching Method | Setting/Condition | Content (discipline) | # Participants |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| #1 | constructivist-oriented frontal teaching | co-located face-to-face lesson (FTF1) | "Aerial Robot Showcase" (Electronics and Computer Science) | 12 |
| #2 | constructivist-oriented frontal teaching | co-located face-to-face lesson (FTF2) | „Mars Helicopter Scout" (Electronics and Computer Science) | 15 |
| #3 | „Think-Pair-Share" (in particular, during „think" phase) | co-located face-to-face lesson (FTF3) | „Mars Helicopter Scout" (Electronics and Computer Science) | 18 |
| #4 | constructivist-oriented frontal teaching | co-located face-to-face lesson (FTF4) | „Mars Helicopter Scout" (Electronics and Computer Science) | 19 |
| #5 | constructivist-oriented frontal teaching | dislocated distance learning lesson (DL) | „Teleoperated Car" (Isop, 2019) (Electronics and Computer Science) | 26 |

*Table 2: Overview of the evaluation, consisting of five individual surveys with a total of 90 participants.*

Framing the overall evaluation, five explicitly voluntary surveys with 90 learners (average response time of less than 5 min) were carried out with five individual "Microsoft Forms" questionnaires (Galang et al., 2022). Based on a six-point Likert scale ranging from "strongly disagree" to "strongly agree", each survey contained up to five items covering the afore-mentioned categories. To encourage participants towards a pro-or-con decision and to prevent any evading of their opinions, even if it was not in fact neutral, a mid-point was omitted (Chyung et al., 2017). The categories of the questionnaire items are described as follows:

- Immersiveness: Being immersed or the ability to put oneself into any teaching content on sides of the learners is a vital concept according to constructivism. In detail, the focus of the evaluation was on the perception of the XR tools VLE in general, including all learning sequences and content during the lesson.
- Comprehensibility: The focus of the evaluation regarding clarity included either robots or robotic components, presented as virtual 3D content. In detail, emphasize was put on the clarity/understanding of size related to the real world and functioning of the components (FTF2, FTF3 and FTF4) or competitions (FTF1) and project goals (DL).
- Interactivity: Since also considered as core concept of constructivism, one focus of the questionnaire items was on how interactive the learners

perceived the delivered teaching content of the XR tool. In detail, emphasize was put on the 2D/3D respawning method (Figure 5) to bring system components closer to the learners in all five settings.

- Acceptance as supplemental method: In a first step, the XR tool is intended to support common, well established, and familiar teaching methods in engineering education. Consequently, one goal of the evaluation was to investigate the acceptance of the XR tool as a supplemental method.
- Acceptance for distance learning: The evaluation of this work overwhelmingly focuses on the use of the XR tool in face-to-face settings. However, the acceptance was also evaluated online to better substantiate and motivate the development of the XR tool towards typical distance learning settings.

The resulting questionnaire to investigate the formulated hypothesis consisted of the following items:

“Throughout the presented teaching method …

- 1) Immersiveness: “… I am able to put myself into the delivered teaching content (content changed between evaluations, please refer to Table 1) very well …”
- 2) Comprehensibility: “… I am able to understand specific connections of the delivered teaching content more clearly (items were adapted to the according teaching and learning content) …”
- 3) Interactivtiy: “… I perceive the delivered teaching content as more lively/interactive …”

… compared to the common/well known teaching methods that I am familiar with.”

Moreover, the acceptance of the XR tool as supplemental method and for the use of distance-learning was investigated with the following items:

- 4) Acceptance as supporting tool for common teaching: “I could imagine the teaching method presented as a supporting/additional method to the common/well known teaching methods that I am familiar with.”
- 5) Acceptance as distance learning tool: “If there would be distance learning again, I would also like to interact with the educator or the virtual environment using the presented teaching method.”

To investigate the hypothesis, mean μ, standard deviation σ, and 95 % confidence interval CI for each group of learners per individual lesson are provided. For significance testing per group, a one-sample Wilcoxon Signed-Rank Test is used with comparison against a benchmark median of 4 (“somewhat agree”). For comparison between the FTF and DL settings a Wilcoxon Rank Sum Test is used accordingly, whereas Z-values and p-values are provided (Everitt & Skrondal, 2010). Whilst the focus of the evaluation is on even investigating towards a positive or negative acceptance of the presented XR tool, it is noteworthy that the baseline ("... compared to the common/well known teaching methods that I am familiar with") was chosen on purpose. The goal was to not downgrade other specific, related teaching and learning tools that are also useful and valuable supplements for common teaching methods in engineering education.

## Results and Discussion

The main outcomes of the acceptance evaluation are expressed in Figure 7. Indicated are the overall trends of all five categories, evaluated per individual survey. This includes four surveys (FTF1 to FTF4) conducted in collocated face-to-face settings and one survey conducted in a dislocated distance learning setting (DL). Whilst the 95 % confidence intervals clearly indicate a trend towards a positive acceptance for the collocated face-to-face settings, the Wilcoxon Signed Rank Test revealed a significantly higher median (FTF1: $\mu$=4,556 - $\sigma$=0,695 - Z=3,729 - $p<0{,}001$; FTF2: $\mu$=4,733 - $\sigma$=1,319 - Z=3,977 - $p<0{,}001$; FTF3: $\mu$=4,557 - $\sigma$=1,515 - Z=3,130 - $p<0{,}001$; FTF4: $\mu$=4,409 - $\sigma$=1,172 - Z=3,238 - $p<0{,}001$ ; DL: $\mu$=5,731 - $\sigma$=0,607 - Z=10,286 - $p<0{,}001$). Remarkably, means, standard deviations and confidence intervals indicate a similar trend amongst all face-to-face lessons, indicating a stable positive acceptance, independent of the presented teaching and learning contents.

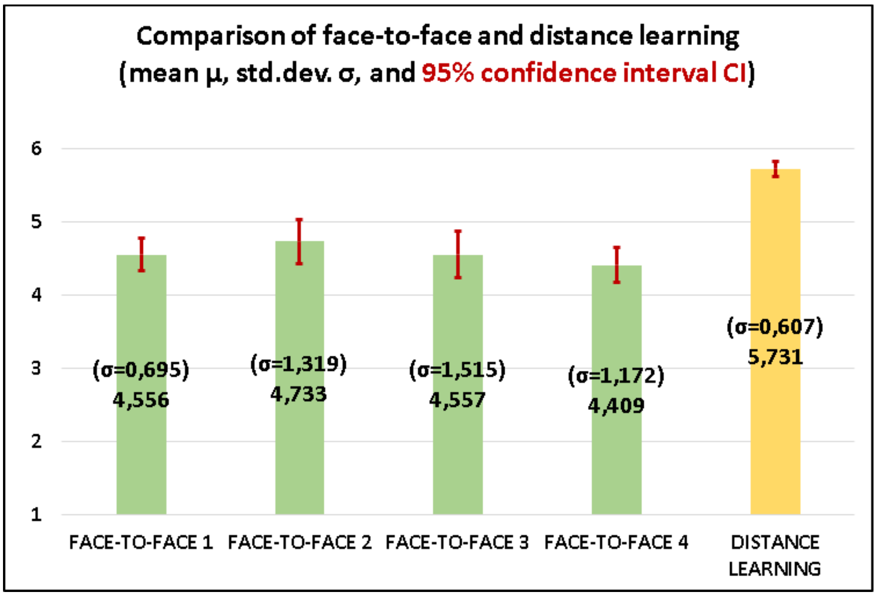


*Figure 7: Perceived overall acceptance for each of the five surveys, summarized over all five categories. The scale ranges from 1 ("strongly disagree") to 6 ("strongly agree") .*

Additionally, Figure 8 depicts the results for each distinct category of the formulated questionnaire items, however evaluated amongst all five surveys. More than 50 % of the participants agreed or strongly agreed to very well perceive the provided XR teaching content as immersive, compared to the baseline. More than 80 % of the participants agreed or strongly agreed to perceive the provided XR teaching content as more clear and more lively/interactive, compared to the baseline. Supplementary, more than 60 % of the participants agreed or strongly agreed to the XR tool being useful as supporting method for teaching. Remarkably, more than 90 % of participants agreed or strongly agreed to the XR tool being useful for distance learning.

Noteworthy, the results of the evaluation indicate that there is a significant difference in the perceived acceptance between the face-to-face settings and distance learning setting. The Wilcoxon Rank Sum Test revealed that the overall acceptance was significantly higher during distance learning (DL), compared to the face-to-face settings (FTF1-FTF4) (Z=-10,407 - p<0,001). The reason might be a significant improvement of overall perceived presence of the VLE and the educator, compared to a typically drastically reduced presence utilizing common teaching and learning tools. This finding is also supported by an overwhelmingly positive acceptance within the category “Distance learning tool”. However, the results do not yet clarify what aspects in detail led to a significantly improved acceptance during distance learning. Moreover, the overall trend towards a positive perceived immersiveness (Figure 8) is not as strong as compared to the other four remaining categories, revealing room for improvement. On one hand the VLE, including its learning sequences, may help to get at least better immersed into the presented teaching and learning contents and better comprehend complex components. On the other hand, the use of appropriate hardware (head mounted immersive XR hardware) to actually immerse the learners into the VLE, was missing.

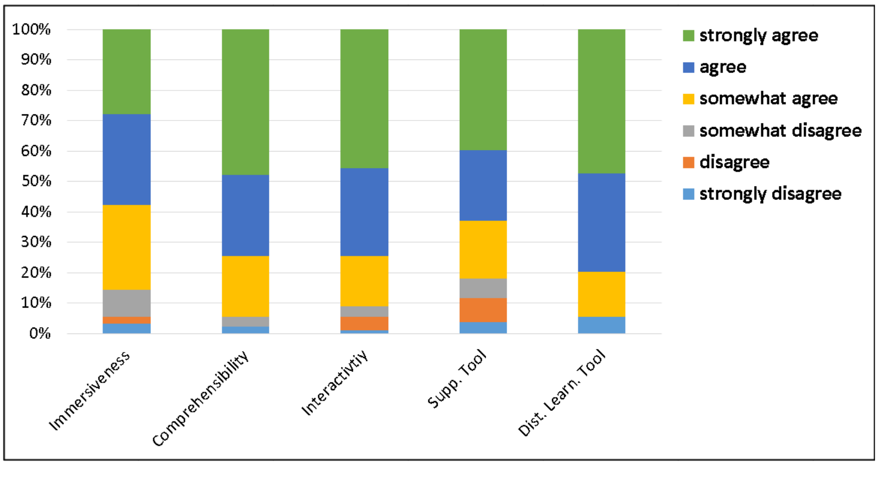


*Figure 8: Perceived acceptance for each of the five individual categories, summarized over all five surveys.*

Undeniably, the responses of the surveys reveal a clear trend towards an overall positive acceptance. Thus, the formulated hypothesis of the evaluation can be accepted. Nevertheless, while the evaluation was able to reveal some details, like an increased overall acceptance of the presented XR tool during distance learning, some details remain unclear. Additional investigations on which interactions and visualizations are perceived more immersive, comprehensible, and interactive, and thus lead to a stronger positive acceptance than others, are necessary. Moreover, as a future step, the use of actual immersive hardware (e.g., smartphone-based, or commercial head mounted XR displays) could improve the overall experience of the learners.

## Conclusion and Outlook

In this article a digital XR teaching and learning tool with a fully 3D-rendered VLE is presented. Core design aspects are highlighted and moreover motivated by basic principles of constructivist learning theories. As essentially the tool supports common constructivist-oriented teaching with dedicated visualizations and interactions from the field of XR, the overall goal is to enrich the teaching and learning experience of educators and learners. In the same step, the tool underlines the natural physical presence of the involved educators and learners as strong sustainable aspect in education. To preliminarily investigate the learner's acceptance of the tool, an evaluation was conducted, consisting of five different surveys. The results of the evaluation clearly indicate a positive trend in the participant's responses, underpinning an overall pro acceptance. Nevertheless, the evaluation also reveals room for improvement, that is to investigate which details of the XR tool led to significantly more positive responses, particularly during distance learning. In addition, since the evaluations were conducted outside of any project or funding context, costly hardware had to be omitted. Consequently, future steps may include more specific and detailed evaluations of distinct interaction and visualization methods of the tool. Additionally, more directed and concrete comparisons against state-of-the art methods and tools could surely help to improve any teaching and learning experience. Ultimately, a project or funding-context may also encourage development, implementation and evaluation of novel methods, incorporating more expensive XR hardware.

## Bibliography

Achenbach, J., Waltemate, T., Latoschik, M. E., & Botsch, M. (2017). Fast generation of realistic virtual humans. In *Proceedings of the 23rd ACM Symposium on Virtual Reality Software and Technology*. https://doi.org/10.1145/3139131.3139154

Al-Qora'n, L. F., Salem, O., & Gordon, N. (2022). Heuristic Evaluation of Microsoft Teams as an online teaching platform: An Educators' perspective. *Computers, 11*(12), 175. https://doi.org/10.3390/computers11120175

Athaya, H., Nadir, R. D. A., Sensuse, D. I., Kautsarina, K., & Suryono, R. R. (2021). *Moodle Implementation for E-Learning: A Systematic Review*. International Conference on Sustainable Information Engineering and Technology. https://doi.org/10.1145/3479645.3479646

Avantis Systems Ltd. (2023). *Virtual Reality Technology for the Classroom*. ClassVR. https://www.classvr.com/school-virtual-reality/

Bada, S. O., & Olusegun, S. (2015). Constructivism learning theory: A paradigm for teaching and learning. *Journal of Research & Method in Education, 5*(6), 66–70.

Bischoff, A. (2004). Virtual Reality Environment with Shared PC and Live Video Streaming for Computer-Supported Collaborative Learning. In *21st ICDE World Conference, Hong Kong*. https://dr-bischoff.de/research/pdf/Bischoff04b_icde2004_fuh_bischoff_seminar_final.pdf

Boy, G. A., Mazzone, R., & Conroy, M. (2010, July). The virtual camera concept: a third person view. In *Third international conference on applied human factors and engineering, Miami, Florida* (pp. 17–20).

Bradley, V. M. (2021). Learning Management System (LMS) Use with Online Instruction. *International Journal of Technology in Education, 4*(1), 68. https://doi.org/10.46328/ijte.36

Chau, M., Wong, A., Wang, M., Lai, S., Chan, K. W., Li, T. M., ... & Sung, W. K. (2013). Using 3D virtual environments to facilitate students in constructivist learning. *Decision support systems, 56*, 115–121.

China Xinhua News (2018, November 8). Xinhua AI anchor, launched on Wednesday, starts presenting news reports from Thursday. Twitter. https://twitter.com/XHNews/status/1060399650434248704

Chyung, S. Y., Roberts, K., Swanson, I., & Hankinson, A. (2017). Evidence-Based survey design: the use of a midpoint on the Likert scale. *Performance Improvement, 56*(10), 15–23. https://doi.org/10.1002/pfi.21727

Dillenbourg, P., Schneider, D., & Synteta, P. (2002, September). Virtual learning environments. In *Proceedings of the 3rd Hellenic conference information & communication technologies in education* (Vol. 2002, p. 01). Rhodes, Greece: Archive Ouverte HAL. https://telearn.hal.science/hal-00190701/document

Elliott, S.N., Kratochwill, T.R., Littlefield Cook, J. & Travers, J. (2000). Educational psychology: Effective teaching, effective learning (3rd ed.). McGraw-Hill College. Boston.

Everitt, B., & Skrondal, A. (2010). *The Cambridge Dictionary of Statistics*. Cambridge University Press. Cambridge.

Galang, A., Snow, M. A., Benvenuto, P., & Kim, K. S. (2022). Designing Virtual Laboratory Exercises Using Microsoft Forms. *Journal of Chemical Education, 99*(4), 1620–1627. https://doi.org/10.1021/acs.jchemed.1c01006

Gatzke, L. (2021). *Die Realisierung von kollaborativen Lernprozessen in computergestützten Umgebungen am Beispiel Microsoft Teams* [Bachelor's thesis, Hochschule Rhein-Waal]. opus4. https://opus4.kobv.de/opus4-rhein-waal/frontdoor/index/index/year/2021/docId/731

Hai-Jew, S. (2020). Evaluating "MS teams" for teaching and learning. *C2C Digital Magazine, 1*(13), 7. https://scholarspace.jccc.edu/c2c_online/vol1/iss13/7/

Herur-Raman, A., Almeida, N. D., Greenleaf, W., Williams, D., Karshenas, A., & Sherman, J. H. (2021). Next-Generation simulation – integrating extended reality technology into medical education. *Frontiers in Virtual Reality, 115*. https://www.frontiersin.org/articles/10.3389/frvir.2021.693399/full

Honebein, P. C. (1996). Seven goals for the design of constructivist learning environments. In B. G. Wilson (Ed.), *Constructivist Learning Environments: Case Studies in Instructional Design* (p. 11–24). Educational Technology Publications.

Isop, W. A. (2019). Open Auditorium – Teleoperiertes Modellauto [Video]. Youtube. https://www.youtube.com/watch?v=ASyGuqdil-Q

Jank, W., & Meyer, H. (2014). *Didaktische Modelle – alle Schulformen*. 11. Auflage. Cornelsen Schulverlag.

Jarmon, L., Traphagan, T., Mayrath, M. C., & Trivedi, A. (2009). Virtual world teaching, experiential learning, and assessment: An interdisciplinary communication course in Second Life. *Computers & Education, 53*(1), 169–182. https://doi.org/10.1016/j.compedu.2009.01.010

Junghans, C., & Meyer, H. (2021). *Unterrichtsmethoden II: Praxisband*. 17. Auflage. Cornelsen.

Marougkas, A., Troussas, C., Krouska, A., & Sgouropoulou, C. (2023). Virtual Reality in Education: A review of learning theories, approaches and methodologies for the last decade. *Electronics, 12*(13), 2832. https://doi.org/10.3390/electronics12132832

Mendes, D., Caputo, F. M., Giachetti, A., Ferreira, A., & Jorge, J. (2019, February). A survey on 3d virtual object manipulation: From the desktop to immersive virtual environments. *Computer graphics forum, 38*(1), 21–45. https://doi.org/10.1111/cgf.13390

Meyer, H. (1987). *Unterrichtsmethoden II: Praxisband*. 13. Auflage. Cornelsen.

Milgram, P., Takemura, H., Utsumi, A., & Kishino, F. (1995). Augmented reality: a class of displays on the reality-virtuality continuum. *Proceedings of SPIE*. https://doi.org/10.1117/12.197321

Nextech AR Solutions Inc. (2023). *Virtual Education*. nextech AR. https://www.nextechar.com/virtual-education

Quigley, M., Conley, K., Gerkey, B., Faust, J., Foote, T., Leibs, J., ... & Ng, A. Y. (2009, May). ROS: an open-source Robot Operating System. In *ICRA workshop on open source software* (Vol. 3, No. 3.2, p. 5).

Reich, K. (2005). Konstruktivistische Didaktik. Beispiele für eine veränderte Unterrichtspraxis. *Schulmagazin 5–10, 73*(3), 5–12.

Reich, K. (2012). *Konstruktivistische Didaktik: das Lehr- und Studienbuch mit Online-Methodenpool* (5. Aufl.). Beltz.

Rybalkin, O. (2022). Sustainable development goals progress in the European Union: correlation with EEPSE green economy index. *Access to science, business, innovation in digital economy, ACCESS Press, 3*(2), 121–135. https://doi.org/10.46656/access.2022.3.2(3)

Schulmeister, R. (2017). *Lernplattformen für das virtuelle Lernen*. De Gruyter eBooks. https://doi.org/10.1515/9783486816204

Seitz, S. (2020). Frontalunterricht versus offener Unterricht: Die Forschung plädiert für beides. *Schulwelt NRW: mit allen aktuellen neuen und geänderten Schulvorschriften,* (3), 18–21.

Semeraro, C., Lezoche, M., Panetto, H., & Dassisti, M. (2021). Digital twin paradigm: A systematic literature review. *Computers in Industry, 130*, 103469. https://doi.org/10.1016/j.compind.2021.103469

Shapovalov, Y. B., Bilyk, Z. I., Atamas, A. I., Shapovalov, V. B., & Uchitel, A. D. (2018). *The Potential of Using Google Expeditions and Google Lens Tools under STEM-education in Ukraine*. https://doi.org/10.31812/123456789/2665

Skulmowski, A. (2023). Ethical issues of educational virtual reality. *Computers & Education: X Reality, 2*, 100023.

Stefanile, A. (2020). The Transition from Classroom to Zoom and How it Has Changed Education. *Journal of Social Sciences Research, 16*, 33–40. https://doi.org/10.24297/jssr.v16i.8789

Stockreiter, V. (2021). *Beeinflussende Faktoren der Online-Lehre in Schulen sowie Optimierungsmöglichkeiten mittels eines Ländervergleichs* [Master's thesis, University of Graz]. unipub. https://unipub.uni-graz.at/obvugrhs/content/titleinfo/6139135

Tam, M. (2000). Constructivism, Instructional Design, and Technology: Implications for Transforming Distance Learning. *Educational Technology and Society, 3*(2). https://www.researchgate.net/publication/26391080_Constructivism_Instructional_Design_and_Technology_Implications_for_Transforming_Distance_Learning

Tengler, K., Schrammel, N., & Brandhofer, G. (2020). Lernen trotz Corona. Chancen und Herausforderungen des distance learning an österreichischen Schulen: Chancen und Herausforderungen des Distance Learnings an österreichischen Schulen. *Medienimpulse, 58*(02). https://doi.org/10.21243/mi-02-20-24

Tory, M., & Swindells, C. (2002). *Exovis: An overview and detail technique for volumes*. Technical Report SFU-CMPTTR2002-05, Computing Science Dept., Simon Fraser University.

Tuovinen, A., Bourhis, A., & Callaghan, M. (2017, July 6). *Electronics Circuits Simulator. Steam*.

https://store.steampowered.com/app/657410/Electronics_Circuits_Simulator/

Turner, B., & DeMuro J. (2022, April 13). Best online learning platforms of 2022. *TechRadar*. https://www.techradar.com/best/best-online-learning-platforms

VReddo (2023). *Virtual Reality Education Platform*. VREDDO. https://vreddo.com.au/vr-rundown-what-you-need-to-know-before-buying-a-vr-system-for-your-school/

Weinberger, A., Hartmann, C., Kataja, L., & Rummel, N. (2020). Computer-unterstützte kooperative Lernszenarien. In Springer eBooks (pp. 229–246). https://doi.org/10.1007/978-3-662-54368-9_20

Wellenreuther, M. (2009). Frontalunterricht, direkte Instruktion oder offener Unterricht? Empirische Forschung für die Schulpraxis nutzen. *Schulverwaltung. Nordrhein-Westfalen, 20*(6), 169–172.

Westerholz, S. (2019). Kleine Methoden – große Wirkung?! Gestaltung und Evaluation eines abwechslungsreichen Frontalunterrichts im Seminar der Biochemie. In *Perspektiven der Hochschuldidaktik*. https://doi.org/10.1007/978-3-658-26990-6_7

Willermark, S., & Gellerstedt, M. (2022). Facing radical digitalization: capturing teachers' transition to virtual classrooms through ideal type experiences. *Journal of Educational Computing Research, 60*(6), 1351–1372. https://doi.org/10.1177/07356331211069424

**Isop Werner Alexander**

Dr. BEd BSc MSc, Engineering Education, Graz, Austria