CEN WORKSHOP AGREEMENT

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eXtended Reality for Learning and Performance Augmentation - Methodology, techniques, and data formats

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CEN-CENELEC Management Centre: Rue de la Science 23, B-1040 Brussels

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European foreword

This CEN Workshop Agreement (CWA 18006:2023) has been developed in accordance with the CEN-CENELEC Guide 29 "CEN/CENELEC Workshop Agreements – A rapid prototyping to standardization" and with the relevant provisions of CEN/CENELEC Internal Regulations – Part 2. It was approved by a Workshop of representatives of interested parties on 2023-04-28, the constitution of which was supported by CEN following the public call for participation made on 2022-05-30. However, this CEN Workshop Agreement does not necessarily include all relevant stakeholders.

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The following organizations and individuals developed and approved this CEN Workshop Agreement:

— Fridolin Wild (The Open University), Chair

— Eleni Mangina (University College Dublin), Vice-chair

— Dimitrios Sklavakis (European School Brussels III)

— Rolf Kruse (Fachhochschule Erfurt)

— Lisa Bowers (The Open University)

— Ana Dominguez (Vicomtech)

— Dorleta Garcia (Vicomtech)

— Na Li (University College Dublin)

— Georgia Psyrra (University College Dublin)

— Effie Law (University of Durham)

— Giuseppe Chiazzese (Istituto per le Tecnologie Didattiche-CNR)

— Mariella Farella (Istituto per le Tecnologie Didattiche-CNR)

— Davide Taibi (Istituto per le Tecnologie Didattiche-CNR)

— Marco Arrigo (Istituto per le Tecnologie Didattiche-CNR)

— Luciano Seta (Istituto per le Tecnologie Didattiche-CNR)

— Andres Leon Geyer (Pontificia Universidad Católica del Perú)

— Thommy Eriksson (Chalmers University of Technology)

— Deogratias Shidende (Duale Hochschule Baden-Württemberg Heidenheim)

— Monique Morrow (IEEE P7030 Working Group)

— Stylianos Mystakidis (Panepistímio Patrón-University of Patras)

— Erlend Øverby (Hypatia Learning AS)

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Introduction

eXtended Reality (XR) is the umbrella term for Virtual, Mixed, and Augmented Reality (VR/MR/AR), customarily perceived to encompass a spectrum of degrees to which alternate views of the physical world surrounding the user are realized digitally (Milgram & Kishino, 1994; Milgram et al., 1994; Skarbez, Smith, and Whitton, 2021). This spectrum ranges from the augmented 'touch-up' use of digital overlays on one end of a polar scale to immersive 'fully-rendered' views of the world on the other. Common to all is that objects are registered in 3D and user interaction is responsive in real-time (Azuma, 1997). XR technologies are increasingly used in education and training to support learning, practice, or even guide work performance.

Relevant standards, however, are scattered across standardization organizations and committees. For example, existing relevant standards work is not necessarily conducted under the auspices of learning technology standards committees but can also be found in hardware-oriented, industry-focused, or human-computer interaction (HCI) sponsorship. Moreover, several existing standards applicable to learning technologies at large focus on the web or mobile. Consequently, they fall short of considering innovation in delivery and interaction devices, and related management and usage protocols.

This workshop agreement elaborates a recommendation for a holistic register of standards (including application profiles of existing standards where appropriate) that can serve to establish interoperability in support of XR learning and performance augmentation.

Deliberately, this agreement links and extends existing work from other standards bodies to provide a comprehensive canon of standards to guide implementers and adopters of XR learning and performance augmentation in making the right choices for system procurement and application development.

The special focus thereby is on interoperability. Interoperability is "a property that emerges when distinctive information systems (subsystems) cooperatively exchange data in such a way that they facilitate the successful accomplishment of an overarching task" (Sobernig et al., 2006). Interoperability for authoring, exchanging and delivering interactive learning content for XR learning and performance augmentation is a complex matter. Achieving such interoperability is complex for multiple reasons.

First, and foremost, the application in education and training is mainstream and therefore can involve a large magnitude of incompatible platforms and services to choose from. This includes a growing market of hardware products, especially in the Smart Glasses segment. Flagship initiatives like Microsoft's Hololens, Lenovo's ThinkReality, Meta's Oculus Quest, or the Magic Leap are accompanied by a flurry of devices from smaller manufacturers, with industry reports routinely listing two dozen and more products already years ago (Inbar, 2014). There are even more SDKs and connected service plans, adding to the fragmentation of the market, with no clear winner emerging. Educational and vocational training institutions as well as individuals, however, have to make purchase decisions, and these decisions can severely impede access to learning resources, services, and applications if interoperability is not a given.

Second, the overarching goal for each of these three use cases –authoring, exchange, and delivery– is the creation of memorable experiences. Providing 3D digital objects and the required connected interactivity for learning and performance augmentation, however, is a complex matter by itself.

Third, affordances for learning and performance augmentation are different from other application areas, such as entertainment, lifestyle, or even productivity. For example, they require special emphasis on assessment, accessibility, and privacy. Relevant affordances for learning and training have to be built into the authoring tools and reflected in the underlying data models.

This CWA seeks to address this complexity and remedy the situation, easing access for education and training specialists to emerging XR technologies. The CWA takes charge, from a European perspective, by stock-taking of existing relevant work scattered across agencies and committees, providing a comprehensive recommendation on which standards should be combined for XR learning and performance augmentation.

The CWA breaks down the standards needed for XR learning and performance augmentation along two axes of investigation, namely data models and guidelines. Thereby, data models are further differentiated into content models, meta-data for retrieval and archiving, performance analytics and associated models for learner behaviour logging, as well as additional data model recommendations regarding virtual humans, mapping, tracking, communication, and sharing. Guidelines are split up into accessibility, usability/user experience (UX), and ethics and policy deliberations for XR in education.

The CWA addresses three particular target groups: educational providers; educational managers, intermediaries, and regulators; and investors. For educational providers, it aims to help set targets for the provision of XR learning content services, to boost resilience of infrastructure. It seeks to provide a systematic and exhaustive way for setting up a service for teaching and learning any-time, anywhere with 3D experiences. Educational managers, intermediaries, and regulators like departments of education on member-state level, educational infrastructure providers, or school systems can be helped by this CWA in identifying appropriate action and effective allocation of resources systematically. For investors, this CWA provides supports in directing the right funding to 3D content infrastructure.

1 Scope

This CWA includes a comprehensive canon of standards for the creation, delivery, and use of eXtended Reality (XR) learning activities and 3D Augmented Reality objects for intensive educational processes. It contains a methodology detailing the techniques that should be employed through the different steps to be followed, to advance knowledge retention and impact positive behaviour in Schools. It intends to enable a common European disruptive educational approach and thus the possibility of sharing 3D content.

This CWA does not define requirements related to educational aspects.

This CWA is intended to be used by:

— Educational providers to establish targets for service provision, also boosting resilience of infrastructure, ensuring that there is a complete and systematic way of setting up a service for teaching and learning any-time, anywhere with 3D experiences.

— Educational managers, intermediaries, and regulators (like departments of education on member-state level, educational infrastructure providers, and school systems) to take appropriate actions and ensure effective allocation of resource for the provision of XR education.

— Investors to properly fund 3D content infrastructure.

This CWA is not intended to be used for certification purposes.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes the requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7010:2019, *Graphical symbols — Safety colours and safety signs — Registered safety signs*

ISO 15836-1:2017, *Information and documentation — The Dublin Core metadata element set — Part 1: Core elements*

ISO/IEC 12113:2022, *Information technology — Runtime 3D asset delivery format — Khronos glTF™ 2.0*

IEEE 1484.12.1-2020, *IEEE Standard for Learning Object Metadata*

IEEE P1589-2020, *IEEE Standard for Augmented Reality Learning Experience Models*

IEEE P92741.1, *Experience API (xAPI) — Part 1: xAPI Base Standard*

Universal Scene Description: https://graphics.pixar.com/usd/release/index.html

Usdz File Format Specification: https://graphics.pixar.com/usd/release/spec_usdz.html

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at http://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
eXtended Reality
umbrella term for virtual, mixed, and augmented reality. Aimed at creating environments that combine natural and virtual input for the user with the help of computer technology and wearable computing

3.2
augmented Reality
technology for supplementing the user's sensorial input instantaneously with digital elements registered in 3D space in addition to the natural stimuli from the outside world in order to provide alternate and typically enhanced experiences

3.3
virtual Reality
technology to simulate a 3D scene or environment with a degree of realism that gives the user an immersive experience

3.4
mixed Reality
spectrum of technologies that vary in the degree of world-rendering from Augmented Reality (no world-model is rendered, digital elements are superimposed) to Virtual Reality (immersive, world model is fully rendered)

3.5
meta-Data
machine-readable, structured descriptions convey information to help sort and identify (collections of) facts or figures stored by a computer ('data about data')

3.6
learning Object Meta-Data
metadata that describes digital learning resources

4 Interactive Learning Content

4.1 General

This core part of the CWA describes how interoperability for learning and performance augmentation can be established with a mix of four key elements, mixing existing ISO and IEEE standards. Moreover, recommendations are provided along three additional technology aspects, i.e., virtual instructors, room scanning, and real-time communication for collaborative learning.

The key element thereby is the IEEE standard for AR Learning Experience Models (IEEE P1589-2020), which conceptualizes an activity description language for delivering content assets, so-called 'augmentations', in an event-driven way, sequenced into task stations and action steps.

IEEE P1589-2020 recommends the complementary use of IEEE P92741.1, the Experience API (short 'xAPI') to log learner behaviour. This log data can be queried as part of the learning experience execution, described in IEEE P1589-2020. But it can also be aggregated into Learning Analytics to provide insights on all learning and performance augmentation (covering not only the XR activity involved).

Moreover, IEEE P1589-2020 provides an environmental description language for defining the user surroundings in a machine-processable way, providing a standard data model for defining locations, points of interest, tangible objects, machine-readable sensors, etc. This opens questions regarding privacy, especially where adaptation to learners' home locations is involved, which are further discussed in the notes on reality mapping and tracking.

One level lower, on the level of assets, the ISO/IEC 12113:2022 provides a graphics language transmission format, glTF, which aims at the efficient, compressed exchange of 3D object data and animations, including their textures.

4.2 Learning Experience Models (IEEE P1589-2020)

The IEEE P1589-2020 standard for Augmented Reality Learning Experience Models has been designed to require no specialist tools and skills; not be tied to a platform; run on any device; integrate with sensors; provide branching and flow control; deliver instructional feedback; allow checking for errors; automatically validate; facilitate updates and reuse; without specialist tool skills.

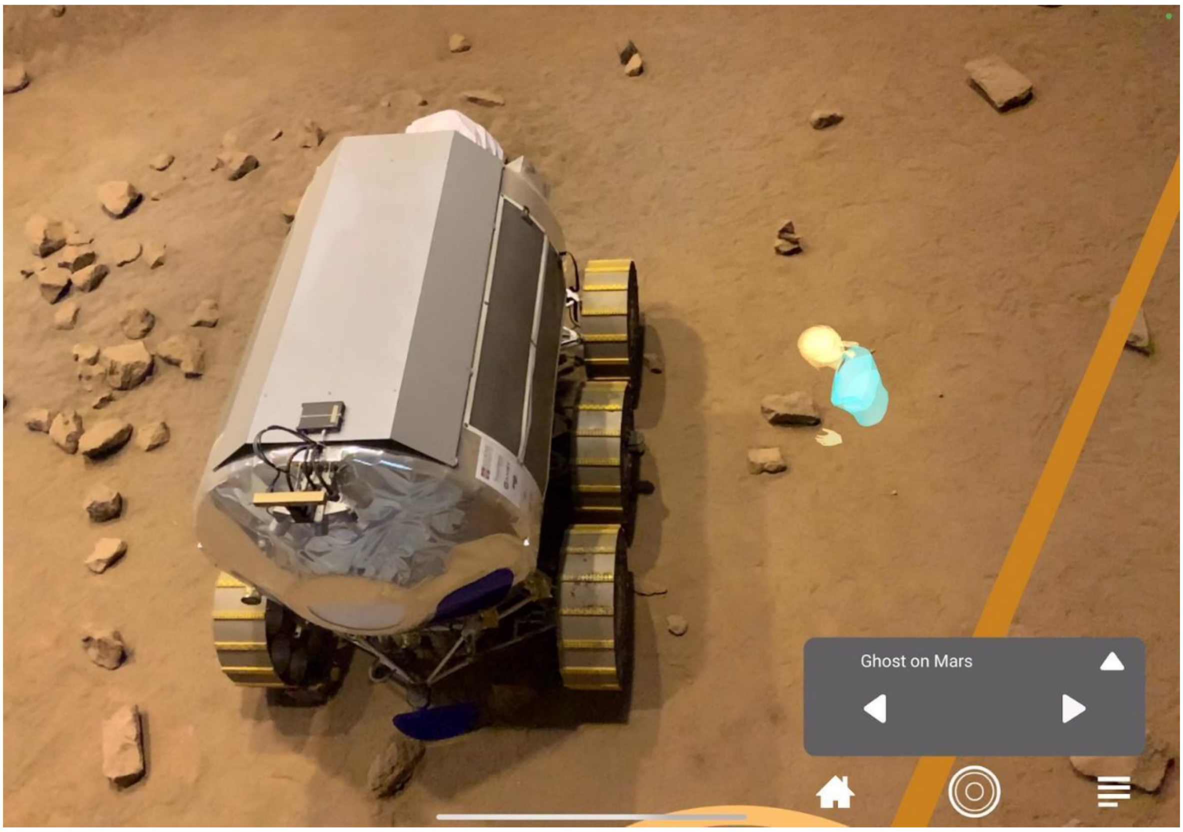

Figure 1 — Augmentation displayed in Mars Terrain Simulator (Picture: WEKIT ECS/Altec/The Open University)

IEEE P1589-2020 consists of two modelling languages, one for describing learning activities, and the other for describing the learners' surroundings. Every activity consists of a linear and/or interactive sequence of action steps. Each action step has a location, the combination of action and location is also known as a 'task station'. At the heart of the activity modelling language is the idea of trigger events, which move execution from action step to action step, and task station to task station.

When a specific action step is started, all the content augmentations that are listed in the data model in the 'active' array in the 'enter' section of this step will be played. There is also a possibility to additionally 'deactivate' augmentations here (upon entering), send messages (e.g., to other users/devices), or evaluate with if-then rules results of queries to the xAPI endpoint.

Four types of events can trigger an action step to move on to the next one that is specified: detect, click ('tap'), voice, or sensor. Detect interfaces with the computer vision engine, reacting, for example, to an image target that becomes visible in the camera (and was detected as 'tracked'). Voice allows reacting to a standard voice command, for example, the word "next" or "MirageXR, next". Click (or 'tap') serves the same purpose but uses a button instead. The sensor triggers an interface with machine-readable sensors to evaluate the value of a specified variable 'key' on a communication channel with 'id'.

Each action step can optionally also have a human-readable instruction, a kind of task card consisting of a title and description.

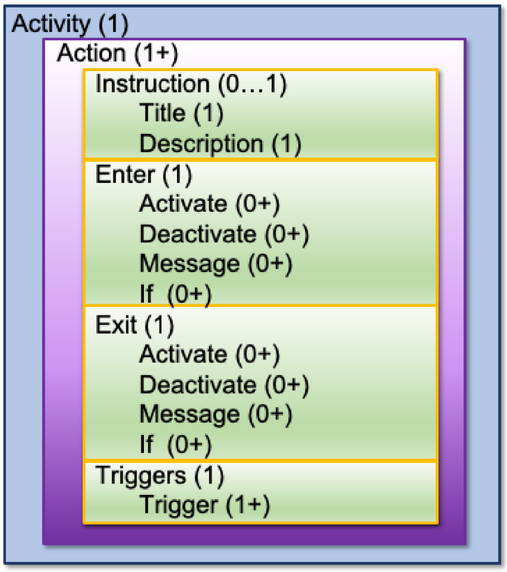

Figure 2 — Abstract model of IEEE P1589-2020 Activity Modelling Language

When the conditions of a trigger are fulfilled, the specified target action node is called up – after executing the stack of the 'exit' segment of the action, if any are specified. These again bring up augmentations listed in the 'activate' array, removing those of the 'deactivate' array, sending messages, and executing if-rules on xAPI data.

The key to the activity execution is the list of augmentation commands provided in the 'activate' arrays of the action steps. These commands render four different types of augmentations, so-called augmentation 'primitives', so-called 'predicates', 'warnings', and other 'actions'. Primitives refer to a set of standard media asset types, including image, video, audio, text label, and animation / 3D model. In the reference implementation of IEEE P1589-2020, the Open-Source project MirageXR, the set of standard primitives is by now enhanced to also encompass: a 'ghost track' avatar and voice recording of an expert instructor; visual effects; character models; a 3D quiz called 'pick & place'; a 3D whiteboard; and a generic type 'plugin' providing a new apps interface.

Supported predicates and warnings should be defined in the workplace model. Predicates ('Action Glyphs' in the MirageXR reference implementation) provide animated 3D symbols for standard user instructions on handling and movement. For example, the 'rotate' or 'allow' predicates provide such standard 3D animations. Warnings provide an interface to the ISO 7010 hazard or warning sign.

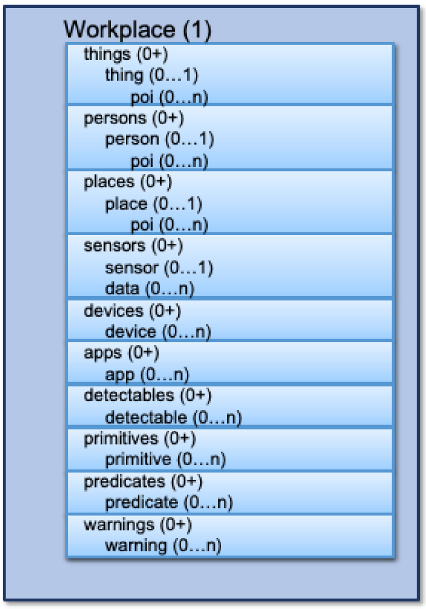

Figure 3 — Abstract model of IEEE P1589-2020 Workplace Modelling Language

In the workplace model, the first three element groups are the 'tangibles': things, persons, and places used in the AR learning activity are defined here, assigning them to display name and ID, and – more importantly – their real-world location and how to identify them using the AR camera. (The location is only linked here, and it is stored further down in the 'detectables' section, where it lists either a target image for tracking or a world anchor with a relative location in the spatial map.)

Under 'sensors', specific internet of things enabled sensors can provide their bootstrapping information. This includes the URL (with protocol) under which to contact their message broker and the model for parsing the data. 'Devices' provide a similar interface for multi-device or multi-user scenarios. The 'app' container allows interfacing with plugins, for example, in the form of prefabs that inject app-external functionality (like specialist interactive animations) into the content unit.

Primitives, predicates, and warnings can be listed here to indicate which are supported in the activity (and to resize them from their standard size if needed).

4.3 Learning Experience Design

'Learning Design' as a process sits at an intermediary level between strategy and activity, translating the aims and objectives from a macro level to enactable competency development guides with concrete (and possibly directly executable) activity instruction on a micro level (cf. Stracke, 2019).

In line with Koper, 2006, a 'learning design' is also used to refer to the output of the same process, denoting then the "description of the teaching-learning process", with the long-standing dream to express this output in a "semantic, formal and machine-interpretable way", as proposed by the IMS-LD standard, originally released in 2003, but abandoned around 2008 (see Burgos, 2018, for an extensive critique of the approach).

This non-XR-enabled precursor of a structured description language for learner activity has influenced our development of IEEE P1589-2020, the interoperability standard that defines the conceptual model of our technical approach to the data layer.

The act of creating AR learning activities is called 'learning experience design' (short 'LXD'), for which we recommend applying the following methodology, which is based on the Design Thinking philosophy. Design Thinking is a process leading through the phases empathize, define, ideate, prototype, test, and implementing. While tools from Design Thinking, in general, can also be applied to Learning Experience

Design, it is recommended to use the worksheets introduced below to understand, explore, and materialize XR learning experiences.

Table 1 — Design Thinking phases (Gibbons, 2016)

Empathize ***Know the user***	**Define** ***Know their problems***	**Ideate** ***Generate innovative ideas***	**Prototype** ***Build***	**Test** ***Return to users for feedback***	**Implement** ***Deliver***
Understand		Explore		Materialize	

There are variations, but they all follow the same principle. Design work happens in three phases and in six process steps, first focusing on understanding the user and their needs, then exploring solutions and building prototypes, to finally materialize and return to users for feedback before delivering.

Common to all is the iterative nature of the process, where loops lead back from specific process steps to inform and revise earlier assumptions, aims, or decisions. Its success certainly seems to be determined by its agility, user-centredness, and openness, openness also regarding responsible innovation and involvement of all stakeholders in the design process (cf. Holter et al., 2022; Jirotka & Stahl, 2020).

Based on the existing Design Thinking methodology, worksheets have been selected, customized, and invented, to guide learning designers in their activity, especially the first four steps.

This includes:

— *Empathy Canvas*: describe how your users think and feel, what they see, hear, say, and do, and what their pains and gains are.

— *Problem Statement Canvas*: Describe the goal in a sentence of the format As a… (user type) I want… (user need) so-that… (user goal).

— *Activity Map Canvas*: map out how the learning activity can be broken down into steps and distributed over the available space.

— *Augmentation Plan Canvas*: develop a more detailed plan of how steps are furnished with media and plan out the timeline in which media elements are kept alive across steps.

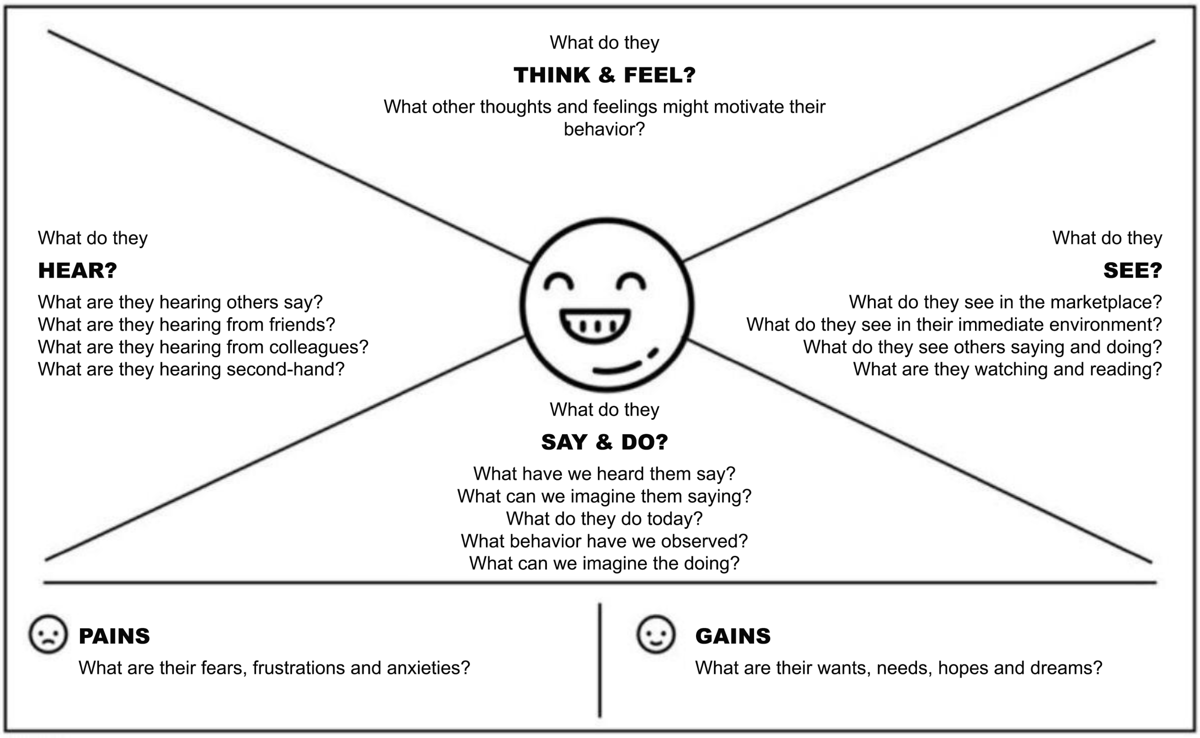

Figure 4 — Empathy Canvas

Who?	Who has the problem…
What?	What is the problem…
When?	When/where does the problem occur…
Why?	Why it is important to address for the user…

Figure 5 — Problem Statement Canvas

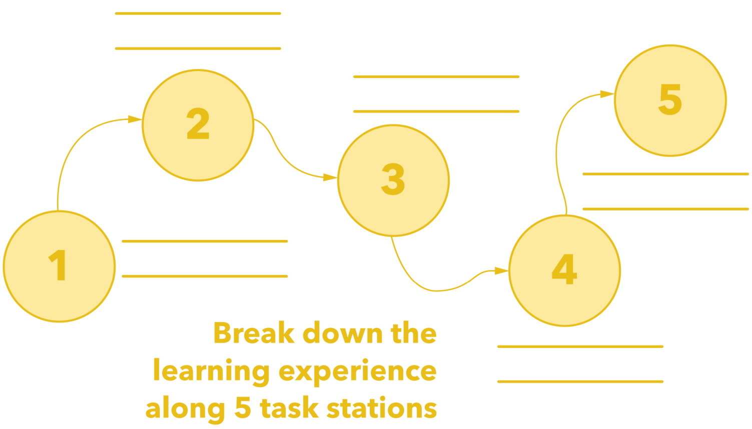

Figure 6 — Activity Map Canvas

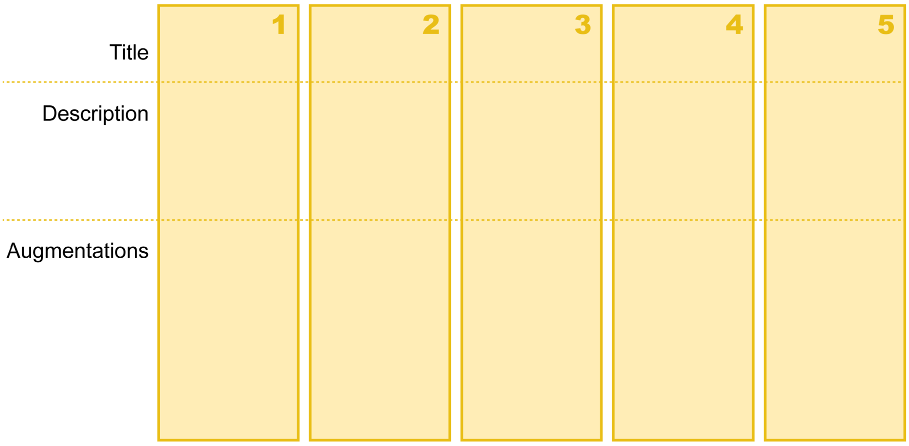

Figure 7 — Augmentation Plan Canvas

For simplicity reasons, Activity Map and Augmentation Plan are limited to five steps, but real experiences designed can of course take on much more complexity.

These worksheets can also be used in collaborative exercises in the training of XR learning designers, typically accompanied by a sensitizing introduction and, between Problem Statement and Activity Map a system demo of the MirageXR authoring side and between Activity Map and Augmentation Plan a more in-depth overview and discussion of available augmentation types.

The process of steps five and six then require additional resources. For testing, evaluation methods are plenty and well documented. This can be rather informal and agile, with a short loop between users and developers, especially in the early stages of prototyping. But this can also be rather formal, in the late stages of development.

For example, following Law & Wild, 2015, we recommend exploring these along the proposed TOPS model (Technical, Organizational, Pedagogical, Social). TOPS helps look at a rich set of objectives and metrics, covering, for example, usability, learnability, operability, accessibility, usability compliance, safety, engagement, the satisfaction of use, attractiveness, emotion, trust, adoption, technology acceptance, long-term impact, efficiency, effectiveness, usage effort, workload, retention, and task success.

4.4 Analytics: behaviour tracking with xAPI (IEEE P92741.1)

Already with the mobile revolution, tracking traces of user behavior became more and more difficult, with user activity spread out across different mobile and web apps. For this, the eXperience API (short xAPI) was developed, providing a decentralized solution for tracking user behaviour in a standardized way. The xAPI specification defines a simple format for recording user activity.

Key to the working principle of the xAPI is that the log statements are (in their most basic form) expressed as triples, i.e., three-part statements following the format of actor > verb > object, for example: *Fridolin read 'P1589-2020'. Thorin wrote 'essay on form'. Katerina viewed 'the final portrait'. Merlin attended 'the networking meeting'*, etc.

These three parts are:

— An actor with a name and a unique identifier.

— A verb that describes the action performed by the actor (composed of a URI and a display name).

— An object identifying what the actor performed the action in the verb.

Actors usually relate to real persons, and verbs tend to have clear definitions. Activities are typically defined by the applications that report the statements. Objects are less predictable, and they can relate to activities, actors, or even other statements (in the special case that a statement needs to be voided). Additionally, xAPI statements can include metadata such as timestamps, context, and result information.

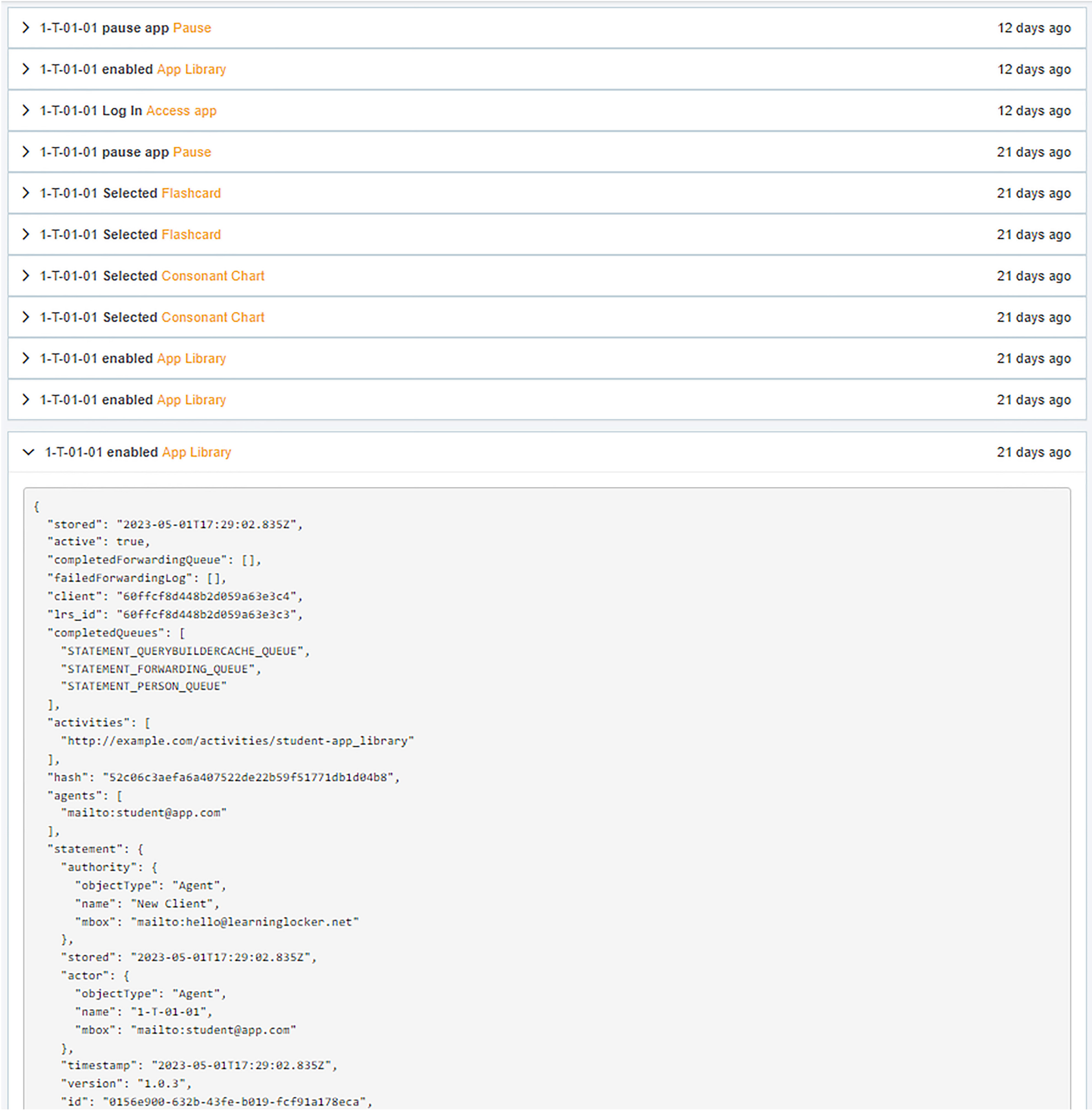

Figure 8 — Example statements

Such a statement is dropped by any participating application to a remote endpoint of a so-called learning record store (LRS), the xAPI learning analytics solution typically providing not just data storage, but also Learning Analytics dashboards.

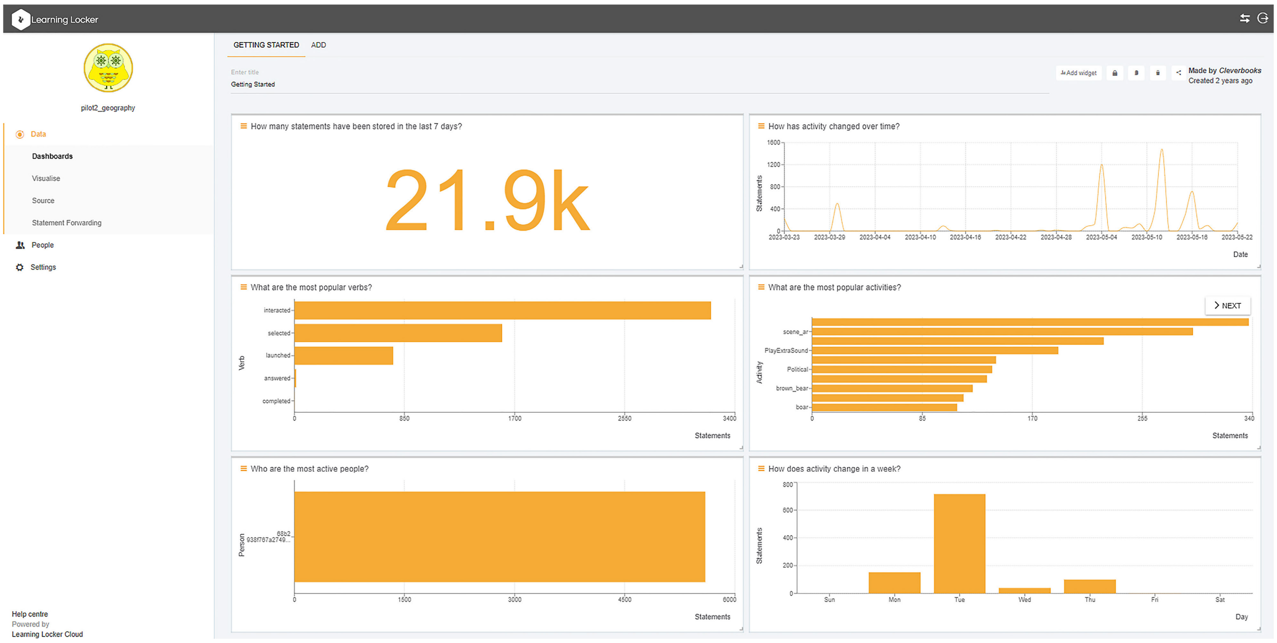

Figure 9 — Example dashboard

IEEE P1589-2020 already recommends logging AR learner activity using the predicates and predicate primitives provided (and the tangible objects handled).

More precisely, in the reference implementation, this means:

Table 2 — xAPI application profile for ARº1

Verb ID	Verb Name	Use in Objects
Primitives		
http://id.tincanapi.com/verb/viewed	viewed	label, image, model
https://activitystrea.ms/schema/1.0/find	found	detect
https://activitystrea.ms/schema/1.0/listen	listened_to	audio, sound
https://activitystrea.ms/schema/1.0/watch	watched	video
Action glyphs		
http://id.tincanapi.com/verb/focused	focused_on	act: Highlight, act: Point
https://activitystrea.ms/schema/1.0/open	opened	act: OpenBox
https://activitystrea.ms/schema/1.0/close	closed	act: CloseBox
https://wekit-ecs.com/verb/packed	packed	act: Pack
https://wekit-ecs.com/verb/unpacked	unpacked	act: Unpack
https://wekit-ecs.com/verb/picked	picked	act: Pick
https://wekit-ecs.com/verb/placed	placed	act:Place
https://wekit-ecs.com/verb/screwed	screwed	act:Screw

Verb ID	Verb Name	Use in Objects
https://wekit-ecs.com/verb/unscrewed	unscrewed	act:Unscrew
https://wekit-ecs.com/verb/rotated	rotated	act:Rotate
https://wekit-ecs.com/verb/lowered	lowered	act:Lower
https://wekit-ecs.com/verb/located	located	act:Locate
https://wekit-ecs.com/verb/lubricated	lubricated	act:Lubricate
https://wekit-ecs.com/verb/painted	painted	act:Paint
https://wekit-ecs.com/verb/plugged	plugged	act:Plug
https://wekit-ecs.com/verb/unplugged	unplugged	act:Unplug
https://wekit-ecs.com/verb/unfastened	unfastened	act:Unfasten
https://w3id.org/xapi/dod-isd/verbs/measured	measured	act:Measure
Further predicates		
https://wekit-ecs.com/verb/noticed	noticed	vfx (vfx:*)
https://wekit-ecs.com/verb/met	met	character (char:*)
Basic activity interaction		
https://adlnet.gov/expapi/verbs/launched	launched	activity - started
https://adlnet.gov/expapi/verbs/initialized	initialized	activity - loaded
https://activitystrea.ms/schema/1.0/complete	completed	activity - completed
https://activitystrea.ms/schema/1.0/start	started	step - activated
https://activitystrea.ms/schema/1.0/experience	experienced	step - deactivated

Apart from the vocabulary profile, another important aspect to consider for behavior tracking is the structure of the application or the experience. In this sense, gamification has been demonstrated to be one strategy that can structure and enhance engagement in learning because adding game elements to learning tasks makes them more fun and engaging for students of all ages.

XR technologies contribute to this gamification as they facilitate the students' understanding of abstract concepts and encourage them to participate and interact during the lessons. But although it is assumed that gamification is positive, an objective evaluation is always needed by the teachers while students complete the activities.

As mentioned before, xAPI provides mechanisms to track user behavior. But to be able to obtain helpful statistics about the performance and retention of the students and to be aware of the usefulness of the contents and their interaction in the experience, it is recommended to create and develop the target application taking into account the following aspects:

— Organization of the activities in a structured way, defining levels or modules to be completed by the students and the specific order to be followed.

— Correct identification of each activity.

— Consistency with the IDs of the activities, 3D objects and users.

— Specification of the relationship between activities if any.

— Inclusion of activities that enable the assessment of the performance of students through scores or assignments of points.

— Tracking of the time the students spend within the app and the number of times they enter and exit.

— Tracking the number of times, the students attempt each activity.

— Inclusion of a qualitative evaluation after each activity to see if there is any correlation between the opinion of the students and their performance.

— Identification of who interacted with whom in multi-user activities, to be able to optimise the learning experience of each student and the learning process of the group in general.

The fulfilment of the previous guidelines enables one to obtain a good summary of the experience in gamified frameworks, allowing one to generate dashboards such as the one shown in Figure 9, that could offer relevant information for the teacher, such as the questions failed or the average scores by levels. Furthermore, a correct structure of the data could lead to the possibility of applying to clustering, to identify different behavior trends, or creating recommendation and prediction systems in case of having a high number of students completing the same activities. This high number could be achieved, for example, with different students in different classrooms or schools, or different students over the years.

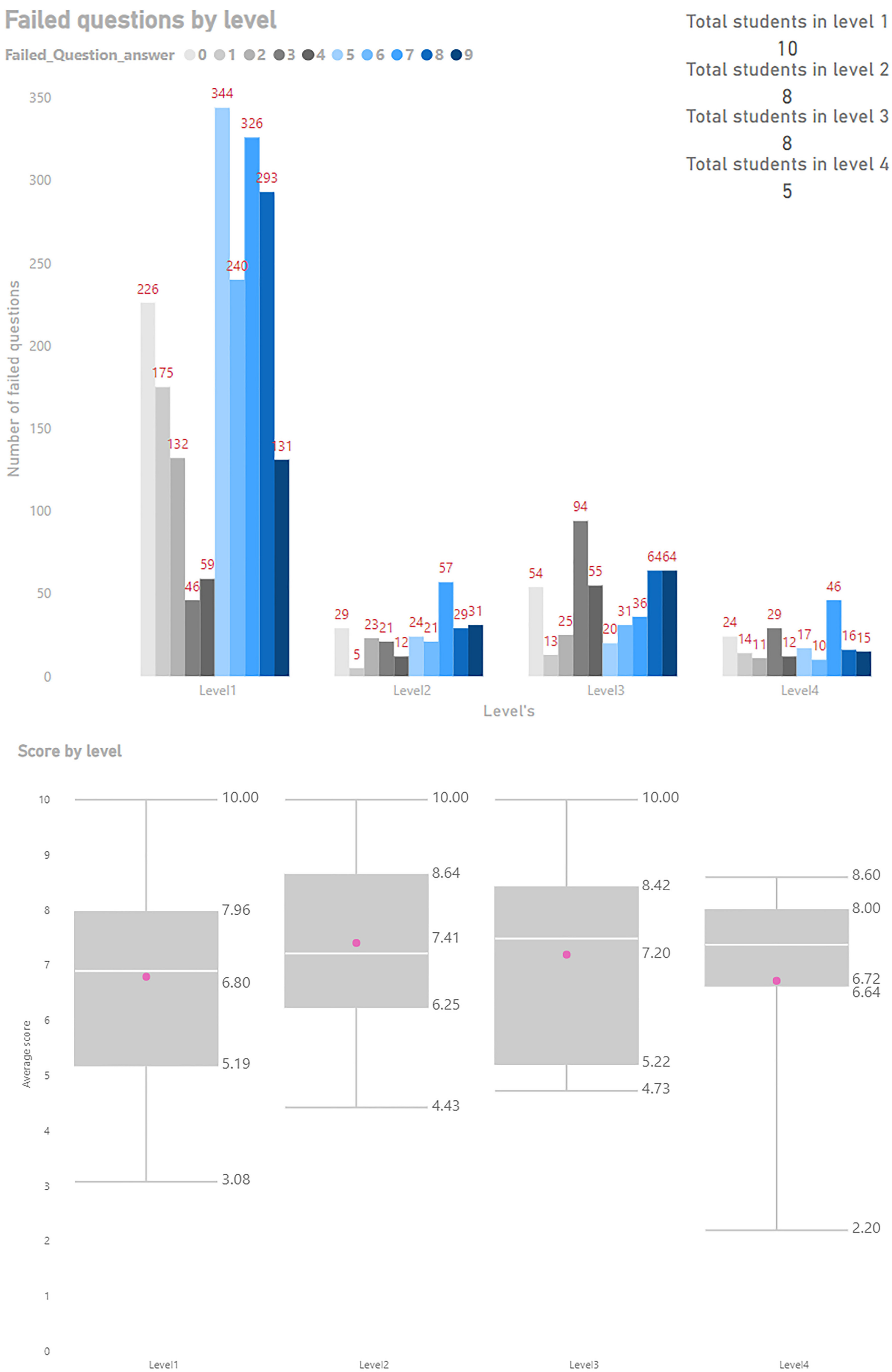

Figure 10 — Progression tracking in the gamified framework (from ARETE project)

4.5 Integration with Learning Management Systems

IEEE P1589-2020 stores the resulting learning content units in form of a zip-compressed archive, wrapping activity and workplace model together with all media assets required for its execution. This means, its integration into existing learning management systems is possible, by simply linking the file from the regular course content.

The standard does not include the use of a protocol, but as the reference implementation shows it is good practice to register with mobile and wearable applications an associated protocol (for MirageXR, this is "wekit://"). This means that any link provided with the application protocol registered in the browser automatically starts the app and, if implemented accordingly, proceeds with download and execution.

A repository service, however, can help simplify the management of AR learning content. The reference implementation of IEEE P1589-2020, MirageXR, works together with an Open-Source Moodle plugin.

The Moodle AR Experience plugin (mod_arete) was developed to establish communication between the P1589-2020 execution engine (e.g., MirageXR) and a Moodle server as a repository service. The plugin uses Moodle web services and the REST protocol for this purpose. The plugin is responsible for both displaying the uploaded activities in Moodle on browsers and for managing communication with requesting apps via the API.

The plugin is available, currently from a GitHub repository. Moodle accepts the repository in zip format. To generate the zip archive, it is necessary to clone the repository, and delete the .git folder and change the folder from "moodle-mod_arete" to "arete". It is possible, then, to zip the entire folder to make the zip archive. Then the archive is imported as all other Moodle plugins, the administrator can drag and drop the zip archive in the box at the site/administration/plugins/installplugins endpoint.

The README on the GitHub page also gives the settings that it is necessary to add to Moodle to make the plugin work with the clients.

The Arete plugin makes available a moodle web service and requires the instantiation of security tokens to accept the REST calls.

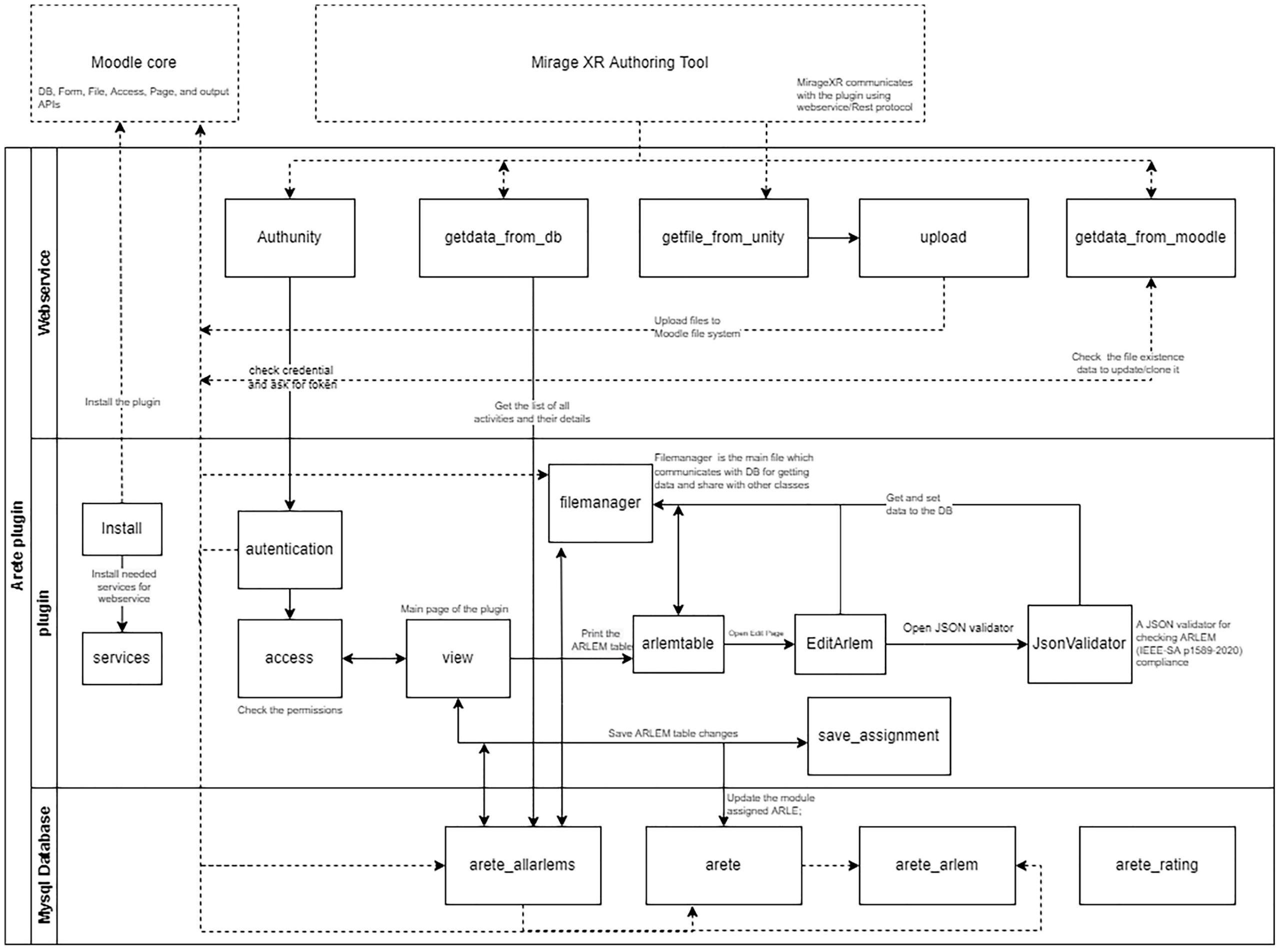

Figure 11 — Moodle repository API of the 'AR experience' module

4.6 3D assets with the Graphics Language Transmission Format (glTF) (ISO/IEC 12113:2022)

4.6.1 General

In the era of multimedia computing, 3D assets and computer graphics have gained crucial importance. They are used in a wide variety of applications, from video games and film animation to industrial additive manufacturing. Typical properties of a 3D asset include geometry, topology, material/appearance and behavior. One of its peculiarities is that it can be fully animated, which makes it an indispensable resource for animating characters and special effects. Also, by using it in the initial stages of a project, there is a three-dimensional blueprint that can be tested for multiple scenarios, which in turn saves a lot of time and resources.

To simplify creation and distribution, information about 3D models is typically stored in a unique file in a format that computers can understand, either as plain text or as binary data. Currently, there are numerous 3D file formats, each of which has its own purpose and use case. Most formats fall into one of two categories: proprietary and neutral.

1. ***Proprietary*** includes 3D formats that can be used only with specific software. Technical documentation of their structure often is not provided, outdated or incomplete. Formats in this category are very efficient, although not flexible. Some prominent file formats in this category are:

a) **BLEND**: Blender's file format is one of the most complete ones. It allows for storing data about 3D models, colors, textures, scenes and even animations. This software is used in the design, video game and animation industries.

b) **.SKP**: It's used in SketchUp, an accessible 3D modelling software used mainly for concept designs and renders. It's a popular format among interior designers and architects.

c) **.3DM**: Used as the standard format in Rhino and Grasshopper. It is popular in the industrial design and architecture industries due to the complex models it can generate, which can be stored in 3DM files as parametric surfaces or simpler meshes.

d) **.3DS:** Originally developed in the early 1990s for *Autodesk 3D Studio*, it stores information on the makeup of 3D vector graphics. This includes mesh data, material attributes, camera, and lighting information, and more. 3DS is an old binary-based file format, restricted which means it's restricted to descriptors rather than the actual image itself. (https://en.wikipedia.org/wiki/.3ds).

2. ***Neutral*** 3D formats are cross-platform or software-independent, which means that an asset can be modified by different software that supports the file format. Well-known examples of the neutral format are:

a) **OBJ**: OBJect was developed by *Wavefront Technologies* in the 1980s. This format is the most used 3D file type, which offers the simplest file support and is the least detailed. (https://en.wikipedia.org/wiki/Wavefront_.obj_file).

b) **STL**: This is the most popular format in the digital manufacturing industry. The 3D models are represented as a triangular mesh with a variable density that does not contain colours, textures, or scenes. This makes this format very suitable for computer-aided manufacturing (CAM), rapid prototyping and 3D printing.

c) **FBX:** An abbreviation of "Filmbox" - a film capture tool from *Kaydara*, which developed the file format in 2005. Today, the format is governed by *Autodesk* as a "free platform-independent 3D authoring and interchange format that provides access to 3D content from most 3D vendors". It is a very popular 3D file type well suited for high-end games and computer-generated imagery (CGI) in film.

4.6.2 Graphics Language Transmission Format (glTF) (ISO/IEC 12113:2022)

In today's era of spatial and immersive computing, where 3D models are becoming a typical component in numerous fields, a format that focuses on the efficient transfer and loading of 3D scenes and models by applications is preferable. In response to this new requirement, *Khronos Group* has developed a new 3D file format called *Graphics Language Transmission Format*, glTF (https://registry.khronos.org/glTF/specs/2.0/glTF-2.0.html), which focuses on compactness, and is vendor and runtime-neutral. Its primary goals are to be deployable on a wide range of devices and platforms, including the web and mobile devices, and scalable to keep pace with growing to compute capabilities.

The first iteration of glTF was discussed in 2012 as an update to COLLADA but was soon further developed as an independent standard with a release of the *glTF 1.0 specification* in 2015. It can be described as JSON files plus supporting external data:

— A JSON formatted file (.gltf) containing a full scene description,

— Binary files (.bin), containing buffer-based data,

— image files (.jpg, .png, etc.) for textures, and

— GLSL text files (.glsl) for GLSL shader source code.

With a growing user base and with feedback from stakeholders across industries, the glTF specification was improved by the Khronos Group in several areas for the release of *Version 2.0* in 2017, including tightening corner cases and optimizing the format for improved application performance:

— Physically Based Rendering (PBR), allows shadows and light to appear more realistic.

— An updated version of the binary file.

— Coding updates for speed and improvements in animation.

— A clear objects hierarchy in the 3D scene structure.

— Storing scene information such as light sources and cameras, supporting instance feature.

— Skeletal (joints), TRS, morph animation support.

With these advanced features and the fact that glTF is designed for maximum compatibility with web browsers – something that other 3D file formats lack– it is becoming the standard format for business blending 3D models and the World Wide Web. The format also has speed advantages over other 3D file formats, as 3D asset files can be up to five times smaller and read up to ten times faster. In the field of animation, glTF is known for its ability to perform complex changes and updates in a relatively short time and to simultaneously handle multiple animations in one file.

Despite all the advantages glTF in its current formulation can offer, some caveats need to be considered: Render quality could be an issue, as glTF is not geared towards high-end game development or special effects in the film industry. The stored models in glTF may be comparable in quality and complexity to FBX, but lack important features such as shader networks. It is also not optimized for 3D printing, so conversion to STL file format or OBJ may be required.

4.6.3 Universal Scene Description (USD, USDz)

Another recent data format that is currently being used mainly for interchange between different tools in film production pipelines is called *Universal Scene Description* (USD), developed and maintained by *Pixar Animation Studios*.

USDz leverages USD's FileFormat plugin mechanism with an archive format that contains proxies for files of other formats embedded within the archive. It is used by *Apple* within its Augmented Reality (*ARKit*) ecosystem. Under the governance of the *Metaverse Standards Forum* efforts are currently being made to join benefits of USD and glTF.

4.7 Note on virtual instructors ('virtual humans')

When creating virtual humans, the following asset types are required for converting them into executable virtual instructors:

— 3D model.

— Rig data with inverse cinematic handles for controlling movement of body, facial expression, eye movement, and lips.

— Animation data with captured motion.

— Voice data with phoneme markup (for viseme control).

— Optionally, dialogue models for conversation.

Generic body animations for virtual instructors can include: “Idle”, “Point”, “Hello”, “Bye”, “Sitting”, “Thumb Up”, “Thumb Down”, “Writing”, “Present Image”.

Currently, standards endeavours for virtual humans are on the way, but have not concluded. These seek to standardize file formats for the efficient and effective exchange of relevant data.

4.8 Note on reality mapping and tracking

Privacy can be affected by the spatial mapping and tracking provided in an XR application for learning and performance augmentation. Depending on whether processing happens locally or in the cloud, raw image data and high-resolution spatial meshes may even leave the device and be processed or stored online. At the same time, (edge) cloud processing promises the much-desired future gains in miniaturization, offloading computationally intense processes for tracking, processing, and rendering. Whether blockchain distributed ledger technologies may provide a secure way out of this dilemma can currently not be predicted.

To assess the suitability and appropriateness of solutions, it is important to scrutinize their data protection statements, which are impacted by the facilities provided by underlying components for tracking, mapping, and rendering.

a) Image targets and markers:

Image targets and markers can be stored in JPEG (ISO/IEC 10918) and PNG format (ISO/IEC 15948:2004). They can then be directly included in the IEEE P1589-2020 archives. When executed, the JPEG or PNG image will be loaded into the Augmented Reality Tracking.

b) Spatial mapping:

There currently is not yet any standard for spatial maps or point clouds, though several are emerging. XR learning and performance augmentation does not require the exchange of room scan data, though this could speed up the start process of applications.

c) Spatial anchors:

Spatial anchors are relative locations in a room scan. IEEE P1589-2020 provides an interface but could benefit from simplification. Currently, tangibles provide a point of interest with the relative location from the world origin, but they can also link to a detectable anchor, with the anchor not providing any coordinate information, which is confusing.

4.9 Note on real-time communication and sharing

Real-time communications and sharing in multi-user AR educational settings can be faced through different technologies depending on the purpose. The most used open-source, real-time communication framework for mobile applications and web browsers is WebRTC. Regarding communication and data sharing between users, the Web Sockets protocol is recommended whenever quick connections are needed. This applies, for example, to support chats, instant messaging services and real-time gaming.

More in detail, Web Sockets provide full-duplex communication channels over a single TCP connection. The WebSocket protocol was standardized by the IETF as RFC 6455 in 2011 and the current API specification allowing web applications to use this protocol is known as WebSockets.

WebSocket is located at layer 7 in the OSI model and depends on TCP at layer 4. While the WebSocket protocol itself is unaware of proxy servers and firewalls, it features an HTTP-compatible handshake, thus allowing HTTP servers to share their default HTTP and HTTPS ports (80 and 443 respectively) with a WebSocket gateway or server. The WebSocket protocol defines a ws:// and wss:// prefix to indicate a WebSocket (unencrypted) and a WebSocket Secure (encrypted) connection, respectively.

The protocol has two parts: a handshake and a data transfer. To establish a WebSocket connection, the client sends a WebSocket handshake request, for which the server returns a WebSocket handshake response. After that, servers are enabled to handle HTTP connections as well as WebSocket connections on the same port. Once the connection is established, communication and data transfer switch to a bidirectional binary protocol.

This bidirectional communication enables the necessary message sharing to guarantee an updated state of all the variables that will provide a synchronized and coherent augmented space. These variables could represent the position of the students/teachers in 3D environments, questions from the teacher to the students or relevant interaction information and could be updated both in broadcast and in unicast modes.

Regarding voice sharing and real-time media communication and consumption, they can be implemented through WebRTC. WebRTC is an open-source project providing real-time peer-to-peer communication, supporting video, voice, and generic data to be sent between peers. The technology is available on all modern browsers as well as on native clients for all major platforms. Relevant protocols used by WebRTC have been standardized by the IETF and browser APIs specifications have been published by W3C.

The flow followed by a WebRTC application usually consists of accessing the media devices, opening peer connections, discovering peers, and starting streaming.

There are many use cases for WebRTC, from basic web apps that use the camera or microphone, to more advanced remote assistance applications using augmented space or collaborative environments where volumetric data and spatial audio are shared.

5 Meta-Data

Meta-Data means, literally, data about data, and is used to refer to information related to the resource, but not crucial for its consumption. Most prominently, this includes the creation date or the typical execution duration of a learning resource. Meta-data is particularly important for search in digital libraries.

Among several metadata specifications, the Dublin Core™ Metadata Element Set (DCMES also known as Dublin Core, ISO 15836-1:2017) is of particular interest due to its capability to support a broad range of purposes and business models. Focused on learning, education and training, the IEEE Learning Technology Standards Committee (IEEE LTSC) used Dublin Core as a starting point to develop (jointly with IMS Global Learning Consortium) a conceptual data model for describing "learning objects" known as IEEE LTSC Learning Object Metadata (LOM).

Both organisations, the Dublin Core™ Metadata Initiative (DCMI) and the IEEE LTSC P1484, realise the benefit in maintaining compatibility between the development of LOM and Dublin Core and aim at an ongoing collaboration acknowledging the expertise of DCMI community in requirements for general metadata and respectively the expertise of IEEE LTSC LOM Working Group in requirements that are specific to learning, education and training (*Memorandum of Understanding*, 2000).

In learning and performance augmentation, Learning Management Systems (LMSs) can be thought of as large digital libraries, sometimes called 'learning object repositories', that are responsible for organizing and sharing learning resources. LOM, by providing a conceptual data schema for defining the metadata instance structure of a LO, can play a particularly important role in facilitating the search, evaluation, acquisition, use, sharing, and exchange of resources in such learning repositories. For example, by implementing LOM, learning technology systems can improve their communication with other heterogeneous systems to share information about LOs, having a high degree of semantic interoperability and offering linguistic diversity of LOs and the metadata instances that describe them. In addition, most of the learning object repositories provide advanced searches on different parameters like subjects, topics, learning resource types etc. Therefore, LOs are more easily searchable when tagged with metadata that describes them, supporting their classification and organization.

LOM defines a LO can be "*any entity, digital or non-digital, that is used for learning, education, or training*" (IEEE 1484.12.1-2020 "IEEE Standard for Learning Object Metadata") and thus it can be used to represent various types of resources, such as diagrams, narrative text and simulations. However, XR is a relatively new technology and such LOs could have different properties and characteristics than conventional learning resources. With the continuous evolution of emerging technologies, shortly the XR learning, and performance augmentation communities will likely implement LOM by adapting it to their needs. LOM allows extensions to the conceptual data schema so that specific community requirements can be met, for example by creating new vocabularies for existing elements, new elements, or element categories.

Table 3 lists the elements provided by LOM (at the first and second levels of the hierarchy) along with the description for each category of elements. It presents some recommendations and ideas that could be considered for describing XR learning and performance augmentation resources, while some of them are more general and can be considered for other types of educational resources as well.

Table 3 — Meta-Data for XR learning and performance augmentation

Category (LOM)	Description	Elements	Recommendation
General	Information to describe the LO.	-Identifier -Title -Language -Description -Keyword -Coverage -Structure -Aggregation Level	Considering the Reusability Paradox, in cases where a LO has not an open licence applied, instructional designers should try to maximise the educational benefits of a LO without incorporating as many contexts as possible, since then they minimise its reuse.
Lifecycle	The history and current state of this LO.	-Version -Status -Contribute	All versions of the LO along with their state should be noted.
Meta-Metadata	Information to describe the metadata record itself. — This is not the information that describes the learning object itself.	-Identifier -Contribute -Meta-Metadata Schema -Language	For semantic interoperability reasons, the metadata schema that is being used (e.g LOMv1.0) should be noted.

Category (LOM)	Description	Elements	Recommendation
Technical	Describes the technical requirements and characteristics.	-Format -Size -Location -Requirement -Installation Remarks -Other Platform Requirements -Duration	- In the case of digital resources, their format should be represented using MIME types based on IANA registration (IETF RFC 2048:1996) and not using their file extension. - A relatively small size of the digital LO (in bytes) is probably preferred by consumers if this does not affect the quality of the content. - Technical requirements such as operating system and browser for the use of a LO should be noted. - The 'Other Platform Requirements' field can be very useful for reporting required software and hardware that cannot be expressed with the 'Requirement' field. In terms of XR, for example, such requirements could be Magic Leap, HoloLens, rumored Apple headsets, or other types of hardware. - Future XR-related LOM extensions may also include in this category fields capable of describing what hardware/software is recommended for optimal compatibility; what kind of XR scene triggers are used (e.g., no marker or use of embedded AR markers); the size of the marker, when in use; as well as environmental requirements such as illumination and free space needed/recommended.
Educational	Describes the educational and pedagogic characteristics.	-Interactivity Type -Learning Resource Type -Interactivity Level -Semantic Density -Intended End User Role -Context -Typical Age Range -Difficulty -Typical Learning Time -Description -Language	- Given that XR offers possibilities for active interactions, instructional designers are advised to take advantage of the technology by avoiding passive learning where they deem it to be beneficial. - The 'Educational' category could also in future extensions list elements to describe LOs in terms of Prior technological knowledge and domain knowledge required for better comprehension; the level to which the LO can immerse the user; and potential user actions required (e.g., user mobility and interaction with other learners).
Rights	The intellectual property rights and conditions of use.	-Cost -Copyright And Other Restrictions -Description	Free/open licences are considered good practices for the free distribution and reuse of XR educational content.
Relation	Defines the relationship with other LOs.	-Kind -Resource	Possible relationships between LOs should be noted for search engines to associate the use of the objects.

Category (LOM)	Description	Elements	Recommendation
Annotation	Provides comments on the educational use of the LO.	-Entity -Date -Description	To support the appropriate use of the LO, comments on its educational use should be noted.
Classification	Provides insight for the classification of the LO.	-Purpose -Taxon Path -Description -Keyword	According to "1EdTech Meta-data Best Practice Guide for IEEE 1484.12.1-2002 Standard for Learning Object Metadata" the 'classification' category can be used to accommodate specific requirements (thus avoiding extensions). The specification also notes that both LOM extensions and the use of the 'classification' category may significantly affect semantic interoperability. In cases where it is deemed necessary and appropriate, the use of general taxonomies such as Blooms' or specific subject domain taxonomies can contribute to the classification of a LO.

6 Human Factors

6.1 XR accessibility

6.1.1 General

XR is an enabling technology that a user can use to 'do' and 'experience' things not possible in actual reality. But XR can also be a disabling technology for some communities of users, for example, having data output in only one modality that not all users can perceive. Limitations like these can present challenges and barriers to use. These challenges can be mitigated with further development and a fuller connection with a wider gamut of users' requirements. In short, we need to establish a greater understanding of users' requirements and limitations when using XR as this can open up XR access 'for all'.

6.1.2 Using user-centred design to put "people first"

XR is still a relatively immature media, both when it comes to hardware, software, and specific applications. There is a great sense of excitement among developers and curators to develop experiences and opportunities, but in this excitement, there is a lack of awareness and focus on accessibility and inclusion. Unfortunately, technologists, designers, and developers place their initial attention on technological architecture and achievable outputs. However, to fully understand accessibility, we need to start by using a "people first" approach working with a human-centred design that starts and ends with users' needs and circumstances rather than technological opportunities.

User-centred interaction design requires developers to follow good usability practices. For example, developers need to eliminate excise, use clear and distinct affordances and pliancy hinting, have an output that uses more than one modality, and give the user extensive possibilities to personalize the input controls and the output modalities of the user interface. A general guide on these best practices can be found in the textbook "About Face" (Cooper, 2014) The design and development process for an XR experience follows a long series of steps, starting with an early pitch and ending with the final user testing and shipment. Care for accessibility should come in as early as possible and stay throughout these outlined steps.

However, when it comes to the development and curation of XR technology and experiences, additional care needs to be taken to cater for the specific needs of the individual and to further understand how they relate to the specific inputs to XR system or tools. Very strict requirements on fulfilling accessibility can stifle innovation, so a balance needs to be found between enabling an experience for the majority and everyone. The W3C XR Accessibility User Requirements: https://www.w3.org/TR/xaur/ is strongly recommended.

6.1.3 Disability and human rights

Human rights postulate that nobody must be discriminated based on:

— age,

— disability,

— gender reassignment,

— marriage and civil partnership,

— pregnancy and maternity,

— race,

— religion or belief,

— sex,

— sexual orientation.

For example, within the UK equality act 2010, "A person has a disability if she or he has a physical or mental impairment which has a substantial and long-term adverse effect on that person's ability to carry out normal day-to-day activities." (Equality Human Rights Act, 2010). The term disability may initially appear to account for the needs of a homogenous community of people. However, to create XR that is both useful and purposeful for a wide range of users, developers need to account for numerous individual and lesser-known barriers to accessing XR for people with specific conditions. It is also important to understand the interoperability between XR applications and existing assistive technologies (AT). Just to exemplify, this can range from basic issues such as having physical space for eyeglasses inside the VR headset to advanced solutions such as voice synthesizers reading text aloud.

It is very common to develop partial, temporary, or fuller disabilities within the human lifespan. At some point in life, we all will have experienced some form of partial or temporary disability. The World Health Organization (WHO) statistics show that over 1,3 billion people worldwide have some form of disability, that is to say, *1 in 6 people* in the world today are classed as disabled.

Many countries across the world are legally obliged to respond to the needs of people with disabilities under international human rights law. Many of the more developed countries have responded to people with ability needs with a more detailed and consolidated response.

6.1.4 Conformance

Various legislation forbids discrimination of any form. Digital discrimination has been refuted by legislatures in many countries and regions. For instance, European Union (EU) directive 2019/882 directs digital products to be accessible (European Union, 2019), whereby Article 9 of UN conventions of rights of persons with disability portrays that technological products should be accessible to people with disabilities (United Nations, 2016). Similar legislations are also available in various countries, such as Germany (Bundesamt für Justiz, 2019) and the UK (United Kingdom, 2018). To enforce these legislative requirements, it is vital to have guidelines that will guide developers to follow during the development process and auditors to use them for auditing purposes. In web accessibility, it is plausible to enforce accessibility laws because of existing guidelines, such as Web Content Accessibility Guidelines, WCAG (W3C, World Wide Web Consortium, 2018).

The situation is different in XR accessibility. In XR accessibility, there are numerous guidelines, each under different organizations. Such guidelines include EN 301 549 ‘Accessibility requirements for ICT products and services’ (ETSI, European Telecommunications Standards Institute, 2021), XR Accessibility User Requirements (XAUR) (W3C, 2021), Apple Human Interface Guidelines (AHIG) (Apple Inc, 2022), and Google Augmented Reality Developer Guidelines (GARDG) (Google Inc, 2022).

ETSI EN 301 549 is a response to EU Directive 2016/2102 on accessibility standards, in which their guidelines are based on WCAG. Another guideline to consider is XAUR. It presents the list of needs and requirements for users with disabilities when using immersive and related technologies. The remaining two guidelines, AHIG and GARDG, are usability guidelines from commercial vendors, Apple, and Google.

When comparing these four guidelines, Koch et al., 2022, found no common aspect to all four guidelines. Many aspects are present in either one or two guidelines, rarely in three. For instance, only XAUR guides on sign language, and multiple device inputs, focusing on essential areas and critical inputs, to mention a few. Moreover, the peculiar aspects of ETSI EN 301 549 are privacy, independent adjustments, documentation, font size, the importance of colours, and background contrast, to mention a few. Besides, some aspects exist in AHIG and GARDG but neither in ETSI nor XAUR. Such aspects include avoiding distraction, gestures, tutorials, and multiple modes, to mention a few.

Further, there are other guidelines and recommendations for VR and AR. For instance, Meta Quest published two Virtual Reality Checks (VRC) for accessibility requirements covering their two headsets (Meta Quest, 2022). Other examples are an accessibility overview of VR environments from Melbourne University (Peillard et al.,, 2019), Game accessibility from various contributors (Various Contributors, n.d.), developers’ guidelines from the XR Association developers guide (XR Association, 2020), and best practices and recommendations from IEEE global initiative on ethics of extended reality (Fox & Thornton, 2022).

These numerous guidelines in XR and their diversities show how complicated it is for XR creators to conform to XR accessibility standards. Therefore, there is a need for the unification of XR guidelines. Until such a unified view is achieved, we would especially like to emphasize the XR Accessibility User Requirements from W3C as an appropriate starting point.

6.1.5 The full XR technology stack

Below, the full XR technology stack is listed and examples are given on how the different parts relate to accessibility. This highlights the need for many actors to take respective responsibility. It also illustrates the need for interoperability and working together to solve problems. For example, some issues, such as motion sickness, are both hardware and software-dependent, and mitigation needs to be applied on more than one level.

a) Hardware (headset, hand controllers etc.): This is of course the responsibility of hardware manufacturers, but the purchase decisions of each local school or university matter. Interoperability between assistive technologies and XR hardware is an important area for further development.

b) Operative system: In XR, the OS on the headset is bundled with the hardware, so the choice of hardware is often also a choice of OS. On the OS level, there can be important interoperability considerations for assistive technologies, and customizability for different user needs should be possible.

c) Application library: This is also often bundled with the hardware. However, open distribution services such as Steam can often broaden the repertoire of applications and thus make it easier to find applications with acceptable accessibility conformance.

d) Application: Much of the accessibility requirements fall on the application/experience. It is the application that needs to allow appropriate input controls and output modalities, and customizability for different users might be necessary.

e) Embedded media: This can be for example text, narration, or video material, and even if this is technically a part of the application it can be appropriate to consider the embedded media separately from an accessibility viewpoint.

When it comes to XR and teaching, there is one extra layer to consider on top of the five outlined above: the design of the learning activity itself. Teachers decide what learners should do and experience in XR and need also be aware of the risk of deciding assignments, actions and such that are challenging for persons with disabilities.

6.1.6 XR accessibility and adoption

As previously discussed, the development of accessible XR technologies should be centred around users-needs. Although XR has the potential to add value to the daily lives of people living with disabilities, as a community working with XR, we should observe some challenges of adoption and acceptance from the field of Assistive Technologies (AT). Petrie et al., 2018, state that users may abandon wearable technologies if the technology ‘does not physically fit the user’s body’.

Petrie goes on to add: “If the AT does not enable the performance of the tasks, or all the tasks, that the user wants to do and cannot (easily) do without an AT, there is also a likelihood of abandonment.” (Petrie et al., 2018).

Understanding the users’ multidimensional needs can also become an indicator of abandonment predictors. A study by Phillips and Zhao, 1993, defines four key factors significantly related to user abandonment:

— lack of consideration for users’ feedback,

— complex procurement,

— poor device performance, and

— a change in users’ needs/priorities.

These key factors are still relevant as reasons for users to abandon technology such as XR, particularly last bullet point is significant, as it speaks to the ongoing adoption of technology. People living with disabilities often find that their ability needs can alter drastically as they age. The challenge of ‘users’ adoption’ of XR technology forms a complex part of ongoing research into XR accessibility, and the struggle to include all users are ongoing and in constant flux.

6.2 Usability and effectiveness of AR-based education

The following usability design guidelines are derived from the general usability design guidelines (Nielson and Molich, 1992) and XR research (LaViola et al., 2017; Law and Heintz, 2021) to verify that the design requirements are appropriate for XR applications:

1. Learnability: XR apps should allow inexperienced users to rapidly grasp the tasks inside the application and execute the required procedures to finish the tasks. A quick-start guide should be supplied to users to offer a brief introduction to the app's functionality to enhance the app's learnability. In addition, the guide should be created using simple, user-friendly terminology, such as iconographic language. In addition, XR interaction should be built by altering real-world items to make use of user-familiar interaction metaphors.

2. Simplicity: XR applications should be simple, aesthetically appealing, and user-friendly. Complex user interfaces demand greater processing time and cognitive strain to comprehend a task, according to human processor models of human-computer interaction (Card et al., 1983). Therefore, the design of the XR user interface should be as straightforward as possible. To keep user interfaces simple, useless or superfluous information or components should be eliminated. In addition, XR user interfaces should employ the same design across the application to increase consistency and simplicity.

3. Engagement: XR applications must be engaging and interactive to use. Users that are motivated are more likely to use the application for a longer period. Moreover, motivated and interested students are likely to remember more information from the session. To further motivate students, gamification components such as a scoreboard and scoring system may be incorporated into the app to establish a mild level of competitiveness. Badge or token systems may also be utilized to inspire students and instil a feeling of accomplishment in them.

4. Help: XR applications should provide users with suitable instructions and/or help options. While help options might be made available via other channels, such as the internet or customer support, providing help options can lessen the workload of customer support. Therefore, a basic help button should be included in the XR application to give simple instructions and remind users of the app's functionality.

5. Suitability: XR applications should also consider real-world scenarios and physical environment constraints. XR activities, for instance, should be planned to be short enough to fit into a comfortable session and should promote pauses to prevent fatigue. To prevent accidents in the real world, the system will also discourage XR interactions that demand a lot of space around the users.

6. Feedback and Error Handling: XR applications should give users timely, relevant, and meaningful feedback, particularly when users interact with XR components. Users are assured that their input has been logged when they get feedback, enabling them to comprehend the present status of the system. Consequently, the XR app should provide both auditory and visual feedback. Feedback will also be utilized to inform users of system errors and potential solutions. As a simple way to correct potential problems and minimize human error, the “back” function should be available for users to reverse their actions, so they do not have to perform the whole task if an error happens.

7. Customizations: XR applications should be customizable and flexible. Users should be allowed to reconfigure their workspaces to enhance ergonomics. For example, users should be able to affix control panels in a 3D location that is easily accessible. In education, teachers should be able to tailor XR materials to the needs of their class, as well as easily produce XR-based learning content and construct learning activities. From the perspective of the students, a customization option that allows them to personalize virtual items and utilize them in the class might further increase their engagement.

8. Marker: If XR applications use markers, the design, and use of the markers must be appropriate. The design of the markers should be recognized and simple to interpret in terms of their function. Multiple users should be able to utilize the marker concurrently without occlusion, while markers and augmented objects should be able to remain inside the camera field of vision of the user's device.

9. Virtual object: XR virtual objects must be visible on the user's device and offer a feeling of co-presence. To increase visibility, virtual objects should fit the field of view of the target device's camera and should face the user when they first show on the device, so the user does not have to adjust their position to observe the virtual objects. Certain sorts of virtual objects, such as text boxes and labels, must always face the users to optimize readability. A sensation of co-presence may be enhanced if virtual objects are anchored in the actual environment without positional and orientational errors. To persuade users that virtual items exist in front of them, lighting and shadows may also be employed to enhance realism.

10. Interactions: XR applications should have an interaction design that is compatible with the physical devices; the interaction design should also consider the physical attributes of the device, such as its weight and size. For instance, tablet user interfaces may be positioned near the gripping points for quicker thumb access while using two hands. In addition, constraints may be applied to minimize the degree of freedom of the user's input to increase manipulation accuracy; for example, users can restrict virtual objects to moving exclusively on the floor, which makes virtual object placement simpler and more precise.

11. Reliability: XR applications should be fast and reliable. The application's virtual objects must be optimized for fast loading. Additionally, the system should be tested on the recommended devices to minimize errors and delays.

7 Policy

7.1 XR ethics

The Extended Reality (XR) Ethics in Education report is the result of work within the IEEE Global Initiative on Ethics of Extended Reality (XR), a multidiscipline group of industry practitioners, ethicists, academics, researchers, educators, and technology enthusiasts. Although policies and recommendations exist on Digital Learning 2020 related to reporting on practice in early learning and care; primary and post-primary Contexts, there is minimal reference to the prospect of XR educational systems. This report, currently under development, builds on work outlined in the 'Extended Reality' chapter of the IEEE's seminal ethics-focused publication "Ethically Aligned Design". The scope of this report is the exploration of ethics-related issues to support the development, design, and deployment of XR applications in Education and the aim is to initiate expert-driven, multidiscipline analysis of the evolving XR Ethics requirements, with a vision to propose solutions, technologies, and standards in future updates. The set of recommendations within this report will hopefully contribute to the industry conceptualization of socio-technological issues, highlight concreted recommendations, and lay the groundwork for future technical standardization activities.

Immersive technologies (XR) in education offer several opportunities: facilitating Authentic Learning Experiences; empowering learners as creative designers and makers; integrating immersive storytelling in learning; integrating immersive learning in STEM; fostering collaboration with Social VR and other XR technologies; cultivating immersive and blended-reality learning spaces and laboratories; developing the capabilities of the future workforce (Lee, Georgieva, Alexander, Craig, and Richter, 2021). But the convergence with Artificial Intelligence, AI, can have a profound impact on ethics considerations for their applications at all levels (Johnson-Glenberg, Bartolomea, and Kalina, 2021). Utilizing AI in XR can reshape human experience and social interactions in education but one of the barriers for adoption is the lack of policy on XR ethics for education (Ligthart, Meynen, Biller-Andorno, Kooijmans, and Kellmeyer, 2021; Wang, Ryoo, and Winkelmann, 2020).

Ethics XR for education is a broad topic that needs to be present within the different levels of education. In the report under development, the most important issues for XR Ethics in education have been described at all levels and propose an initial set of recommendations to further develop in the future in more detailed policy on Ethics XR for Education for reference from all levels (Isidori and Cacchiarelli, 2017).

Practices of digital learning for the adoption of ethical XR should focus on:

— XR Digital Strategy for Schools.

— XR Digital Teaching & Learning Framework.

— Ethically approved XR Teaching & Learning methodology.

— XR technologies to ethically encourage student active and collaborative learning.

— XR technologies to ethically create new knowledge, content, and 3D artefacts.

— XR technologies supporting effective teaching and learning assessment strategies.

Although within the current educational system spectrum, there are predefined factors for the progression of an individual student, specific factors must be considered depending on the level of education at which the XR technology is to be adopted:

— Impact of educational policies and resources for the adoption of XR in education.

— Definition of educational equality and equity within XR Education.

— Level of the impact of XR towards the contribution to quality and equity in student performance.

— The structure of differentiation within education systems and the applicability of XR within those systems.

— Decentralization of ethically approved XR educational systems.

The report listed 42 recommendations in the following areas for further exploration:

— Privacy in Education Requirements (6 recommendations).

— User Requirements (2 recommendations).

— Hardware Requirements (5 recommendations).

— Software Requirements (5 recommendations).

— Accessibility (6 recommendations).

— Teaching & Learning (5 recommendations).

— Authoring Tool Kits (2 recommendations).

— Educational (5 recommendations).

— Societal (6 recommendations).

The principles, values, and aspirations based on the desired code of conduct of XR applications in Education, need to be put in place for the stakeholders to safely and with integrity can carry on education tasks within XR educational environments. Although there is no policy on XR Ethics for Education, in summary, the activities to be found in XR Educational Systems should include:

— Maintain ethical standards of practice in educational teaching, learning, and research.

— Protect human subjects from harm.

— Ensure that the practice of fully informed consent is observed from all individuals.

— Ethics requirements adhere to the ethical national legislations and directives for the utilization of XR at educational levels.

— The establishment of the External Ethics Advisory Board at each educational level for policy reform, with specific roles and responsibilities.

— Provide reassurance to the public and policy regulation bodies that all the above are done.

7.2 XR ethics Metadata

The standardization project IEEE P7016.1 has been approved, and the standard is active for the next 5 years. IEEE P7016.1 is currently working on a Standard for Ethically Aligned Design and Operation of Metaverse Systems, which was approved 30th of March 2023 (project authorization request PAR7016.1). The projected completion date for submission to the new standards committee of the IEEE standards association is April, 2025.

This standard defines a high-level overview of a conceptual data schema for a metadata instance based on ethics concepts for a learning object utilised within XR systems and Metaverse applications. This standard does not aim to define whether procedures and operations as presented through the Metaverse are ethical or not. This standard does not involve evaluation of the ethical value of learning content objects. Use case examples of the conceptual data schema are defined. This standard also describes a high-level ethical design methodology of learning objects for XR and the Metaverse applications, using IEEE 7000 applied ethical approach.

8 Conclusion

This document documents existing standards that can be used in combination to facilitate eXtended Reality learning and performance augmentation. It proposes to combine, most notably, the IEEE P1589-2020 augmented reality learning experience models standard together with the IEEE P92741.1 experience API proposal, clarifying thereby what a useful application profile for tracking reality interaction could be. Moreover, it outlines how to go about learning experience design. Furthermore, it recommends the use of glTF as interchange format for 3D graphics, and provides pointers for specialist aspects regarding spatial mapping and tracking, integration of virtual humans (for virtual instructors), and real-time communication and sharing. To assist findability, recommendations on how to express meta-data about the XR learning resources using learning object meta-data (LOM) are made. Furthermore, emerging standards for XR accessibility, XR usability and user experience, as well as XR ethics are reviewed.

Educational providers therefore have concrete guidance for system implementation and compatibility. Educational manager, intermediaries, and regulators receive guidance on what to focus on during procurement and introduction. Finally, investors can derive information about resource allocation from the structure provided in the report.

To take this forward to further standardization, it is recommended to establish a new work item proposal for a more integrated data model standard. Separate to that, a guidelines standard for the introduction, implementation, and use of XR for learning and performance augmentation could complement this.

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