Electronic, didactic and innovative platform for learning based on multimedia assets

e-DIPLOMA

Funded by the European Union

D.4.1 Platform technology specification

Version No. V1.3

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(*) According to the section “Review and Submission of Deliverables” of the Project Handbook

1. Technical References

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2. Table of Contents

3. Introduction

3.1. Executive Summary

This document D.4.1 of e-DIPLOMA project analyzes the requirements for the e-DIPLOMA Platform based on the stated objectives and task to be completed during and after the project, as well as expert opinion gathered in WP2. It formulates decisions on core technologies and outlines options for accommodated technologies that can be used in creating course prototypes and other learning material. A module structure is laid out, the functionality of all modules is defined, and their interoperability is specified, along with the standards that must be adhered to.

The document takes some results from earlier research on expert opinion T2.2: *Analysis of remote e-learning in teacher training* and serves as a basis for *T4.2 Creation of the cloud resource management, network synchronization, and avatar-based interaction for virtual rooms*.

3.2. Relation to Other Project Documents

This document is related to the D2.2 Review of e-learning ecosystem, in that it derives requirements from the expert opinion gathered there.

This document is ***not*** an API specification for the platform, as that can only be finalized after the completion of T4.2 and will be part of *D4.2 E-platform software*.

3.3. Abbreviation List

Among the acronyms more used in the present document are, in alphabetical order, the following:

AI: Artificial Intelligence

API: Application Programming Interface

AR: Augmented Reality

AWS: Amazon Web Services

EC2: (Amazon) Elastic Compute Cloud

eLTI: Enable Learning Tools Integration

GDPR: General Data Protection Regulation

GUI: Graphical user interface

ID: Identity

LDS: Learning Design System

LMS: Learning Management System

LO: Learning Object

LTI: Learning Tools Integration

NLP: Natural Language Processing

OAuth: Open Authorization

OEM: Original Equipment Manufacturer

OIDC: OpenID Connect

REST: REpresentational State Transfer

SAML: Security Assertion Markup Language

SNS: (Amazon) Simple Notification Service

SQL: Standard Query Language

UE: Unreal Engine

VM: Virtual Machine

VR: Virtual Reality

3.4. Reference Documents

See the References Section included in this document.

4. Requirement Analysis

4.1. Summary of Previous Findings on e-Learning Practices and Ethics Issues

4.1.1. State of education in participating countries

Based on the technology survey conducted in D.2.2, there are certain infrastructural opportunities and constraints for using disruptive technologies in higher educational institutions and vocational schools (see table 1).

Table 1. The summarised infrastructural opportunities and constraints based on D.2.2.

	Opportunities in institutions	Constraints in institutions
Internet		Rather do not provide sufficient internet speed for METAVERSE learning
Hosting LMS	Institutions can use regional hosting systems (LMS, LDS, videoconferencing, repositories, clouds)	Central LMS provision – not available in Bulgaria, Hungary
LMS	The institutional provision of e-learning environments in different countries is not similar. Moodle is the most institutionally provided system according to the students view. Several countries' universities and vocational schools use frequently Udemy (Spain, Hungary), Coursera (Estonia, Spain, Cyprus) and Khan academy (Italy, Bulgaria), Codeacademy (Italy, Bulgaria), Microsoft Teams (Estonia, Spain) and Google	

	Classroom (Hungary), Google drive (Estonia), as learning management systems.	
AI empowered LMS, recommender systems		Rather do not provide AI based feedback in LMS systems. Rather do not provide digital data management in institutions empowered by AI to enable adaptive learning paths. Availability of AI empowered feedback, chatbots in LMS systems – partially available in Italy, and Spain. AI managed data recommendations – available only in Spain and Cyprus
Cloud repositories	Access to institutionally paid cloud repositories	
Institutional storage space	The sufficient institutional storage space for VR, AR data.	Rather do not provide central digital repositories in own server
Video-conferencing tools	Institutionally provided video-conferencing tools are available. In practice the most commonly used video conferencing tools for e-learning lessons in higher educational and vocational schools are Zoom (more popular in Estonia, Spain), Microsoft Teams (more popular Hungary, Bulgaria, Cyprus, Italy, Net) and Google Meet (Estonia, Spain, Bulgaria, Italy, Hungary). Video conferencing tools have facility to work in groups with shared objects	Zoom and Google Meet may have issues with GDPR compliance.
Digital portfolios	Students have digital portfolio spaces, i.e a computer-based collection of student performance over time. In higher education, it is, mainly as provided by popular LMS. In lower education, it is often state-mandated.	
Interoperability	The e-learning ecosystem tools are mutually compatible and interoperable in most of the countries	Interoperability between LMS and repository – rather not available in Hungary, Italy
Digital devices		The staff owned computers are fit not sufficiently for processing METAVERSE

		The students do not have adequate computers fit for processing METAVERSE
Headsets		The availability of VR headsets per country samples is very low (1-3 per institution in few institutions), only in Spain and the Netherlands there is better availability ranging 10-20 headsets per institution, with several institutions featuring these numbers. Delft campus has a special VR Zone with even more headsets.
User identification		Biometrics based identification tools – available only in Cyprus and Spain

4.1.2. Value-based evaluation of disruptive learning scenarios by experts

In D.2.2, we observed the values via an empirical workshop on disruptive learning scenarios and the survey also listed specific value-based items. All the following values were considered to have relevance in defining the aspects along which disruptive learning can be evaluated:

- **Accessibility** - The learning scenario should be developed in an accessible language and the possibility of personal adaptation to the individual needs of the learners. People with disabilities should have the same learning experience.
- **Adaptability, flexibility, responsiveness** - Adaptability to the VR environment, adaptability to the virtual classroom is expected. Participants expect the possibility to switch the room or method if the conditions of the participants change. **Rigidness** of scenarios is a threat; pre-prepared scenarios hinder **flexibility**. Development tools must be available to the teachers and learners to promote learner-centred and personalized learning. The learning space should not be out of teacher-student control.
- **Accuracy** is considered important. For example, accuracy is increased if the initial assessment comes from an automated mechanism (e.g., online quiz) that is not influenced by the teacher's emotional background in relation to the student.
- **Legal compliance** of the systems must be ensured. For example, before group learning, all involved parties (e.g., students, teachers) are supposed to agree what activities could be monitored, recorded, or used for AI-assisted profiling. Country specific legal compliance of learning systems is important.
- **Data control and privacy** should be followed in personal data management, management would make clear where and for how long the data will be stored and who will have access.
- **Autonomy and agency** of learners should be increased within learning environments and learning designs, students could be promoted to try out their own strategies rather than predefined ones by teacher; **control and coercion** of learners by teacher, or by AI must be reduced. The students should have the opportunity to follow the lesson at their own pace. The students should have free movement in the learning space and in the sequence of picking objects.
- **Trust** in technology, **personal security** must be ensured; **surveillance, cyberbullying and unwanted exposure** may cause vulnerability.

- **Equity, fairness** - The system should promote each of the learners to participate equally with ideas and activities.
- **Responsibilities** during learning acts in the system should be technologically maintained, such as students should be made aware about their responsibility and role during the learning and agree upon it.
- **Sustainability** - The tool should provide opportunities for teachers to use virtual resources instead of physical resources, which might be wasteful or expensive. The learning situations and learning event designs could be reused, modified, and shared across users.
- **Interaction promotion** in learning activities is expected to be promoted in the technological spaces: e.g., peer-interaction, peer-teacher interaction, peer-chatbot interaction, interaction with the objects in the situated space. Use instructions that provide several interactivity level actions between agents-contents-objects-technology (Cognitive) and enable collecting learning analytics for monitoring these interactivity levels. Provide the interaction opportunity with the other agents or with the situations to receive feedback and scaffolds (Metacognitive, Cognitive, Affective) and enable collecting learning analytics for monitoring these support action types. The students should be provided channels for communication between different students, groups.
- **Interaction monitoring** should be possible by the system to promote learning analytics only if the user agrees to it.
- **Group and class dynamics** (individual, peer, group activity proportions, learner participation in these) should be pre-programmable into the specific learning sequences and analytically monitored about the classes and for each student if the users agree about it.
- **Social and group relations** between the learners should be technologically promoted in the learning space, for example role distribution options are required.
- **Social motivation** could be prompted with monitoring of peer-learning group learning.
- **Empathy** of technological support agents is required; the facial expressions of avatars are expected to support motivation.
- **Reflective features** for students, facilitators should be provided to promote self-learning,
- **Instancy** of the feedback for the students from tasks
- **Negative health issues** (nausea, balance issues, cognitive issues, emotional issues) of users should be avoided. There are harmful effects to the users ranging from cognitive, metacognitive, affective, physical to the social effects. Consider that the distribution of objects in 3D space may cause attention and navigation issues with objects (Cognitive and Psychomotor). Consider the position of the learner in situations, the mediatedness of control over learners' body and movement (Psychomotor)
- **Be presentation mode specific:** When using e.g., overlay text features, control buttons that simulate 2-D or analog situations, evaluate potential harmful effects in the Cognitive and Psychomotor domains and adapt presentation to avoid them.

4.2. Analysis of Practical and Ethics Requirements

Finding of WP2	Implementation in WP4
Low internet speed possible	Include e-DIPLOMA applications with limited action space resulting in lowered bandwidth requirements
LMS are widely adopted	Integrate e-DIPLOMA with LMS
AI for learning not yet adopted	Explore the role of AI as specified in the proposal, and optionally incorporate generative and game AI in Learning Objects, where appropriate.
Cloud is used	Implement core e-DIPLOMA platform modules into cloud-based services

Storage space available	Allow hosting on-premises (BUT only if it conforms to the data management plan).
Videoconferencing widely adopted, but GDPR may be an issue.	Make use of video conferencing in e-DIPLOMA applications. Evaluate GDPR compliance.
Digital portfolios already in place	Do not replicate existing functionality in e-DIPLOMA.
Lack of interoperability is hurtful	Adopt widely supported interoperability standards (LTI).
User devices may be insufficient, no VR equipment	This is difficult to address. Some technologies will be expensive. The project should provide these during the pilots. Alternative Learning Objects with lower device requirements are a possible workaround.
User ID not biometric	Rely on widely adapted ID providers
Accessibility	Automatic translations should be provided
Adaptability, flexibility, responsiveness	Open up LO authoring toolchains for co-creation.
Accuracy may come from AI	Incorporate feedback based on AI profiling.
Legal compliance, data control	The e-DIPLOMA platform should provide options to manage and redraw consent. Maintain what data is stored under which users' consent.
Coercion must be reduced	Allow the definition of institutional policies that limit the rights and available action associated with the teacher role.
Personal security	The platform could be prepared for monitoring actions for alarming patterns and notifying teachers. However, this is not in the scope of the e-DIPLOMA project. Individual methodology and approved ethical procedures dictate the process during the project.
Equity	Actions could be monitored for equal access to resources and educator attention, teachers can be guided to correct course.
Sustainability	Implement some LOs that work as virtual reconstructions of complex or expensive real systems (in particular in Prototype 2: Social Entrepreneurship).

4.3. Technical Requirements

The e-DIPLOMA Platform is a framework based on existing technologies and standards. It must be compatible with existing systems used in education to the highest degree possible, but also bring high-end gaming, virtual and augmented reality technologies into the framework.

In this section, we identify the use cases of the e-DIPLOMA Platform and derive required items of functionality.

4.3.1. Use case: conducting research into novel visualization, simulation, gamification, AR, and VR techniques.

During the e-DIPLOMA project, partners need to analyse existing techniques and develop new methods in various fields of research. These include:

- Real-time graphics. New methods allow for displaying richer content on a wider range of devices.
- Real-time physical simulation. New methods allow for a more realistic and immersive experience on a wider range of devices.
- VR visualization techniques. Expressive visualization can enhance user comprehension, while realistic rendering may produce better immersion.
- VR navigation techniques. Resolve problems sensory input inconsistency in VR.
- AR solutions. Explore options for more ergonomic applications.
- Real-time societal and civil infrastructure simulation. These are needed for reactive environments and consequential actions in the virtual space.
- Procedural content generation. Create virtual worlds and learning scenarios with reduced artistic input.
- Content generation by AI. Automate the process of creating learning materials.
- Behavioural AI. Improve interaction with computer-controlled characters.

These widespread research goals would make it impractical to fix a single virtual environment, game engine, or technology stack for every partner to work with. Instead, the e-DIPLOMA Platform must make it possible to add various applications using different software and hardware components. Parts of the platform must be interchangeable without affecting other components, as long as interface specifications are upheld. Formally, the platform must meet the following requirements:

- Extensibility
- Modularity

4.3.2. Use case: developing course prototypes.

e-DIPLOMA partners develop course prototypes as part of WP4. These are based on teaching materials and practice of respective experts among e-DIPLOMA partners but must be adopted to disruptive technologies in a manner that makes evaluation of these technologies possible. The development process could be a classic game/application development endeavour, but it is supposed to showcase the capabilities of the platform and the integrated technologies. Therefore, they should act as blueprints for creating later courses, by independent institutions and educators, in the exploitation phase of the project. As laid out by the project proposal, and as the current state-of-the-art in VR application and game development dictates, the authoring of new teaching material is going to require the same level of expertise and effort that the development of the original prototypes required. It is an optional research question to see if new technologies affect this aspect and allow for easier generation of personalized content.

Therefore, we need a process that is well-documented and reproducible. The platform must prescribe data formats for multimedia assets, implying the use of tools that are able to work with such formats. Prototype developers should document, formalize, and, if possible, modularize their process of creating individual Learning Objects or custom assets. These documents and software tools will form a part of the e-DIPLOMA platform. The tools could enable content authoring for users, not only in the roles of educational material designers, but for teachers and students, possibly in a co-creation scenario.

At the same time, development of learning objects in course prototypes should not be independent of each other or started from scratch. Most learning objects are expected to be implemented in just a few individual applications. The platform must provide templates for typical application architectures to help the partners working on the prototypes. These will be operative examples of specific game engines integrated into the platform, with documentation on the integration requirements.

Formally, the platform must meet the following requirements:

- Design transparency
- Documentation
- Example-based
- Reusability
- Interface by demonstration

4.3.3. Use case: piloting prototype courses and evaluation of the training.

Partners may use cloud resources or resources on-premises (if available, to reduce costs or network overheads). Both options, or hybrid solutions in case the on-premise resources must be supplemented, must be seamlessly provided.

The project proposal posits that in T5.4 comparative studies between the effectiveness of learning in a traditional way (as it is currently carried out) and the use of new AR and VR technologies. A system for collecting information (questionnaires, interviews, and level tests) on the effectiveness of both the traditional part and behavioural and psychophysiological metrics of the use of the platform will be designed. Note that the exact methodology of evaluation is up to WP5 to define, and from the point of view of platform requirements, the proposal only requires the prototypes using disruptive technology to be implemented in the platform. If any comparisons with classic methods are necessary, those should be, almost by definition, not performed within the platform. However, the classic components in the platform, like the LMS, may well be able to manage classic course materials to facilitate comparative studies.

Summarizing, we can state that in order that the outcomes on the teaching methods used can be evaluated, it is necessary to record outcomes in a way that is comparable to classic grading systems.

Formally, the platform must ensure:

- Portability (hosting)
- Evaluability

4.3.4. Use case: gathering data for learning analytics.

The e-DIPLOMA project must evaluate the effect of disruptive technologies on education. This will be done through teaching the prototype courses in various countries, recording activities, communications, physiological data, and learning outcomes. These records will be subjected to scientific analysis to draw conclusions and inform policy recommendations. Therefore, the platform must support the safe, secure, GDPR-compliant acquisition and storage of these data. This requires that data is recorded on a machine that is either under the full control of the subject, or, under unambiguous and anytime revocable consent of the subject, is under the supervision of the researchers participating in the e-DIPLOMA project, using safe technologies. Therefore, we need networking and database technologies and services that conform to the standards outlined in the Data Management Plan, and specifically the GDPR regulations of the EU.

Formally, the platform must ensure:

- Automated data acquisition

- Management of granting and revoking consent
- Data safety
- Data security

4.3.5. Use case: AI-guided learning.

Data must also be gathered as an input to the AI solution that should profile the students based on their activities and outcomes and recommend activities. Much the same considerations apply for data storage and acquisition as in the previous section. The data must be available both for training the AI, and for inference, i.e., producing the recommendations from current student status. The platform should provide a way for the AI module to communicate recommendations to the students, possibly with an educator or researcher tasked and authorized to supervise, to process, and to filter AI bias or inaccuracies, or conversely, keeping the recommendations private to protect student privacy.

Therefore, the platform must feature:

- Human—AI communications
- Supervision by authorized humans
- Configurability with respect to rights and roles

4.3.6. Use case: developing courses by exploiters.

After the conclusion of the e-DIPLOMA project, assessment of disruptive learning technologies, corresponding best practices, and policy recommendations will be available. The course prototypes will be useful in teaching the selected high-importance subjects with elevated value. The e-DIPLOMA platform should ensure that the findings and techniques can be adapted to other educational materials in any institute. This should be possible on different scales of invested effort, technical expertise, and reliance on e-DIPLOMA resources. On the one hand, the process of adapting existing, classic learning materials to existing e-DIPLOMA applications should be straightforward, supported by available assets and tools, and assisted by automation where possible. On the other hand, blueprints (i.e. documented examples for major game engines) for creating new applications that fit into the e-DIPLOMA ecosystem should be available.

Formally, the platform must provide:

- Extensibility
- Authoring instrumentation
- Stock assets

4.3.7. Use case: teaching by exploiters.

After the conclusion of the e-DIPLOMA project, educators who adopt the platform must be able to use it to teach courses over the time span of multiple years. The platform infrastructure must therefore be either replicated under the control of these educators (if they could be presumed to possess the required expertise) or provided to them as a service in a continuing fashion. In any case, the cloud-based infrastructure must have the ability to be moved under the auspices of a different entity or replicated by multiple partners. In any case, safeguards against runaway costs resulting from uncontrolled use of cloud resources are useful.

If multiple educational entities use the platform as a service, the Quality-of-Service measures and scalability to higher loads becomes important. The number of simultaneous sessions possible and response times are indicators to be considered. The platform must assure reasonable minimum values for the QoS and choose technologies that can be scaled up if the rate of exploitation outgrows those limits.

Maintenance of not only the platform as a service, but also the applications and learning materials must be possible. These may be the responsibilities of their respective developers; may they be the original e-DIPLOMA partners or later adopters. Any security updates should be installed immediately on user devices. For the users, the process of updating any software components on their machines should be automatic.

Therefore, the platform must provide:

- Infrastructure as Code
- Cost controls
- Quality of Service standards
- Automatic updates

4.4. Evaluation of technology alternatives

The e-DIPLOMA project does not aim to replace or replicate existing and proven methods, standards, or systems, but to augment them with capabilities featuring disruptive technologies in a manner that makes it possible to evaluate them consistently. Also, the e-DIPLOMA platform should be easy to integrate with existing digital infrastructure in most institutes. Therefore, it must rely on widely accepted standards, make use of widely adopted systems, and accommodate tools likely to be used for the implementation of novel learning materials.

We identify the following choices in technology:

- Authentication: provides a means for users to identify themselves, verifies credentials for secure communication
- Learning Management System (LMS): provides user management and grading tools.
- Session management: provides an interface for organizing groups sharing multi-user sessions.
- Cloud: provides a means to implement backend services, possibly paid on a per-use basis
- Hosting: provides of manages dedicated cloud or on-premises resources
- Game engine: provides rendering, simulation, and user interaction in a virtual environment.
- Multiplayer: provides synchronization between multiple game engine instances over a network
- Database: provides storage for data

In this section, we evaluate the possibilities and reasons behind eventual decisions. In many cases, the interplay between the choices must also be considered. In several cases, we opt for supporting multiple options, and/or defer the decision to latter phases of the platform development, the application development, the learning material authoring, or deployment at educational institutes, or the teaching. This is in accordance with the project proposal positing e.g., that graphics, gamification, and AI technologies are to be specified and developed in tasks T3.5, T3.6, and T3.7, respectively.

4.4.1. Authentication

User authentication is a crucial factor in the e-DIPLOMA for the following reasons:

- It is possible that sensitive personal data, activity monitoring data, AI-based profiling data, data over learning outcomes, and records of physiological measurements need to be processed and stored. Access to these must be only available to those who have been granted access permission. Data security is imperative.
- Users may join activities in various roles (e.g. student, teacher, researcher). Proper identification is necessary to assign appropriate roles.
- Applications within the e-DIPLOMA framework exchange data over the network. Third parties interfering with this communication, capturing or altering data, or impersonating someone, must

be impossible. This requires constant verification of authorization during the communication process.
- Components of the e-DIPLOMA platform must interface with items of existing infrastructure and learning tools. Exchanging data and matching user records requires mutually acknowledged authentication protocols.
- In order to provide users with a hurdle-free experience, authentication should be a familiar, trusted, and quick process.

These requirements point towards a widely used, cross-platform, safe and secure authentication protocol. The e-DIPLOMA platform should support, directly or through linked infrastructure, both OAuth 2.0 and SAML 2.0.

OAuth 2.0, which stands for "**Open Authorization**", is a standard designed to allow a website or application to access resources hosted by other web apps on behalf of a user. This is promoted by Google and allows the "Log In using Google" or "Log in using Facebook" options.

SAML 2.0 (**Security Assertion Markup Language**) is an open standard created to provide cross-domain single sign-on (SSO). Many educational organizations, including e-DIPLOMA partner BME, use this extensively to sign into all university services on a single page.

OAuth and SAML essentially allow the same thing, and educational institutes will want to stick with their choices made earlier.

Technology worth considering is **Amazon Cognito**, especially if we go with AWS cloud technology. Cognito is also a single-sign-in solution. It supports both OAuth 2.0 and SAML 2.0, so it is possible to use those identity providers to sign in to Cognito. The big advantage is that these users can be given roles and customized access to the cloud resources. If e-DIPLOMA ends up running a cloud-based service for all educational institutes using our learning resources, then it is essential that security and customizability per user is possible. Using Cognito may make relying on LTI (discussed later in this section) unnecessary, as the LMS and our AWS elements would both use the same OAuth or SAML login, and Cognito would provide the authorization tokens to our tools.

Epic Online Services also can be used as an authenticator. It has polished integration with game engines. It uses OAuth 2.0.

LTI support is possibly of great importance. Learning Tools Interoperability (LTI) is a standard developed by 1EdTech Consortium, which allows courseware and learning tools from different vendors to be launched within a learning platform, which is most often an LMS. The LTI integration allows the student to move seamlessly from one tool to the other, with minimal effort from instructors or students. Essentially it would allow us to rely on the authentication system of the LMS in all our interactive learning materials. Every institution could keep their own authentication system and no additional logins into our tools would be required.

A number of Learning Management Systems are LTI compliant:

- D2L Brightspace,
- Instructure Canvas,
- Blackboard,
- BenchPrep,
- LAMS,
- OpenLearning,
- Sakai,

- Moodle,
- iTeach,
- Open edX.

4.4.2. Learning Management System

The e-DIPLOMA platform needs to be integrated with an LMS to handle the following functionality:

- Handle user identification: LMS may already have a database on students and teachers, with appropriate roles and rights defined. They may be integrated with institutes administratively within an established legal framework. E-DIPLOMA capabilities should be accessible using the same credentials.
- Distribute learning material: students can access learning resources in one place. There is a unified interface for teachers to upload diverse learning materials. This should include the ability to connect external tools, like the respective modules of the e-DIPLOMA platform.
- Provide grading tools: The traditional way of measuring learning outcomes is grading. The LMS should provide a widely configurable set of grading scales, and include the possibility of external tools submitting grading information, in addition to the ability to author assignments and quizzes.
- Provide analytics tools: The learning outcomes represented by grades should be aggregable for data mining to enable analyzing correlations or trends. E.g. grader report sheets should be compiled.

Prime options:

- Moodle
  - Market share overall 10%
  - **Market share in Europe 65%**
  - Free
  - Open source
  - **LTI support**
- Blackboard LMS
  - Market share overall 0.25%
  - Market share in Europe 12%
  - Commercial
  - Proprietary source
  - **LTI support**
- LinkedIn Learning
  - Market share 9%
  - Not free
  - Proprietary source
  - **LTI support**
- Google Classroom
  - Market share 7%
  - Free
  - Proprietary source
  - Lacks LTI support
- TalentLMS
  - Market share 6%
  - Free
  - Open source
  - Lacks LTI support
- Brightspace
  - Market share 0.1%
  - Commercial

- Proprietary source
- **LTI support**

Overall, **Moodle** seems to have the widest adoption, an extensive set of authentication options and support for authentication-sharing technologies via extensions. It being open source means we can integrate anything we need to. **Blackboard** is a commercial option with a similar feature set, and popular in Europe. **LinkedIn Learning** also ticks the boxes, and is a major platform for online courses, but does not have a big presence in European institutes.

4.4.3. Matchmaking and lobbies

A lot of learning activities need multiple users in the same virtual space. It may be just one teacher and a student, or it may be multiple students in a group activity. There may be a single teacher supervising multiple groups in separate virtual environments. When users join the activity from their LMS, they need to be organized into sessions, with different roles having different options in influencing the grouping.

Matchmaking means gathering session requests from many users, and pairing/grouping them up automatically. Some criteria may be taken into account, but the process is essentially random. This is a useful approach with a large user base when we do not want a lot of control over the grouping.

Lobbies are applications to organize matches (or group learning activities) with extensive user interfaces. Users logged in to a lobby see other users, can communicate with them via chat or video conferencing, and they can create, join, leave, and launch sessions. This model is more suitable for organizing group work within a class, especially if the teacher has extra tools to override the grouping decisions of the students.

Once a session can be started, it is necessary that a server is designated and that all clients can join that server. There are three options:

- **Client-client architecture.** No server is required, the clients communicate with each other. From a security standpoint, if an attacker (e.g., a student with the intention of cheating) is able to modify the operation of the client, they may produce fraudulent results which could go undetected. The solution could also be less beneficial if we want to gather data at a central location.
- **Client-hosted server architecture.** One of the clients acts as a server. This may require a strong client computer. Again, gathering data at a central location is a challenge.
- **Dedicated server with external hosting.** There already is a strong computer at the disposal of the education institute that can be used. External here means that it is external to the matchmaking service: the educational institute must provide it.
- **Dedicated server with cloud hosting.** A suitable computer is allocated from the cloud and the game engine is launched there. Clients are provided with the connection information through cloud services.

The following technologies could be considered:

- AWS GameLift: matchmaking and dedicated server hosting solution
  - Easy integration with AWS
  - Standalone mode: when used for matchmaking only.
  - Supports dedicated servers with external or cloud hosting.
  - Realtime servers: suitable for lightweight servers (e.g.: turn based game)
  - Commercial

- Photon: multiplayer service and state synchronization framework
  - Supports client-client architecture without server, no external server hosting required.
  - Supports client-hosted server architecture, no external hosting required.
  - Supports dedicated server architecture, external server hosting required.
  - Easy integration for Unity
  - CCU-based billing (CCU=concurrently connected users)
  - Lobby/session-based solution doesn't support random matchmaking.
  - Commercial, but has a free plan up to 100 connections. Dedicated servers require an Enterprise subscription.
- Epic Online Services: multiplayer service
  - Supports client-hosted server architecture, no external hosting required.
  - Supports dedicated server architecture, external server hosting required.
  - Easy integration for Unreal Engine
  - Free of charge
  - Lobby/session-based solution doesn't support random matchmaking.
- PlayFab
  - Easy integration with Azure
  - Supports both random matchmaking and lobby/session based.
  - Commercial
- Web-based lobby
  - A hand-crafted solution
  - Possible integration into LMS webpage
  - Only an option for learning materials that do not really require servers.

In case of an AWS cloud service, GameLift is a logical choice, in case of Azure, PlayFab is. Photon has features extremely useful for multiplayer environments, but is not surrounded by an entire ecosystem of cloud systems (e.g., database) that we may need. It is possible to use Photon together with the AWS or Azure cloud.

4.4.4. Hosting

- AWS
- Azure
- Unity Multiplay

This comes down to pricing, which is not easy to compare, as it may change by time, location, and the exact configuration of the required server virtual machine. Overall, AWS seems to be somewhat more flexible, with cost during development not significant. However, attention must be paid so that game servers are not left running indefinitely. Solutions that allow for safeguards against this are to be preferred.

4.4.5. Database

- AWS DynamoDB: managed NoSQL database, supports pay-per-request usage.
- AWS RDS: managed relational DB service
- AWS Aurora: fully managed relational DB service, supports pay-per-request.
- AWS S3: managed object storage for unstructured data
- Azure CosmosDB: managed NoSQL database, supports pay-per-request usage.
- Azure Blob Storage: managed object storage for unstructured data
- Firebase

This depends on the choice of the cloud service. DynamoDB is the standard choice for AWS GameLift solutions, but it may be that a relational database is preferred for the purposes of data analysis.

4.4.6. Video conferencing

Video conferencing tools widely used in European education are: Microsoft Teams, Google Meet, and Zoom. All of these are services provided by non-European companies, and may fall under US jurisdiction, and be subject to national security reporting requirements that could be incompatible with EU regulations. All companies assert that they operate in all jurisdictions under the applicable regulations, including GDPR, and that they strive to achieve compliance. Several entities in EU countries have expressed reservations about the sufficiency of legal procedures (e.g., Standard Contractual Clauses) to transfer data to non-EU countries [8]. In any case GDPR compliance of these tools remains a legally contested issue, where reaching a satisfactory, guaranteed-to-be-legal setup for users is, euphemistically speaking, wrought with challenges [6]. Resolving these disputes is beyond the scope of the e-DIPLOMA project. While our applications should prefer technologies that minimize such issues (e.g., by not transferring data out of the EU), the above listed solutions are already widely integrated with the education processes of European institutes, as well as commercial settings, and e-DIPLOMA must accommodate this fact.

5. Platform overview

The e-DIPLOMA platform is a suite of interconnected software components, running on hardware including desktop computers, mobile devices, on-premises servers, and in the cloud. Many of these components could be replaced by different implementations or service providers, should the need arise because of technical, financial, or legal reasons. Therefore, the platform architecture described in this chapter should be seen to specify the functionality of modules and interfacing technologies between them, as well as the implementations pursued during the e-DIPLOMA project platform development phase, but extensibility and adaptability, even with the possibility of replacing underlying implementations, is maintained.

5.1. Standards and APIs

The e-DIPLOMA platform will be integrated into the Moodle LMS system. Any e-DIPLOMA activities will be accessible from Moodle courses as *External Tools*.

With Moodle acting as an LTI Platform, other e-DIPLOMA components exchange authentication and grading data with it as an LTI Tool, using the LTI Advantage standard (built over LTI 1.3). This includes communication through OIDC (OpenID Connect) which in turn is based on OAuth 2.0.

The e-DIPLOMA platform will support user identification through the OAuth 2.0 and SAML 2.0 standards. This is to be provided by Moodle.

e-DIPLOMA web services will serve content in the form of HTML5 pages. These will use ECMAScript 6 (also known as ECMAScript 2015, JavaScript ES6, or ES6) for client-side functionality, including WebGL 2.0, which is the JavaScript implementation of the OpenGL ES 3.0 standard. Adoption of the upcoming WebGPU standard is possible. The use of WebAssembly (Wasm) for performance-critical tasks is possible. The client-side code may be written in any programming language that translates to browser-executable code, including ones typically employed in this area, most prominently TypeScript, Kotlin, Go, and Python.

Server-side components may be served by dedicated servers or cloud resources in serverless solutions. Core e-DIPLOMA functionality will be an application hosted on the AWS cloud. Server-side logic can be implemented in any language permitted by the cloud solution, typically Node.js, Go, or Python. LTI 1.3 compliance is ensured by incorporating the eLTI (Enable LTI) [5] service.

Applications with rich virtual reality content will be implemented through the use of game engines. The preferred choices are Unreal Engine 5 [18] and Unity 2022.2.9 [19].

Game servers may be hosted in the cloud. In this case, the AWS GameLift [23] service should be employed, with a fallback to AWS EC2 [4] cloud service in case short start-up times would be crucial. In addition to this, on-premises servers can be registered using a custom solution developed for e-DIPLOMA.

Networking between application clients and servers will be handled by in-application solutions or cooperating components. In particular, the Photon Engine [14] will be used for multiplayer functionality in gamified groupwork-based learning objects.

Data storage will be using the database services part of AWS. In particular, DynamoDB [3] will be used to store user session and authentication data, AWS Aurora [1] will be used to store recorded student activities, and S3 [15] will be used to store application binaries and media.

Media assets should conform to capabilities of the applications in which they are used. For 3D resources that should be portable between applications and are part of the e-DIPLOMA asset repository, a version conformant to the glTF 2.0 (ISO/IEC 12113:2022) standard [7] should be provided. Video assets should conform to the MP4 standard [11] (MPEG-4 Part 14, based on ISO/IEC 14496-12:2004 International Standard). Image assets should conform to the PNG specification [13] (Portable Network Graphics, ISO/IEC 15948:2003), or the JPEG format [9] (ISO/IEC 10918-7:2021 International Standard).

Matchmaking may rely on the AWS GameLift FlexMatch service, but as the platform must support a wide set of scenarios, a custom solution will be developed.

5.2. Platform modules

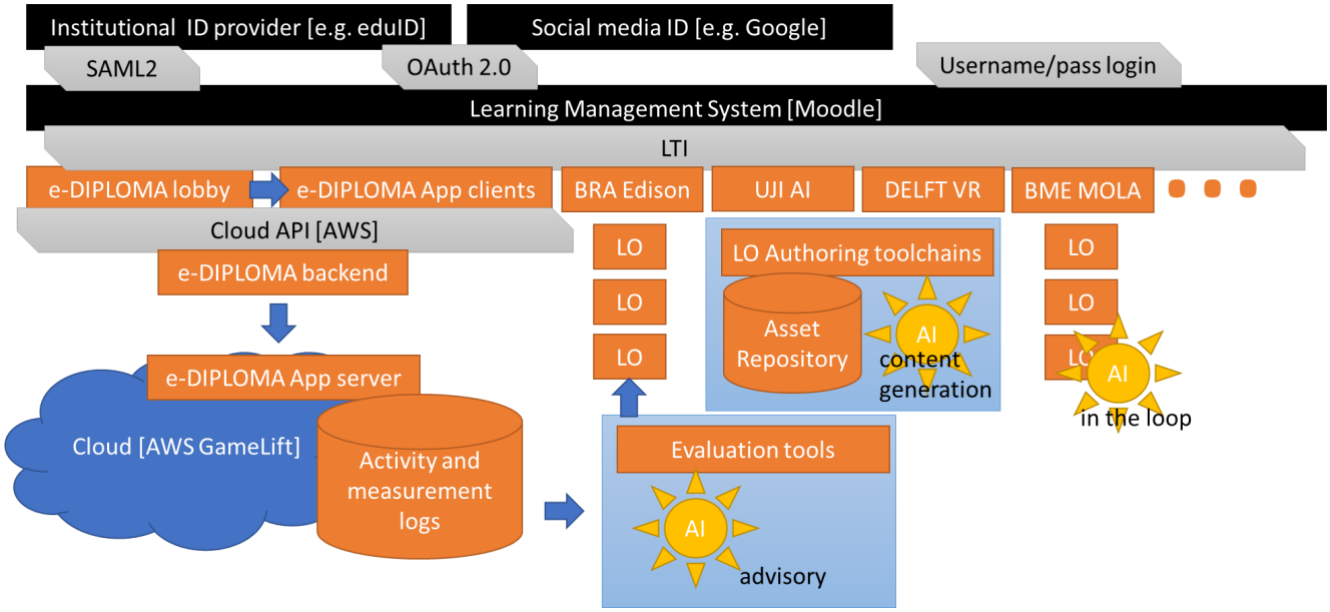


Figure 1 Module structure of the e-DIPLOMA Platform

Figure 1 shows the modules of the e-DIPLOMA platform. Black boxes symbolize pre-existing infrastructure, key interfacing standards are in gray, and orange boxes are high-level modules of the platform. Users log in to *Moodle* using the method preferred in their institutes. Often, this means using a

global service (e.g., log in with Google, or login with Facebook), or an institute-wide solution (e.g., EduID [22]). These services are based on the OAuth 2.0 or SAML 2.0 protocols. Alternatively, Moodle may be configured to allow other ways of logging in, like registering usernames and passwords only for Moodle. Once users are logged in to Moodle, they can access courses according to their roles. External Tool activities can be added to course pages by content editors or teachers and launched by students. The *e-DIPLOMA Lobby* is such a Tool. Moodle and the e-DIPLOMA Lobby are interfacing using the LTI protocol. The e-DIPLOMA Lobby is a web service for launching *Learning Objects* (LOs), including organizing events or sessions where multiple users take part. While some LOs may be implemented as web services themselves, the need for using high-end technologies like AR, VR, and gamification would typically require specialized desktop applications built on extensive middleware, and game engines in particular. Practically, a single application should be used to implement many LOs. Typical game AI like pathfinding may be accompanied by disruptive AI like chatbots to provide a responsive and immersive experience. It is foreseen that e-DIPLOMA partners contributing to WP4 each implement one or a few *applications*, and several LOs within each application, as part of the prototype course development process. In order for the development process to be replicable by adopters in the exploitation phase of the project, creation methodologies and toolchains must be documented and provided along with the applications. Procedural or AI-assisted content generation may be employed. For multiplayer scenarios (which includes not only group work but also real-time teacher-student interaction), application instances running on user devices must be connected to create a synchronized game world. This is provided by the *application server* component. Depending on the type of the LO, multiple simultaneous instances of the game world need to be simulated, accommodating interacting groups of students and teachers. These instances may be run on on-premise servers, but typically they need to be hosted in the AWS cloud. Launching these dedicated server computers in the cloud, managing the authentication of users joining the sessions, linking client applications to the server application, and monitoring resource usage is the task of the e-DIPLOMA backend, which is an AWS service. One could consider the e-DIPLOMA Lobby and the e-DIPLOMA backend to be a single, AWS-based service, with the lobby serving as the matchmaking interface for the backend. Finally, the server applications may record user activity relevant to academic or scientific evaluation. They can store this data in the cloud through the backend. The data is also accessible to *AI analytics*, which serves as the AI-assisted learning pillar of the e-DIPLOMA project. The feedback (e.g. LO recommendations) from the AI to the users, may appear in the e-DIPLOMA Lobby, or routed through it to Moodle. If it makes sense for a LO to directly interface with the AI, it should be possible e.g. using the AWS cloud API.

5.2.1. Moodle

A Moodle server must be maintained by the partners, or later, the educational institutes to manage users and conventional course management activities. The e-DIPLOMA Platform will be integrated into Moodle as an LTI-compliant *tool*. It will be registered as a site-wide tool [10], making arduous manual configuration unnecessary when inserting e-DIPLOMA material into courses. The course prototypes of e-DIPLOMA will be created as Moodle courses, the pilots will manage student evaluation through Moodle.

5.2.2. Web Lobby

The central hub of the e-DIPLOMA platform, a web service with user-facing visual interface. This means that an interactive web page is provided, where students and teachers can see users logged into e-DIPLOMA through clicking the same activity in the LMS. They can communicate, organize groups if necessary, and launch an application presenting the Learning Object associated with the activity. The service performs matchmaking, gathering the users willing to join the same interactive LO. Through the

lobby, they may communicate to organize shared sessions and launch shared virtual worlds. Users may do the following, depending on their roles, rights, and institutional policies:

- Create a new table.
- Set conditions for joining a table. (e.g., free for all, on invitation, certain roles only)
- Limit the number of users at a table.
- Invite someone to a table.
- Accept or decline an invitation.
- Join or leave a table. (Joining multiple tables is possible.)
- Spawn an AI user (bot) for a table.
- Launch an application performing a shared LO activity with current users at a table.
- Force another user to take one of the above actions.

This set of features should enable LO designers to grant teachers and researchers the required amount of control on how student groups are formed. Teachers can join multiple sessions, switching between them on demand, supervising and guiding activities.

The Web Lobby will also be the interface where users can access e-DIPLOMA functionality that Moodle cannot accommodate, e.g., AI recommendations can appear here.

The e-DIPLOMA Lobby will be implemented as an AWS service, incorporating the eLTI (Enable LTI) [5] service for LTI compliance. It will be closely integrated with the backend, practically forming a single AWS solution, with the Lobby being the user interface part.

The Lobby needs to be able to start desktop applications on client computers. This is only possible if those applications are installed and registered in the operating system for this to be allowed. Therefore, the Lobby will be accompanied by a Launcher component, similar to the launchers employed by Steam, GOG Galaxy, Epic Games, EA, Ubisoft, or Battle.net. The Launcher is responsible for keeping the installed e-DIPLOMA applications up-to-date and starting them when required by the lobby. Only the Launcher will have to be registered with the operating system for browser access.

5.2.3. Applications

Applications are developed by e-DIPLOMA partners as part of WP4, while creating the prototype courses. Later adopters may also develop applications, although that is not expected from users of e-DIPLOMA.

Some applications may be implemented as web services. Others, being desktop applications, have to be installable and updatable through the e-DIPLOMA Launcher. They must work in close concert with the Web Lobby component and the backend in general for session management, authentication, and grading. The eLTI API will be exposed to them so that they can benefit from LTI functionality.

Most applications are expected to work in a client-server model. The server should be made ready to be launched by the backend on dedicated server instances in the cloud, as described later in section 5.2.7.4.

The server is also expected to store activity data for analytics.

5.2.3.1. Planned stubs.

All applications are expected to perform the above tasks of communicating with the backend and the LMS. Also, they need to support multiplayer capabilities for synchronizing the game worlds on user computers in real-time. Therefore, two example implementations will be prepared by the WP4 lead partner BME, which can be used as starting points of integrating novel features implemented by any partner.

5.2.3.1.1. Unreal engine

The UE stub is a classic 3D First-person view multiplayer game environment with multiplayer networking, using Unreal Engine's built-in capabilities. User avatar and key object positions, as well as chat communications are logged to the database.

5.2.3.1.2. Unity+Photon

The Unity stub is a MOBA (Multiplayer Online Battle Arena) style game environment using the Photon Engine [14] for multiplayer capabilities. All player actions are recorded in a replayable manner.

5.2.3.2. Virtual education/co creation environment

For e-DIPLOMA, Brainstorm will adapt and integrate the Edison software (SW) to the project platform. This SW asset consists of an authoring tool to set up immersive environments where a presenter is embedded in real time thanks to green screen technology. This system is actually employed for virtual production in corporate and small studios settings. The flexibility and simplicity of the SW provides the opportunity to transfer the tool to the educational sector, where there is still a lack of tools to produce interactive and visually attractive content. This type of tool, widely employed in the broadcast field, provides the possibility to teleport the presenter in virtual and augmented reality environments with the aim to involve more deeply the viewer in the topic that is being presented (Figure 2).

Figure 2 Examples of virtual production results.

The tool improves the possibility to visualize data and details related to the presentation in a dynamic and engaging way, employing 3D models and animated graphics.

The current limitation of the tool is the need of powerful hardware to render in real time the contents in the virtual environment. This point is limiting the spread of this type of technology. To solve this issue for the e-DIPLOMA platform, and open access to this tool, Edison will be adapted and deployed on cloud with the support of virtual machines in order to avoid the need for professors and students to employ powerful local machines. Although this is not likely to be feasible for VR content, streaming rendered and composited 2D content to user devices can be an attainable aspiration. This step opens the access to the tool from different locations, removing the barriers of hardware and software compatibility (devices working with operative systems different from the used to deploy the solution). From VNC clients, remote desktop applications and even employing a simple web browser, this space will be set up in order to permit simultaneous access of different users, being professors or students. This point allows the employment of the tool in a collaborative mode, an interesting new feature for the educational sector, that will promote the live interactions of the participants increasing the engagement in the session, especially for the students. This will give the opportunity to access the tool and interact with the class while this is being carried out by the professor, transforming the initial tool to a virtual educational space that allows interactions.

The access to this module will be regulated through the e-DIPLOMA platform users' authentication and the related profiles rights. The professor will be able to invite students to access the module and get control of the space tools. The professor, once the students logged in to the interactive session, will act as a live moderator, having privileges to stop the student's interaction or to limit some functionality of the interface to maintain the session under control. Depending on the requirements defined and on the characteristics of the machines hosting the module, the students can access the space with the same features of the professor (contributing audio/video feeds and interface control) or represented by avatars to avoid the need to transport the live audio and video signals of their capture devices to the virtual machine. The professor, as the main figure in the virtual space, will be continuously present through its video/audio feed and moderator controls. The moderation features will allow the professor to pass the total control of the VM GUI interface to determined users (students) or choose if the invited student can carry out just determined actions, like answer a multiple answer question or write on the virtual black board. The level of control on the students is another feature that should be investigated, to obtain a valuable and helpful tool for co-creation and student-professor interaction.

Due to remote access and practical limitations, not all the students will be involved directly at the same time in the live session. In case of synchronous interactive sessions, the video and audio output will be distributed to the rest of the class integrating the videoconferencing tools implemented by the e-DIPLOMA platform. With this solution only the invited students will access the virtual interactive space, avoiding the virtual machine overload in terms of network (bandwidth due to remote access requirements) and functionality. The number of supported concurrent users interacting in the virtual educational space will be established through technical and functional validation of the module once developed. This module will also allow distributing the resulting live video and audio feeds through different formats, enabling the consumption of the learning session and related contents through several device types and modalities. In case of no-interactive sessions, the virtual class content could also be distributed employing higher latency channels, streaming it through the most common live and on demand multimedia platforms and social media.

5.2.3.3. VR

In the context of the prototype applications, reusable plugins will be developed to improve the usability and effectiveness of VR/AR in education. The resulting demonstrators will be provided as standalone or plugins, bundled and distributed as a game engine asset. The focus of the developments will lie on:

- Navigation. The scale of virtual environments will be mapped to the available space of users of VR using methods to navigate through the environment and inspect objects.
- Interaction. Interaction in VR requires mechanisms to map the virtual interactions to the controller paradigm. Besides different methodologies, sensory modalities, available on VR/AR headsets, will be considered for positive or negative feedback loops.
- Visualization. Rendering style can be an important component to support assimilation. The target is the development of several non-photorealistic rendering techniques.
- Collaboration. Group interaction and presence are important topics for VR/AR education and be considered for this toolkit.
- Perception. Finally, opportunities for exploiting perceptual insights about the human visual system will be explored to enhance the learning experience.

The demonstrators will make use of the OpenXR API [20] to ensure widespread compatibility. It is the leading API to interact with VR headsets. It is supported and used by default by both Unreal Engine and

Unity. The API relies on an underlying OpenXR Runtime as a translation layer for the different VR headset series. Most headset OEMs provide their own runtime implementation:

- Microsoft - Windows Mixed Reality [21]
- Valve - SteamVR [16]
- Meta - Oculus [12]
- HTC - ViveOpenXR (on the Vive Cosmos) [20]

For the lowest overhead and highest stability, we will use and recommend the runtime provided by the OEM. If there is no OEM-specific option, SteamVR's OpenXR Runtime is the recommendation. In case that there is no functional OpenXR Runtime for a specific headset, Unreal Engine and Unity can fall back to using Valve's OpenVR API to connect to SteamVR's deprecated built-in headset translation layer.

All generic VR controllers will be tracked using OpenXR. This tracking will be implemented using readily available plugin assets in both engines.

Eye tracking will be added using OpenXR when available. Some headsets require the use of a device-specific SDK instead. For the HTC Vive series, the TobiiXR SDK [17] and HTC SRAnipal SDK [2] are required.

Augmented reality on the Microsoft HoloLens requires the modular Mixed Reality UX Tools in Unreal Engine and the Mixed Reality Feature Tool in Unity. We will include dependencies on the relevant components of these plugins when working with AR.

5.2.3.4. MOLA

Multiuser Online Learning Activities are MOBA adapted to learning experiences. Instead of focusing on adversarial tactics, the emphasis is on cooperative group work in shared virtual environments. The MOLA application will accommodate Learning Objects like shared simulations of complex societal systems, where communicating plans and expected outcomes, coordinating actions to perform agreed-upon actions, and observing the results are possible and desirable. MOBA mechanisms will rely on the capabilities of the Photon Engine.

5.2.4. Learning Objects

Three specific prototype courses will be implemented on the platform, each designed in accordance with the recommendations provided by report D2.2, based on different learning domains. Each prototype will consist of LOs that feature explanations via immersive videos, interaction with virtual environments and 3D objects through immersive VR technology, practical activities through video games with useful feedback in addition to promoting the students' engagement, and personalization of the learning experience using AI to support students throughout their learning process. Particularly, the platform will provide LOs on block programming and sensor management, social entrepreneurship, and VR content generation for education.

The creation process of each LO will not only be properly documented to ensure reproducibility, but also the integrated assets will also be available for further re-use.

5.2.5. Authoring toolchains

It should be possible for later adopters, who are not necessarily computer engineers, to develop LOs for the e-DIPLOMA applications. This requires all applications to feature as many as possible of the following

tools, either within the application, or as an external tool. The tools may well be pre-existing or third-party tools, where appropriate.

- Asset creation via modelling, editing, or capture tools for audio, video, images, and 3D models.
- Asset creation via procedural methods
- Asset creation via generative AI
- Level editor
- Activity logic scripting
- Activity logic via generative AI
- Content import for conventional formats (e.g., slides)

5.2.6. Asset repository

The applications involved in the e-DIPLOMA platform are mainly VR and AR based. As stated, these types of applications entail the employment of 3D models and other graphical assets to enrich the related immersive and augmented environments. For the creation of classes and educational experiences applying virtual production technology, the employment of high quality and dynamic graphics is mandatory to increase the level of attractiveness and visual engagement of the content. For this reason, the implementation of a graphical assets' repository is crucial to give the professors and students the possibility to embed high-quality and attractive graphics in their presentations and related contents.

There are two main types of required assets:

1. A set of **virtual scenarios** to create the environment where the educational session is carried out. The scenarios could be complex 3D models that reproduce spaces and premises like classes, laboratories, iconic sites, historical places, and architectures, etc. The other type of scenario for virtual production are videos of real places recorded employing tracked capturing devices. These types of assets increase the opportunity to teleport the presenter or students to remote real premises with the possibility to embed in the view AR assets like data visualization and environment features highlights to improve the attractiveness of the generated visual content.
2. A collection of 3D Models, reproducing every kind of object and related motions, mechanisms, compositions, and animations that can help to visually explain the connected knowledge, behaviors, and didactic notions. The employment of animated 3D models (Figure 3) reporting complex dynamics and processes could increase the level of assimilation of the contents bringing a valuable improvement to the currently employed graphical assets.

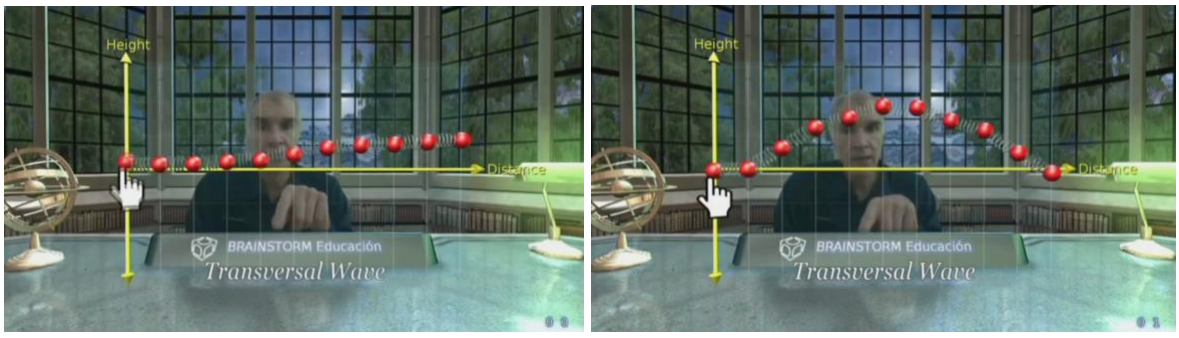


Figure 3 Example of animated 3D model for educational purpose.

The repository will be open to the platform audience gathering the possibility to upload and download content. In case of upload the content will be subject to compatibility verifications to ensure that the uploaded item is compatible with the virtual reality and production technologies of the platform. The

assets compatibility specifications will be determined considering the most common 3D assets production pipelines and creation tools to try to offer a wide variety of options to the users to design their content and then upload it to the e-DIPLOMA platform environment. In case that the asset would not pass the compatibility verification, the uploading user will be warned about it and requested to implement the required modification to make the asset compatible with the virtual education environment. The Assets repository will allow the users who act as contributors to have feedback on their uploaded or modified assets in order to improve the intercommunication and collaboration between different profiles inside the platform. The collaboration between different educational sector profiles will then increase the number of generated assets, combining expertise and content from different subjects and disciplines, improving the variety of the assets provided by the repository. In line with this aspect, the repository will also take care of the authoring rights of who is uploading or modifying the content in order to track the users' contributions. The repository will support a detailed asset classification that will enable it to provide research capabilities to ease the identification of valuable assets during a search or to limit the access to certain assets in determined cases.

5.2.7. AWS backend

5.2.7.1. Backend objectives

The AWS backend must be capable of creating sessions for Web Lobbies and automatically starting a dedicated server for each session. A session is a shared virtual experience in which the members of a Web Lobby can interact with each other. Sessions can be started in a self-service manner or with the permission of an authorized person (e.g., a teacher). Dedicated servers are responsible for managing and synchronizing the application state between the participants of a given session as well as collecting data about user-specific events, for analytical purposes. By default, the AWS backend will launch a Virtual Machine in the cloud for each session, on which the dedicated server will be hosted, therefore, partners won't have to operate their own servers. Using on-premises infrastructure for dedicated server hosting will be supported as well.

5.2.7.2. AWS Services

The infrastructure behind the AWS backend consists of the following services:

- GameLift – A fully-managed service which simplifies the process of setting up, scaling, and managing dedicated game servers. The service supports a wide range of game engines, including Unreal Engine, Unity, and custom-built engines, and can be used for session-based multiplayer applications. With GameLift, dedicated servers can be deployed to AWS-managed or on-premises infrastructure. Also, the service includes a feature called FlexMatch, which is a matchmaking service that enables developers to build and deploy custom matchmaking logic for multiplayer applications.
- DynamoDB – A managed NoSQL database service that is designed to be highly scalable and can handle millions of requests with automatic scaling. In the AWS backend, the service is used for storing state information about users and sessions.
- SNS – A managed messaging service that can be used to publish events and notifications to multiple subscribers or endpoints in real-time, such as email addresses, mobile devices, or AWS Lambda functions, which can then perform actions based on the event. In the AWS backend, the service is used for sending email notifications about critical events, and for decoupling the components of the architecture, making it more flexible and scalable.
- Lambda – A serverless compute service that allows developers to run code without the need to provision, manage, or scale servers. With Lambda, we can simply upload our code and AWS takes care of the underlying infrastructure. It supports a variety of programming languages, including Node.js, Python, Java, C# and Go. The service is designed to be event-driven, meaning it can automatically execute code in response to events such as incoming API requests or messages

published to SNS. It provides several benefits, including automatic scaling, pay-per-use pricing, and high availability. The service is used for multiple purposes in the AWS backend, such as managing sessions and the lifetime of dedicated servers, handling and responding to user requests, and sending email notifications about critical events.

- EC2 – The Elastic Compute Cloud service enables us to launch and manage virtual machines (EC2 instances) in the cloud. We can select the operating system, CPU, memory and storage capacity for each instance, and pay for only the resources we use. If GameLift is not used for hosting dedicated servers in the AWS backend, then hosting them on EC2 instances may serve as an option.
- S3 – A scalable, highly available cloud storage service. In the AWS backend, it is used for storing the application dedicated server binaries which can be later downloaded to EC2 Instances during an initialization step.
- API Gateway – A managed service that allows us to create, publish and manage APIs such as REST or WebSocket APIs, and securely expose them to the internet in order to be called by client applications. APIs created with API Gateway can be easily integrated with other AWS services such as AWS Lambda. The service can also be used to create custom authorization and authentication mechanisms, as well as to throttle and monitor API usage. In the case of the AWS backend, the core functionalities will be published through a WebSocket API, so that the backend can send notifications about specific events to the client applications in real-time.

5.2.7.3. Cost Structure

GameLift – https://aws.amazon.com/gamelift/pricing/

- FlexMatch: $20.00 per 1 million Player Packages + $1.00 per 1 Matchmaking Hour
- GameLift-managed instances (virtual machines): pay-per-second billing, depends on instance type.
- Data Transfer OUT from Amazon GameLift Instances to Internet: multi-tier pricing (per GB)

DynamoDB – https://aws.amazon.com/dynamodb/pricing/

- Two different pricing models: on-demand vs provisioned.
- On-demand capacity mode: pay-per-request, suitable for unpredictable application traffic.
- Provisioned capacity mode: suitable for predictable application traffic
- 25 GB storage + 25 provisioned Write Capacity Units + 25 provisioned Read Capacity Units per month is free (enough to handle up to 200M requests per month, according to Amazon)

SNS – https://aws.amazon.com/sns/pricing/

- $0.50 per 1M requests, first 1M requests per month is free.
- Email notifications: $2.00 per 100 000 notifications
- No charge for deliveries to Lambda
- Data transfer into SNS: free
- Data transfer from SNS to Lambda: multi-tier pricing (per GB)

EC2 – https://aws.amazon.com/ec2/pricing/

- Virtual Machines: pay-per-second billing, depends on VM configuration and region.
- Data transfer from Internet to Amazon EC2: free
- Data transfer from Amazon EC2 to Internet: multi-tier pricing (per GB)
- Pricing for volume storage (Amazon EBS): https://aws.amazon.com/ebs/pricing/

Lambda – https://aws.amazon.com/lambda/pricing/

- $0.20 per 1M requests, first 1M requests per month is free.
- Compute time × memory usage (GB-seconds), multi-tier pricing, cost depends on selected CPU architecture (x86 or Arm) and memory configuration, first 400 000 GB-seconds per month is free.

S3 – https://aws.amazon.com/s3/pricing/

- Object storage (per GB-month) depends on storage class.
- Number of requests, depends on request type.
- Data transferred from an Amazon S3 bucket to any AWS services within the same AWS region as the S3 bucket.

- Data transferred from Internet to Amazon S3 is free.

API Gateway – https://aws.amazon.com/api-gateway/pricing/

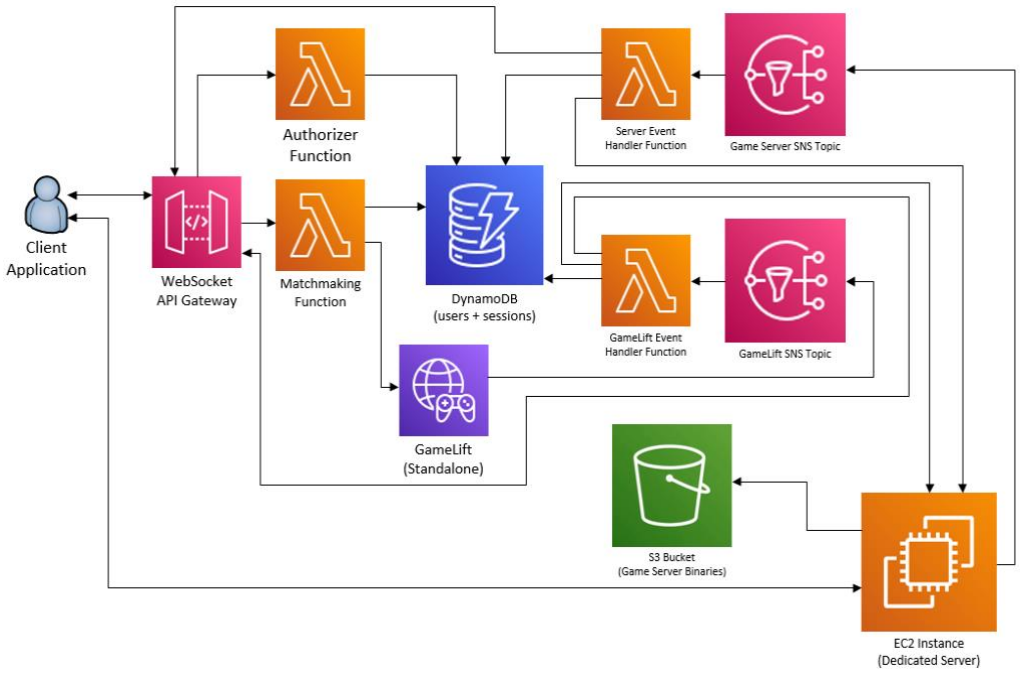
- WebSocket connections: $0.25 per million connection minutes
- WebSocket message transfers: $1.00 per 1M (first 1 billion), $0.80 per 1M (over 1 billion)
- Data transfer: same as EC2 data transfer rate

The above complex cost structure, a multitude of options to choose from, and regionally and temporally varying prices are not conducive to a general estimate on costs, or a straightforward comparison of options. Many of the factor are likely to be different for individual Learning Objects, depending on the number of users cooperating, the new technologies used, and the amount of data to be exchanged. However, we can give an estimate using current pricings for a course we deem more or less typical, using high-end machines with the AWS GameLift cloud (which is a comprehensive solution, with less customization be considered). If we go with a course that has **14 2-hour lessons**, with **24 students** participating, using the AWS calculator available at https://calculator.aws/#/addService/GameLift we obtain a *Total GameLift Instance Cost* for half 14 days of **108 USD**. While other services we use may contribute to the total, this is going to be the most significant cost factor. During the e-DIPLOMA investigations, these costs are well within the budget. For later exploitation, the costs are low enough to put the technologies in reach of educators who do not have the appropriate game servers on their premises.

5.2.7.4. Architecture Overview

The AWS backend is based on a reference architecture suggested by Amazon, found in the GameLift documentation:
https://docs.aws.amazon.com/gamelift/latest/developerguide/gamelift_quickstart_customservers_designbackend_arch_serverless.html

The following architecture diagram illustrates what resources the AWS backend consists of and how they communicate with each other. Each arrow points to the direction in which a request is initiated. In the architecture below, GameLift is used for generating sessions only, while dedicated server hosting is managed through the EC2 service by custom Lambda functions.



Each resource performs the following tasks:

- WebSocket API – Publishes session related functionalities to the Client Application and sends back notifications to the clients about specific events, e.g., when the dedicated server for a session to which a user belongs has been successfully started.
- Authorizer Function – When a client tries to establish a connection with the WebSocket API, the Authorizer Function is automatically invoked, checking whether the client is authorized to use the API.
- Matchmaking Function – Processes WebSocket messages sent by the Client Application.
- GameLift – In Standalone mode, GameLift acts as a matchmaking service. When it detects that a session can be started, it publishes a message to the GameLift SNS Topic.
- DynamoDB – Stores a list of the active sessions, the WebSocket connection IDs of connected clients, and the ID of the session a user belongs to. This is necessary since GameLift doesn't store any state information about sessions in Standalone mode. Situations such as placing the same user into two simultaneous sessions at the same time can be prevented by managing the relation between sessions and users in the database properly.
- GameLift SNS Topic – Receives messages from GameLift and forwards them to the GameLift Event Handler Function.
- GameLift Event Handler Function – Reacts to GameLift related events. Launches EC2 Instances when needed and notifies clients when they have been successfully placed into a session.
- Game Server SNS Topic – Receives messages from dedicated servers and forwards them to the Server Event Handler Function.
- Server Event Handler Function – Processes messages sent by dedicated servers, notifies clients when the dedicated server for the session they belong to has been initialized successfully, and stops EC2 Instances at the end of each session.
- S3 Bucket – Stores the dedicated server binaries so that they can be downloaded to EC2 Instances at the beginning of each session.

The lifecycle of a session consists of the following steps:

1. The Client Application tries to establish a secure WebSocket connection with the WebSocket API by sending an access token to it which was previously obtained from an external authentication service after a successful login.
2. The Authorizer Function checks the validity of the access token. If it is valid, then the WebSocket connection is successfully established, the Authorizer Function saves the WebSocket connection ID into DynamoDB, and the Client Application will be able to send WebSocket messages to the API. Otherwise, the connection request is rejected.
3. When the user decides to start or take part in a session, the Client Application sends a specific WebSocket message to the API, which then gets forwarded to the Matchmaking Function.
4. The Matchmaking Function fetches DynamoDB and checks whether the user belongs to an existing session already. If they do, then the public IP address of the corresponding dedicated server and a session access token are returned to the Client Application (if the server has been started already), then we proceed to step 9. If the user is not a participant of any sessions, then the Matchmaking Function creates a ticket for the user by calling the GameLift service, causing the user to be placed in one of the waiting queues of GameLift.
5. When GameLift detects that a session must be started, it publishes a message to the GameLift SNS Topic, containing a random session ID and a list of the session participants. The message gets forwarded to the GameLift Event Handler Function.
6. The GameLift Event Handler Function saves the new session data into DynamoDB, requests the launch of an EC2 Instance, and sends a WebSocket message to each participant of the session through the WebSocket API, indicating that the session is about to start.

7. After the EC2 Instance has started, a User Data initialization script downloads the dedicated server binaries from an S3 Bucket, starts the dedicated server process, and sends a notification to the Game Server SNS Topic that it is ready to accept client connections.
8. The notification will be processed by the Server Event Handler Function, which fetches the public IP address of the EC2 Instance associated with the given session, saves the address and the updated session state into DynamoDB, and sends a WebSocket message to the session participants which contains the IP address of the server and a session access token with which the clients will be able to authenticate themselves on the dedicated server.
9. The Client Application connects to the dedicated server process and sends the session access token to it.
10. The dedicated server checks the validity of the token. If it is valid, then the connection is successful, and any further messages sent between the dedicated server and the client are handled by the application (the messaging protocol depends on which game engine the server and client application have been built with). Otherwise, the user gets kicked from the dedicated server.
11. After all session participants have joined, the dedicated server notifies the Game Server SNS Topic that the session has started to run. The Server Event Handler Function updates the session state in DynamoDB.
12. When the session is over, the dedicated server disconnects the clients and sends a notification to the Game Server SNS Topic about the event. The Server Event Handler Function saves the session results into DynamoDB, then requests the termination of the EC2 Instance.

5.2.7.5. Safety, robustness, observability features

Observability features are essential in a backend system as they help identify and resolve issues that may arise during the operation of the service. We have considered adding at least the following features:

- When a runtime error occurs in any Lambda function, an email notification will be sent to preconfigured email addresses, containing relevant information about the error. This mechanism helps detect problems that may require human intervention to correct. The feature can be implemented by using CloudWatch filters and SNS.
- The health status of the dedicated servers will be checked periodically by a Lambda function and an email notification is sent if a dedicated server is detected as unhealthy. This can happen if the server process crashes due to an unhandled error in the application or any other incident related to the EC2 Instance.
- Institutions will be able to monitor the current and historical load on the service (e.g. the number of active users and sessions at a given moment, or the length of sessions) to better estimate their future costs, recognize usage trends, or even detect possible anomalies.

Robustness features help to improve the fault tolerance of the AWS backend. Even in the presence of accidental runtime errors and transient failures, such mechanisms can automatically detect and resolve incidents without the need of any human intervention, keeping the service in a healthy state which results in the assurance of user experience and the avoidance of unexpected charges. At least the following robustness features will be added to the AWS backend:

- Stopping dedicated servers which are unhealthy or have been running for so long that they have exceeded the maximum allowed session duration (which can be configured as needed).
- Repeating Lambda function invocations that failed to run properly, presumably due to some temporary error, resulting in partially completed processes. This can be usually detected if the state information stored about users and sessions in DynamoDB became inconsistent or does not adequately reflect reality, e.g., if the dedicated server of a session has been successfully shut

down, but the session has not been registered as finished in the database yet, and users have not been removed from it, making it impossible for them to start or take part in a new session.

5.2.8. Analytics

The platform will host an artificial intelligence recommender system designed to assist students throughout their course journey. To develop this system effectively, it is imperative to gather relevant data on students' interactions within the platform. Initially, the plan is to leverage student interactions with LOs, as well as higher and lower-level elements. The recommender system will benefit from analysing all forms of student engagement, including interactions with files, videos, external links, and forums. Additionally, capturing data on the duration of these interactions, idle time, lesson completion time, and other related factors would be valuable.

All the aforementioned data collectively contribute to the recommendation process as students' progress through the course and generate new data. However, during the initial stages or when students are new and their capabilities and interaction patterns are unknown, it may be challenging to provide suitable recommendations. Therefore, it would be beneficial to augment the student's history with relevant data to address this issue. This additional data could encompass the student's mastery level in related subjects, learning preferences, and other relevant information. The objective is to build a learner profile that can better anticipate their behaviour in various situations.

Among the various types of data that can be utilized, interaction data holds the utmost significance. Obtaining this data is relatively straightforward as it can be automatically logged whenever students interact with or access any learning resources on the platform.

6. Exploitation outlook

There are some determinations about the platform that cannot be made in the present phase of the project. These concern the way the results are going to be exploited by the education community in Europe. The e-DIPLOMA platform is certainly intended not only to serve the purposes of the project in evaluating disruptive technologies and formulating policy recommendations, but also to provide a tool aligned with those findings. There are multiple ways the platform can be used:

- **Teaching the prototype courses.** This is foreseen in *D8.4 Business Strategy Baseline*. The prototypes in themselves are valuable assets in teaching the specific subjects.
- **Teaching other courses.** These would presumably be created following the prototypes. Whether this will be a simple task possible for any educator, or a development task requiring technical expertise, will depend on the specific application and research outcomes during the project.
- **Integrating third-party applications.** The e-DIPLOMA platform can be used as an integrator of various applications, as long as they adopt the launcher and communication protocols.
- **Using individual applications stand-alone.** If the platform in general is not used for some reason, applications may still be launched manually, but without the benefits of integration with LMS or other e-DIPLOMA components like advisory AI. This is a worst-case scenario for the exploitation of the platform itself, but successful ideas may still enhance learning for many.

In all but the last of the above cases, the e-DIPLOMA platform is used as a service. The question that cannot be answered in the platform design phase, as it is a business decision, is who is going to maintain that service. An AWS solution costs money, and as the number of users and their activity increases, the costs can get very significant. The following scenarios are possible:

- One or more of the **partners** in the e-DIPLOMA project **maintain the service**, directly or through a start-up company, as a for-profit or non-profit enterprise. This requires a willingness to take business risk and responsibility, and a positive business outlook at that future time.
- Several instances of the **service** are maintained, paid **for by their respective users**. This requires the service to be provided as code (IaC, Infrastructure as Code) that can be set up by any governmental or educational institute. This may be possible if some countries or major educational players would like to use e-DIPLOMA as their official platform, but under their control. There would be not one, but many e-DIPLOMA platforms.

In any case, the set of users and the maintainer of the service are likely to be different. Users may want to develop their own Learning Object, Courses, or even applications for the platform. Under what circumstances can new code and content be added to the platform must be determined by the maintainer. As the number of users increases, Quality of Service (QoS) considerations become increasingly important. The infrastructure must remain scalable to high loads, without the service being unavailable or response times escalating. While the technologies selected in this document provide the means for scalability, additional development addressing emerging business needs can always be necessary.

7. Conclusions

This document has analysed the requirements for the e-DIPLOMA Platform based on the stated objectives and task to be completed during and after the project, as well as expert opinion gathered in WP2. After analysing the technical options in the light of the requirements, an overall module structure was proposed, with the interface standards between the modules determined. A decision on core technologies, including the LMS and the cloud service for backend implementation, has been reached. A wide latitude in the choice of technologies for the implementation of prototype courses and working modules has been maintained, but the way these applications have to work together with the core platform was laid down, and the technologies to be featured in them was projected. The document can serve as a basis for the development of the platform, and a roadmap for the integration of emerging e-DIPLOMA applications into the platform.

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