xAPI Made Easy: A Learning Analytics Infrastructure for Interdisciplinary Projects

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Abstract—Learning Analytics provides plenty of pedagogical uses. However, the integration of learning analytics must be accompanied by different perspectives: technical, organizational, and pedagogical. At this point, there are still gaps, e.g., the need to connect the various stakeholders and support the systematic, structured, and sustainable process. This paper presents different approaches to making the learning data standard xAPI for interdisciplinary projects easier by working on other starting points. Starting with a basic infrastructure to support the interdisciplinary collection of definitions for the standardized data format, it continues with a graphical user interface supporting different stakeholders. A modular tool for quickly connecting programming IDEs with the vocabulary is also presented. Last, a connector is shown for easier multi-modal data management using virtual reality as an example.

Keywords—xAPI, learning analytics, educational virtual reality, research data management, interdisciplinary research, open science, definition registry, scientific collaboration, research infrastructure, lab-based learning

1 Motivation

Physical and digital laboratories are essential for education in science, engineering, and technology-based careers [1], [2], [3]. The importance of labs and hands-on learning is, for example, visible in the criteria for accrediting engineering technology programs, which include "Physical and Natural Science: The physical or natural science content of the curriculum must be appropriate to the discipline and must include laboratory experiences" [4]. Or the curriculum of civil engineering technology programs must provide credits in the area of: "performance of standardized field and laboratory tests" [4]. Another point is that students from many engineering curricula should learn the preparation of lab reports. All in all, lab-based learning leads to different learning environments, on the one hand, the laboratory itself, and on the other hand, traditional software, e.g., for creating reports. Additionally, research showed that combining different lab experiences, physical and digital labs, like VR, could lead to a higher conceptual understanding [5].

Reference [6] describes a scenario in which an IoT laboratory is analyzed in different stages of the Reality-Virtuality continuum model [7] and the learning objectives pursued. One challenge they name for the project is to research the learning processes within the project. However, because the students use different learning sources while working in the lab, it's complex to identify the critical learning activities.

Learning Analytics – "the measurement, collection, analysis, and reporting of data about learners and their contexts, for purposes of understanding and optimizing learning and the environments in which it occurs" [8] – is one way to deal with these challenges. Particularly suitable for such a multi-modal field of lab-based learning is the specialization of learning analytics, called multi-modal learning analytics [9], which is often used in complex learning environments. However, conducting work in multimodal learning analytics (MMLA) is as complex as these scenarios, as there are technical, organizational, and pedagogical challenges.

Another challenge is the interdisciplinarity of MMLA projects, e.g., the people working in labs are experts, usually from highly specified fields of lab-related work. Often with knowledge of gathering technical data, but not experts in collecting data on users' behavior. There are data formats & specifications, but they do not adhere to technical uniformity like sensor data. Thus, it requires more thorough definitions and accompanying metadata to be considered in line with fair data principles, an essential precursor to scientific discourse [10].

1.1 The objective and structure of this paper

This contribution showcases an approach to making the toolset of (multi-modal) learning analytics more accessible to scientists striving for a deeper understanding of their students in the lab or using innovative technology. Therefore, the overall infrastructure is described first: A summary of the technical foundations to generate standardized data from multiple sources, like Moodle, virtual reality, or sensors in a lab. This is followed by a more thorough breakdown of challenges concerning xAPI and possible solutions, a collection of requirements and the corresponding parts of the system, as well as the community-centered approach to gathering a solid collection of definitions and necessary vocabulary as a vantage point.

After that, potential stakeholders' perspectives are covered in-depth: A user-friendly web-based front-end to take along researchers beyond computer science and which could also help enhance the communication between developers and researchers/teachers. Next, taking the developers' perspective, the implementation of convenient packages to support software engineers along the path of implementing interfaces into their research prototypes is presented. And finally, another example of additional components for easy xAPI projects is provided, a web-based tool that guides and assists researchers in collecting learning data. The paper ends with an outlook on the many possibilities this infrastructure might bring along.

2 The xAPI infrastructure

xAPI is a specification, currently on the brink of getting IEEE standard, for recording learning experiences of any kind [11]. It helps researchers by giving a baseline and providing structure, outline, toolkits, and open-source learning record stores (LRS).

The core concepts are simple: Every learner's experience is represented by a statement in the LRS, consisting of an actor, a verb, and an object (precisely, an activity, an actor, or another statement). These mandatory elements can be supplemented by extensions providing further information on either result, context, or the activity itself. All this is to be denoted in a specific form, like grammar, without additional requirements for the actual content. [12]

While xAPI defines the grammar, sustainable usage of collected data requires clear definitions, in best-case referencing to further meta-data, which set statements into context. The classic example the specification uses is the definition of the verb "fired"[1]. Depending on the context, it can both mean dismissing an employee or setting a flame on an object. The minimum requirement of the specification demands the provision of a unique id, called IRI (international resource identifier), containing authority (by web domain), context (by path), and the verb itself. There are use cases where this probably suffices, but that does not hold for scientific standards. The specification documents provide the means for meta-data – a valid URL can also serve as IRI. URLs open two opportunities: First, definitions can be augmented in much more detail than within the IRI. There are operationalizations in science, which vary in the specifics between scientific domains and sometimes even within. Hence, it is essential to make clear which is referred to in the dataset. Second, a systematic approach to hosting meta-data will bring along the structure of a directory, making it easy to browse definitions, possibly even by context, and select those fitting the own research project.

There are several such so-called registries, catalogs of definitions upon definitions for usage in xAPI applications. The advantages and shortcomings of those various attempts are not in the scope of this paper but are discussed in detail in [3]. Instead, this contribution focuses on a possible approach to a science-first implementation. Science-first has multiple implications: It has to align with good scientific practice (e.g. [13]), respect modern research data management conventions (e.g. [14]), and consider the FAIR data principles [10]. Furthermore, to be sustainable, it has to find broad acceptance within "the community," which is another key feature [15]. To achieve that, an egalitarian, participative approach is essential.

The registry presented in this paper (see Figure 1) aims to satisfy those standards and has been thoroughly planned in all its aspects for years. First and foremost, the essential element, the definitions repository, must be kept as simple and straightforward as possible. As it is open-source components like more user-friendly websites (see next part) and feature-rich programming interfaces could be further discussed and improved as the community of scientific users of this infrastructure grows.

[1] https://xapi.com/blog/deep-dive-verb/?utm_source=google&utm_medium=natural_search [14.07.2022]

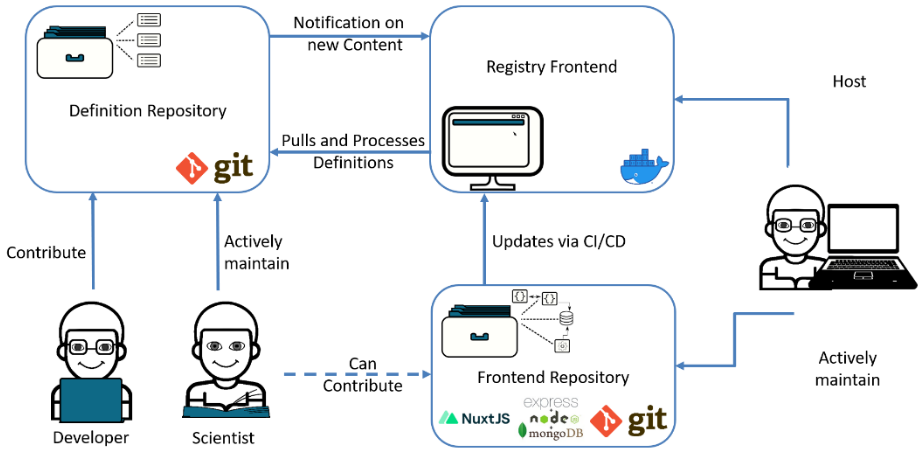

Fig. 1. The basic infrastructure of the xAPI definitions: storage and maintenance

Versioning is a major challenge in managing data; it's important to track changes [16]. Using software to tackle this helps to track revisions and compare definitions and data. We chose Git for versioning, rights management, and as a decentralized architecture to achieve level participation.

Still, to kickstart such a "database" content-wise without the strong influence of a single institution is challenging. Copying the content from existing registries is not a considerable path, as those are often polluted with half-bred ideas and concepts far from being measurable (I.e., verbs like "imagined" or "troubleshot") or simply lacking proper definitions. Furthermore, due to the origins of the xAPI project, some registries contain a significant proportion of military terminology [17], possibly inducing an unintended bias and thus driving off possible future contributors.

Consequently, a structured approach has been developed to create a seed vocabulary. In parallel, definitions from the own working contacts and projects were collected. To eliminate bias as far as possible, this has been done in cooperation with thesis projects and other researchers and by collecting requirements both from literature as well as interviews. Simultaneously, a questionnaire about concepts and fields of application of learning analytics and lab-based user interaction has been distributed in the scientific "neighborhood" of the authors' institution, using contacts from conferences, current and former project affiliations, and specific mailing lists. The questionnaire started with information about the specification, and every question included examples to help the participants who were not used to the specification.

The survey has yielded valuable results: As the invitation was issued with a request to forward, response rates are impossible to calculate, but all in all, 28 researchers completed the questionnaire. The specificity of the answers varied expectantly with the interdisciplinarity of the participants, so some focused on didactical concepts as their main research interest while others related to more or less specific tools in their answers. Others again described whole multi-modal research scenarios or explicitly explained research methods.

Still, a definite trend is recognizable: Many participants wish to use xAPI as a means to track user interaction in Extended Reality (AR and VR – 9x), in lab-based learning (5x), and the data collection with specific (non-traditional) devices and sensors (5x), e.g., setups with more than one cameras or multi-touch displays.

Another hotspot of interest lies in collaboration and different forms of group work (5x), including gamification elements, game-based learning, and serious games. Beyond that, the expected concepts found mentioned as well, like traditional learning management systems (4x), e-assessments (4x), interaction with websites, browsers, and IDEs (3x), and didactical considerations like the reaction to feedback and personalization, videos, open badges, etc.

The participants could choose to remain anonymous, but few opted for that. Based on the analysis of the data provided, the responses include answers from at least 18 distinct research projects or sub-divisions. As a result, suggestions for 139 verbs, 109 activities, 45 context extensions, 29 result extensions, and 21 activity extensions have been collected, pre-screened, and processed for inclusion in the repository. For full disclosure, not all proposals could be included: The overall implications of the xAPI structure, especially of the concept of the extensions, are hard to convey in a relatively short questionnaire. Consequently, concepts have been checked for compatibility with the specification and tested (or researched) for measurability, and a few had to be discarded. Nevertheless, this procedure was only the kick-off initiative. Any missing concept can be added through (informal) scientific discourse in the future (see next part and Figure 3).

The mechanics for that are intended to be straightforward: Scientific institutions interested in an active role (and some degree of responsibility) for the registry and invited to take a role as "owner" or "maintainer" in the git repository. Individual researchers can either join as developers (responsible for specific branches) or fork the repository and contribute their additions by issuing a pull request later. The maintaining institution checks for the scientific validity of the definitions and formal correctness of the request and approves such a request.

The registry itself is therefore kept as simple as possible: definitions are put into a folder structure denoting context and type of the definition (i.e., eye tracking/verbs) in the form of a JSON file (like fixated.json), which is deemed a good compromise between human-readable (and writeable) without deep computer science knowledge or special software, as seen in Figure 2.

At this point, it is important that Git is a versioning system, which enables us to refer to a specific version of the definition whenever required, so even if scientific consensus on definitions changes and therefore the entry in the registry along with it, it is still discernable, which definition has been referred to when a statement was recorded. So if, for example, the definition of how long a fixation lasts should change over time or become more precise so that a distinction can be made between fixations of different lengths, this can be noted without making the older implementations or studies unusable through the update.

Despite all efforts, it would be illusory to expect all other scientific domains to share the computer scientists' enthusiasm for Git and editing JSON files in text editors. Therefore, equally powerful components which provide a higher level of convenience will be described in the upcoming sections.

fixated.json

```
{
    "name": {
        "en-US": "fixated",
        "de-DE": "fixierte"
    },
    "description": {
        "en-US": "An actor fixated an object with her eyes.
        A fixation was detected, i.e., the eyes stayed in a
        small area between 100 and 500 milliseconds without
        sakkades.",
        "de-DE": "Eine Akteurin fixierte ein Objekt mit
        ihren Augen. Eine Fixation wurde erkannt, d.h. die
        Augen haben ohne größere Sprünge zwischen 100 und
        500 Millisekunden in einem kleinen Bereich verweilt."
    }
}
```

Fig. 2. Example JSON file: description of fixated.Json

3 Making it easy for (interdisciplinary) researchers: xAPI registry frontend

As analyzed in [17], there are different types of registries, two repositories that function as the "official" repositories[2], some industry repositories, some CoP initiatives, and academic approaches. Moreover, some registries are not public, not open to contribution, or it is not apparent how to participate. A list of requirements for a new solution is shown in [17], explaining the need for a shared and sustainable solution for xAPI registries with which they want to tackle some problems concerning the actual infrastructures, e.g., impossible revision, missing IRIs, and poor oversight in the few larger repositories. Additionally, the approach presented in [17] and the last section demonstrates an infrastructure that compensates for the weaknesses of previous solutions while facilitating interdisciplinary collaboration.

A central element to promote openness is the *xAPI Registry Frontend*, which is already available in its second version. The presentation of definitions should not only be optimized for machine readability but also the humans. The xAPI Registry Frontend, a website displaying the definitions also accessible via the corresponding URIs, is the entry point for researchers. This group is the most important group for describing research data [15]. The same is valid for learning data as for research data: "[Researchers] are not necessarily knowledgeable in data management practices, but can provide domain-specific, more or less formal descriptions to complement generic data. [15]" The requirements for the xAPI Registry Frontend are to represent a functioning, stable, and user-friendly xAPI Definitions Registry.

At the time of writing, there are just under 500 definitions in the repository, which are collected into 14 categories. The expansion and the work with the definitions made it necessary to improve the usability of the Website, e.g., by adding filter options.

[2] registry.tincanapi.com/ and http://xapi.vocab.pub/ [15.07.2022]

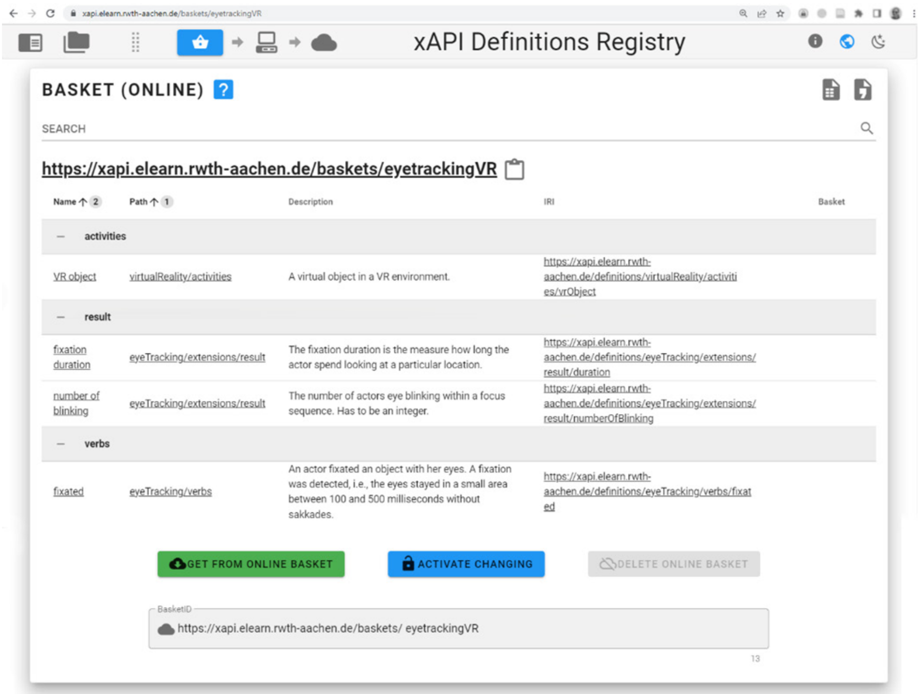

Fig. 3. Example basket: a collection of remote lab definitions

A concept used to work with a high number of definitions is to define profiles[3], which, e.g., define patterns and provide templates so that the vocabulary can be contextualized even more. These are currently not yet supported, but the interfaces are available. An intermediate step on the way to profiles are so-called baskets. Baskets, a screenshot of a custom demo collection visible in Figure 3, allow the creation of a subset for a specific use case, for example, to generate user interfaces or to foster communication between software developers and researchers. The xAPI registry front-end also provides a non-technical shortcut for proposing new definitions by providing a form in which new proposals can be submitted. The new front-end was tested with experienced and new users with an interdisciplinary background. The fields of Computer Science, Physics, History, and Computational Engineering Science were represented. Methodologically, different approaches were followed that can be classified as user-centered design: role-playing, walkthroughs, simulations, and usability testing. The front-end workflow matches other attempts to onboard interdisciplinary researchers, like [18] or [19].

The functionality described here is part of the bright yellow "LearnTech xAPI definitions" in Figure 4, shown in the next part. Different stakeholders could use it to define vocabulary, which then could be connected to delelopment environments.

[3] https://adlnet.github.io/xapi-profiles/xapi-profiles-about.html [14.07.2022]

4 Making it easy for developers: the xAPI definitions fetcher

The part before explained how researchers could easily define the xAPI vocabulary. This part shows the next hurdle we identified in a specific project and how we solved it in a generalizable way for this and other projects.

Virtual reality (VR) has a high potential for teaching in different domains, like engineering [2], [6], because it enriches learning environments [20]. The use of VR could enhance experimental learning [21]. With interdisciplinary stakeholders in our projects, we designed a system to simplify the xAPI tracking setup, according to iterative design and design-based research [22]. The stack can be seen in Figure 4. Each stakeholder can define xAPI definitions (see section 3), and a web panel supports researchers (see section 5). This way, researchers can easily configure a VR client's tracking configurations (without computer science knowledge). The xAPI specification can track learners' activities in VR and different application fields by creating xAPI statements – e.g., what learners read in the application (and how long it took, etc.). After analyzation of these statements, it is possible to get findings about the learner's behavior – but before, concrete xAPI statements must be implemented for the specific learning scenario, which is a task done by developers in cooperation with the other stakeholders.

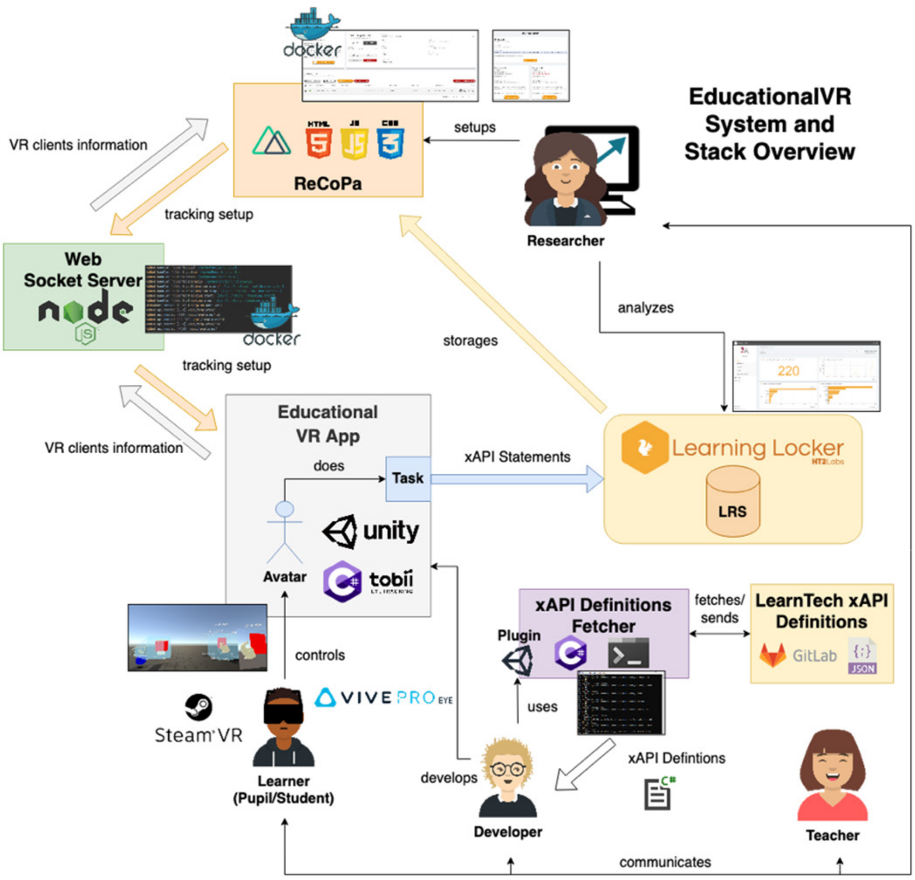

Fig. 4. Educational VR stack: software and architecture

During the development of VR learning scenarios, we identified difficulties in using xAPI. Even though the xAPI statements can be generated and sent to Learning Record Store using the library TinCan.NET[4], the generation is still complicated.

The developer provides the statement templates with IRIs of the vocabulary in the messy, possibly quicker, and dirty (hand-coded) variant. As a result, the developer wrote repeating code, only variating string parameters. The xAPI definitions generated for the xAPI Registry Frontend (section 3) help developers, but they still have to copy URLs into C# code by hand. As a consequence, updates of a registry must be synchronized with this hard-coded library. Additionally, synchronizing the definitions by hand is an effort risking inconsistency. The repeating code could be reused for multiple projects. Thus, it makes sense to create a library to share and reuse in other projects.

The aim of the xAPI Definitions Fetcher, the purple box in Figure 4, is to make the synchronization of xAPI definitions easier for developers. Using C# and Unity, the xAPI Definitions Fetcher console application translates the pre-defined xAPI vocabulary from section 3 into C# classes holding their contents (see Figure 5). Depending on configurations, it takes xAPI definitions contents either from a local copy of the repository or from the master branch of a GitLab repository. For easy usage, we have implemented a Unity editor plugin passing from editor arguments to the console application.

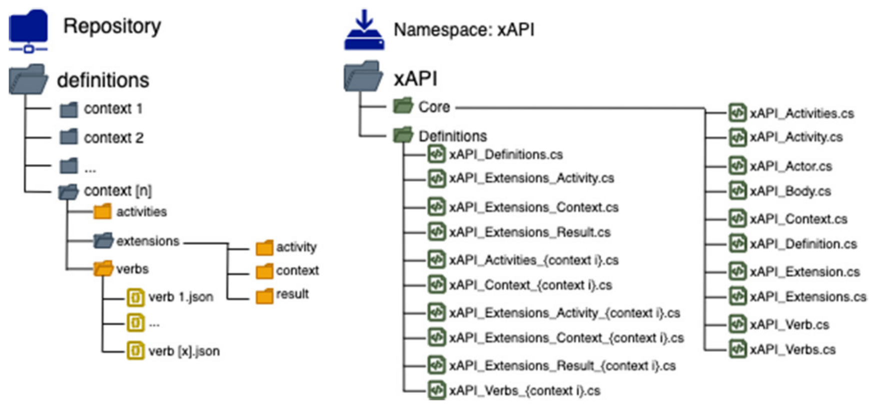

Fig. 5. xAPI definitions fetcher process: transformation of json files into C#

The code design of these classes allows composing xAPI without describing them by hand. The amount of needed code lines is much less than doing it by hand, and the usage is guided by intelligent code completion, e.g., IntelliSense functions in Visual Studio Code. The JSON-based verbs and activities were transformed into properties holding their different languages, names, and descriptions. The xAPI extensions (activity, result, and context) are designed in the form of C# methods. The method's name represents the key of an extension, and the parameter represents the extension value. In Figure 6, an example C# snippet shows how an xAPI statement is created and supported by the generated C# classes, properties, and methods. The property *fixated* can be used applying the same path as in the xAPI registry (definitions/eyeTracking/

[4] https://github.com/RusticiSoftware/TinCan.NET [15.07.2022]

verbs). The property is a C# class instance, holding all information about the verb fixated, as seen in Figure 2. The same is valid for the activity *vrObject*. This example uses four xAPI extensions to provide further information to the statement (vr object name, number of blinking, time span, start value). The extensions are provided as a collection with holding values. As each method returns its' type again, further information from the same extension type can be provided by just typing a dot again (see start value).

After building an xAPI statement, it will be automatically passed to the TinCan.NET library via the method *SendStatement* of our written Unity component *LRSController*. As a result, the developer can update an xAPI code vocabulary by updating the JSON definitions and using the xAPI Definitions Fetcher to transform them into code. Afterward, the developer can use it like a standard C# class library, including the support of IntelliSense and code descriptions. Submitting the written JSON definitions to a common Git repository ensures a consistent, safe, and non-redundant usage of xAPI vocabulary in the developer's environment.

First user tests of this approach highlighted benefits and potential improvements. After the release of the xAPI Definitions Fetcher for Unity, an online survey for developers of learning applications identified other programming languages which could benefit from a similar approach. We found the need for JavaScript, Java, and Python. Therefore, we started extending the xAPI Definitions Fetcher for JavaScript and Python. Instead of (only) having the console application and Unity editor plugin, the survey results inspired other usage variants. Based on the results, we started creating the xAPI Definitions Fetcher as a Visual Studio extension and web service. We extended it to support export for C# DLL, JavaScript, and Python. In further iterations, the web service will be directly linked with the xAPI registry front-end to export.

```
LrsController.instance.SendStatement(
    verb: xAPI_Definitions.eyeTracking.verbs.fixated,
    activity: xAPI_Definitions.virtualReality.activities.vrObject,
    extensions: new xAPI_Extensions[]
    {
        xAPI_Definitions.virtualReality.extensions.activity.vrObjectName(gameObject.name),
        xAPI_Definitions.eyeTracking.extensions.result.numberOfBlinking(numberOfBlinking),
        xAPI_Definitions.generic.extensions.result.timeSpan(timeSpan).startValue(0)
    }
);
```

Fig. 6. Example C# code: sending an xAPI statement with the verb *fixated* and the activity *VR object* with further information using xAPI extensions

5 Making it easier for investigators: the researcher companion panel

The selection of tracked variables for learning analytics and MMLA differ depending on the investigators' needs and must be aligned with the General Data Protection Regulation (GDPR). The investigator, (for example) a teacher, researcher, or developer, should be able to adjust the variables in a user-friendly way without having to have programming knowledge. The configuration and control of the learning analytics setup are done with a web panel called the researcher companion panel (ReCoPa). This panel has a live connection to a VR learning scenario implemented in Unity and can store information concerning the LRS (see Figure 4). Using the ReCoPa, the investigator can provide commands to the observed VR clients, e.g., start eye calibration, start/stop tracking session and close the VR client. It is also possible to save and restore tracking setups via this web panel.

The ReCoPa is designed to be modular and valuable for various learning applications. Following modular design principles (MAPs), as done in [23] for architecture products, the web panel could easily be extended for other applications in Unity or other LRS. In addition to this requirement (to react to technical enhancements and innovations [component swapping, component sharing, adjustment]), another vital point is to respond to different experimental designs. Dealing with different experimental designs has been part of the core functionality of ReCoPa from the very beginning by giving the investigator complete control over the tracked interactions, objects and events.

After a proof of concept implementation in 2019, the ReCoPa has been in use since 2020, and since the first release, we have observed and implemented further requirements. An essential concern in multidisciplinary projects is the good usability of technical developments and the research infrastructure [24], which we tried to ensure, e.g., by following usability factors named by Nielsen [25]. We found that the display of the various connections and the status of the whole system must be displayed particularly clearly to give a secure feeling to all user groups. For example, interdisciplinary researchers need direct feedback on whether the learning analytics tracking is working, so a live connection to the LRS (in our case Learning Locker) was added, as seen in Figure 7 highlighted with a purple color (xAPI Statement Monitor).

A concrete usage scenario for the ReCoPa could look like this: e.g. for a (VR) application like the Rendering Pipeline in VR used in [22] or the virtualized RFID laboratory described in [6], the researcher can specify which data is interesting for the current experiment. In this example, the researcher wants to collect the interaction data and certain gestures like specific head movements. And what the subjects looked at (using descriptions like "actor fixated VR object RFID tag for 400ms"). To do this, the researcher can specify all learning-relevant objects to be tracked in ReCoPa. This helps to fulfill the requirement to quickly change the recorded modalities if necessary, for example, if a subject disagrees with specific planned data sources. The configuration is done in the green marked part in Figure 7 (and can be saved or retrieved in the orange one). The researcher can check and adjust the status of the connection to the learning record store in the red (fold-out) section. As soon as the experiment begins, the tracking can be started in the configuration panel. A circle shows the status of the application – the red circle could mean that the calibration for the eye tracking is still missing. The already named purple panel is primarily for user comfort and a good user experience, as it gives direct feedback on whether data is sent to the LRS. The researcher could also check if all intended data sources are collected quickly. To avoid an excessive number of statements from sensor data, statements with the same verb are grouped.

In this way, studies can be quickly adapted, modified, and extended, and investigators do not need to be familiar with the programming environment.

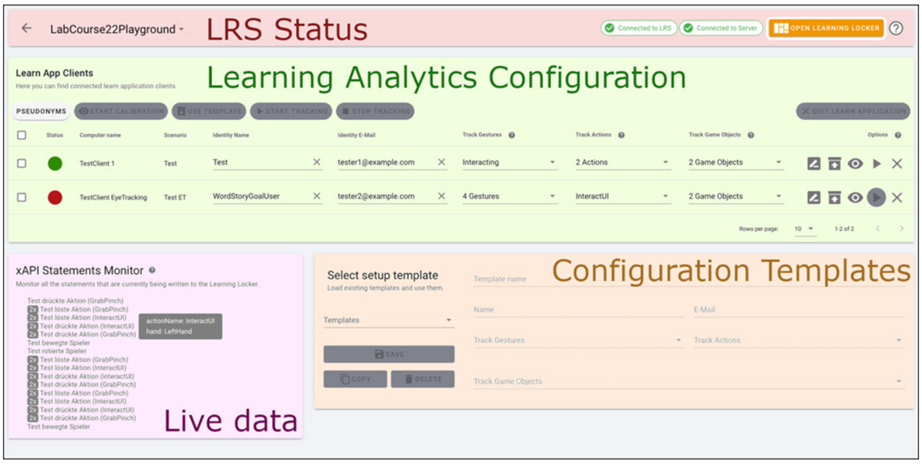

Fig. 7. Screenshot of the researcher companion panel (ReCoPa). colored overlays show the structure and the main functionalities

6 Conclusion

Even large student numbers are not an obstacle to lab courses with hands-on experiences; see [26] presenting a course with over 400 students and hands-on labs. However, especially with such highly scaled numbers, integrating learning analytics can be worthwhile to provide individualized feedback to students [27] and give instructors a better overview [28]. And researchers can work on learner modeling based on the generated learning data [29].

Our work's main limitations are i) the tools need to be tested with more end-users, and ii) we want to integrate further contexts and learning scenarios. Another challenge scaling up learning analytics raises is that analytics and dashboards become more elaborate and complex. A project that addresses these tasks and creates a complement to the multi-modal approaches of this work is EXCALIBUR LA [30].

The whole research data management is a core component of scientific work and should be considered from the different perspectives of the various stakeholders for a good process [24], [15]. Therefore, the goal of this initiative is not only to achieve a learning analytics infrastructure supportive of an "active and informative" learning data management but to create an environment that is "optimized for reuse" [31].

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