

RESEARCH

Free and Open Access

# Implementing enriched context descriptions for efficient scaling of learning analytics

Jeanette Samuelsen<sup>1,2\*</sup>, Weiqin Chen<sup>1,3</sup> and Barbara Wasson<sup>1,2</sup>

\*Correspondence:  
[jeanette.samuelsen@uib.no](mailto:jeanette.samuelsen@uib.no)  
Centre for the Science of Learning  
& Technology, University of  
Bergen, Norway  
Department of Information  
Science & Media Studies,  
University of Bergen, Norway  
Full list of author information is  
available at the end of the article

## Abstract

Learning analytics (LA) collects data about learners and their contexts to enhance learning. Integrating data from multiple data sources may provide a more holistic picture of learners and enable more useful analysis than is possible from isolated data sources. Learning activity data standards, including xAPI, can support data integration and thus help scale up LA. Research, however, has shown such standards are not widely used for these purposes, possibly related to limits in their expressibility. In this study, we provide implementation of recommendations for enhancing xAPI context descriptions and expressibility, as part of a technical solution that could be used by users preparing activity data for LA. The technical solution, realized through the creation of an xAPI profile and following affordances and constraints of xAPI, is adapted to the K-12 school adaptivity case. The technical solution is evaluated through user testing with technical experts having real-world experience with xAPI data description, allowing participants to explore the solution at a general level and consider different aspects related to its implementation. The evaluation results indicate that the technical solution meets criteria for usefulness and effectiveness. Furthermore, the results indicate user satisfaction with the solution at a general level, related to the recommendations, while also pointing out room for improvement in terms of the implemented solution. By enhancing the context descriptions of xAPI, which enables Learning Analytics (LA) to analyze data from multiple sources as evidence and supports adaptation, this research has the potential to contribute to both adaptive learning and evidence-based practice.

**Keywords:** data integration, interoperability, learning analytics, learning context, scalability, xAPI

## Introduction

In education, an increasing variety of digital tools and platforms are available to support students and their learning. When students interact with such tools, the tools generate trace data that are stored within individual data sources. Technological advances such as ubiquitous Internet and smartphones mean that use of digital learning platforms and related



© The Author(s). 2026 **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons license, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons license, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons license and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this license, visit <http://creativecommons.org/licenses/by/4.0/>.

tools are no longer constrained to the physical environment of educational institutions. In addition, publicly available Application Programming Interfaces (APIs) and devices with sensor technologies enable data regarding aspects such as the physical environment and various internal states of a learner to be recorded. Thus, data about and related to learners can be generated from a variety of contexts, where a context can be defined as “any information that can be used to characterize the situation of an entity” (Dey, 2001, p. 5). Different data models have been created that enable the description of learning context (e.g., Jovanović et al., 2007; Schmitz et al., 2011; This et al., 2012; Lincke, 2020), where they vary in aspects such as unit of focus (e.g., learner or learning object), flexibility of data registration, and context categorization (flat or hierarchical) (Samuelsen et al., 2021). Learning analytics (LA) is “the collection, analysis, interpretation and communication of data about learners and their learning that provides theoretically relevant and actionable insights to enhance learning and teaching” (SoLAR, 2025). Related to LA, Bakharia et al. (2016) emphasize that it is essential to add contextual data to learning activity data, i.e., data that describes a learner interacting with a learning object in a learning environment, as a means to improve analysis.

Data integration has been identified as “a key driver of value in analytics” (Cooper, 2014). Integration of data from different contexts, where data exist in disparate data sources, can improve areas such as personalization and adaptive learning (De Meester et al., 2018). Many of the questions stakeholders wish to understand using LA require the combination of data originating from multiple sources (Kitto et al., 2020). Integration of data is also an important factor of LA scalability (Samuelsen et al., 2019).

Closely related to data integration is interoperability, which can be classified according to semantic, technical, legal, and organizational levels (European Commission, 2017). Within LA there are two well-known educational data standards, i.e., learning activity data standards, that address interoperability at the semantic and technical levels, namely Experience API (xAPI; IEEE, 2023a) and Caliper Analytics (1EdTech, n.d.). Both standards utilize profiles that enable the definition of vocabularies and enable learning activity data to be governed by specific rules. More information on the standards and a detailed comparison is available in Griffiths and Hoel (2016).

Despite the promise of these data standards with regard to data integration, previous research has indicated that they are not widely used for combining data from multiple sources within LA in the context of higher education (Samuelsen et al., 2019). For xAPI, one potential reason for this lack of adoption in terms of data integration may be that the xAPI standard has a number of gaps and needs that can hinder consistent data descriptions across multiple data sources (Samuelsen et al., 2021).

The research identifying xAPI gaps and needs that may be a barrier to consistent data descriptions was the first of a two-part exploratory case study examining the challenges of

using a current learning activity data standard (i.e., xAPI) for describing the learning context. The case is the Activity data for Assessment and Adaptation (AVT) project (Morlandstø et al., 2019; Wasson et al., 2019), which explores how data from multiple EdTech vendors can be integrated and analyzed to provide learner adaptivity. The first phase of the case study resulted in recommendations to address the identified gaps and needs, focusing on xAPI context descriptions and expressibility, meaning it should be possible to describe data in a consistent way across data sources. The research described in this paper represents phase two of the case study, where we aimed to implement and evaluate the recommendations that address the identified gaps and needs regarding xAPI context descriptions and expressibility. This involved developing a technical solution to provide implementation of the recommendations, where the search for the technical solution was based on a study of the xAPI and xAPI profile specifications, considering the available functionality and constraints<sup>1</sup>. To accommodate the AVT project case, the technical solution was tailored to the adaptive learning domain. The usability of the technical solution was evaluated by technical experts who provided evidence regarding aspects such as its feasibility and effectiveness in supporting expressibility.

This study seeks to answer the following research questions:

- RQ1: How can the recommendations for enhancing xAPI context descriptions and expressibility be implemented through a technical solution?
- RQ2: How does the technical solution support technical experts in describing learning activity data from multiple data sources for LA data integration?

## Background

This section provides information on xAPI that is related to the technical implementation of the recommendations, and the AVT case. Starting with xAPI, the structure of the xAPI statement is explicated, and more information is given regarding xAPI profiles and their functionalities. Subsequently, the case is detailed, including how its focus on adaptivity and assessment relates to existing structures of xAPI. Finally, we revisit the recommendations that were implemented as part of the technical solution.

### xAPI

xAPI enables description, integration, and exchange of learning activity data, through the xAPI standard (IEEE, 2023a) and the xAPI profile specification (Advanced Distributed Learning, 2018a). The xAPI base standard provides the general structure to describe

---

<sup>1</sup> When the research detailed in this paper was conducted, xAPI was released as the technical specification xAPI version 1.0.3 that was a de-facto standard. xAPI has since been standardized by Institute of Electrical and Electronics Engineers (IEEE) as xAPI 2.0 (IEEE, 2023a). The challenges identified through the research detailed in this paper, and the technical solution offered, apply equally to xAPI version 1.0.3 and version 2.0.

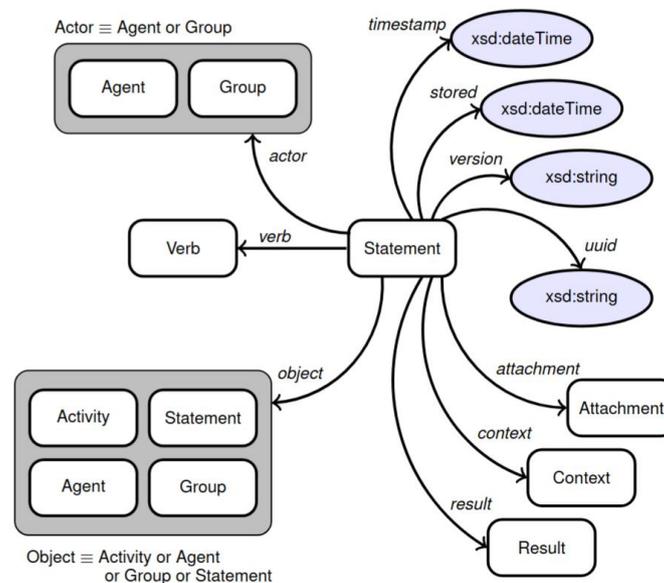
learning activity data through xAPI statements, while the xAPI profile specification mainly concerns itself with the content of the statements by addressing the needs of specific use-cases (IEEE, 2023c).

### The xAPI statement

The xAPI statement, described using the JSON format, consists, at the most general level, of the structure "*actor verb object*", meaning that someone (typically a learner) did something, e.g., "learner (*actor*) answered (*verb*) an exam question (*object*)". The object is typically of the type xAPI Activity, which represents something that an actor has interacted with. The interpretation of an Activity is broad, where it can represent both virtual and concrete objects (IEEE, 2023c). Figure 1 shows the general structure for an xAPI statement (Vidal et al, 2015).

**Fig. 1**

xAPI statement (Vidal et al., 2015)



The Activity object includes the required property *id* (an Internationalized Resource Identifier [IRI]) and *definition* (a JSON object that can contain metadata). The Activity definition object has three recommended properties: *name*, *description*, and *type* (IRI used to define the type of Activity). It also includes optional properties, including (Activity) *extensions* that is a JSON object that can contain any properties as needed (IEEE, 2023b). The number of available properties and sub-properties for the Activity signifies that this object can become long and complex, impacting human-readability and leading to duplication across statements. Thus, xAPI allows Activities to be stored in the statements themselves but also includes the option of storing the Activity definition object in the

Activity id IRI (referred to as the hosted metadata solution). With the latter solution, the Learning Record Store (LRS) may act as a metadata consumer, thus downloading metadata from the IRI rather than finding it in the xAPI statement (IEEE, 2023b).

The context structure, which exists on the same level as the actor, verb, and object structures, allows for registration of contextual information related to the learning activity. This structure has 9 properties, where 7 of them (e.g, instructor and platform) accept a single value or single object representing one entity. Context data that are not suitable as values for these 7 properties can be placed in the contextActivities or (context) extensions structures. ContextActivities enables the inclusion of a “map of the types of learning activity context that this Statement is related to” (IEEE, 2023b). This structure utilizes the xAPI Activity, typically used for the xAPI statement object, to also store contextual information. The Activities can be stored in the learning activity context types: *parent*, *grouping*, *category*, and *other*. The extensions structure enables the addition of a “map of any other domain-specific context relevant to this Statement” (IEEE, 2023b). The key for an extension must be an IRI, while the value may be any JSON data structure. When using the data structure *JSON object* as the value, it is possible to include multiple levels (properties and sub-properties) of contextual information, with corresponding values (Advanced Distributed Learning, 2018b). The result structure, another structure on the same level as the context structure, allows for registration of context regarding a measured outcome (IEEE, 2023b).

### **xAPI profiles**

xAPI profiles are specified in the JSON for Linking Data (JSON-LD)<sup>2</sup> format, which builds on JSON and semantic technologies, meaning term definitions can be reused from established vocabularies. For instance, the Simple Knowledge Organization System (SKOS)<sup>3</sup> is reused in the xAPI profile specification. For individual xAPI profiles, communities of practice may define their own vocabulary concepts, such as verbs, activity types, and extensions. The concepts may be newly created or reused from other profiles. Profiles can also include statement templates and patterns. Statement templates “provide a set of instructions for what data is required in an xAPI statement which describes a particular event” (Advanced Distributed Learning, n.d.-a). They can include rules that are checked by an xAPI profile validator (human or machine), where the rules may regard presence (inclusion or exclusion) of properties or property values according to statement vocabulary concepts. Patterns define how a group of statements, as defined by statement templates, should be ordered (Advanced Distributed Learning, 2018b). Specific to

---

<sup>2</sup> <https://json-ld.org/>

<sup>3</sup> <https://www.w3.org/TR/skos-reference/>

definition of extensions, the JSON Schema<sup>4</sup> specification can be used within individual xAPI profiles to specify constraints on (sub)properties and values (e.g., value type, [regular expression] pattern and format). Such constraints may be defined in a profile for each extension concept using the *inlineSchema* or *schema* property and may be more finely specified than what is possible using statement template rules.

### **Activity data for Assessment and Adaptation (AVT)**

The research case, the Activity data for Assessment and Adaptation (AVT) project, is a Norwegian research and development project that originally ran from 2017 to 2019 and subsequently received funding to continue until the end of 2025. The project explores data sharing between K-12 EdTech products for cross-product LA that can be used to provide recommendations for learner adaptivity and further explores how the data and analysis results may be used for formative assessment. Data coming from multiple EdTech vendor tools were transformed according to a common standard (i.e., xAPI) to enable description, integration, and exchange of data. The type of data to include was informed by research (Morlandstø et al., 2019; Hansen et al., 2020), involving interviews with teachers on what they would like to know about their students as input to a learning analytics dashboard being developed in the AVT project.

For consistent data descriptions, the project reused existing xAPI vocabulary concepts and added concepts not previously described into the AVT xAPI profile<sup>5</sup>. The vocabulary concepts, including school and school owner, were defined in the profile as activity types. A number of example xAPI statements were also developed for the AVT project, adhering to the AVT profile, which the EdTech vendors that participated in the project used as templates for their own xAPI statements (AVT, 2021; Samuelsen et al., 2021). Several example statements represented the common case of a learner answering a question in a math test provided by a digital tool, where statements varied according to aspects such as the specific tool used and the tool provider. The example statements pertaining to this case all contain information about the actor (learner; including their account information), verb ("answered") and object (the specific math test quiz question that was answered; including the id [URI], description and type of question). Additionally, contextual information was added to the statements, including the result of the learner answering the question, the learner's school, and the school's owner. All AVT example statements, including their full specification in xAPI format, can be viewed through AVT (2021).

The AVT xAPI profile addresses both adaptivity and formative assessment. Formative assessment needs have been addressed in xAPI through the (Activity) *Interaction*

---

<sup>4</sup> <https://json-schema.org/>

<sup>5</sup> <https://github.com/KS-AVT/avt/blob/AVT2/avt.jsonld>

*properties* and the *result* structure<sup>6</sup>. Additionally, some of the published xAPI profiles, e.g., the SCORM profile<sup>7</sup>, include concepts related to assessment. Regarding adaptivity, i.e., adapting learning to the individual learner, there are fewer available vocabulary concepts for xAPI, e.g., regarding learner context. Thus, the new vocabulary concepts added to the AVT xAPI profile were mainly related to the use case of adaptivity, although the profile also supports collecting data related to assessment. Further details on the AVT project case can be found in Samuelsen et al. (2021).

The technical solution developed as part of the research reported in this paper is enabled through the creation of a new xAPI profile, i.e., the school adaptivity profile, which is customized to specifically address the use case of adaptivity at the K-12 level. Consequently, use of the technical solution requires in-depth understanding of xAPI, meaning its target users are technical experts that have expertise with xAPI. Therefore, the recommendations are validated through user testing with technical experts from the AVT project that have experience with xAPI.

## Recommendations

In previous work (Samuelsen et al., 2021), we identified challenges of using xAPI for learning context description through a systematic analysis of data originating from 1) interviews with the stakeholders within the AVT project, and 2) inspection of the xAPI and xAPI profile specifications (Advanced Distributed Learning, 2018a; Advanced Distributed Learning, 2021). Thereafter, we recommended solutions to support interoperability and data integration, with emphasis on descriptions of xAPI context, while also providing some recommendations that relate more generally to the xAPI framework (i.e., recommendations for data typing and validation, and documentation). For the list of recommendations, please refer to Samuelsen et al. (2021).

## Methods

This research is based on an exploratory case study methodology (Oates, 2006; Bryman, 2012), where Figure 2 conveys the seven research steps. The first four steps of the case study were addressed in previous research (Samuelsen et al., 2021), while the final three steps form the research that is presented in this paper. Here, a technical implementation of the recommendations, adhering to available functionality and constraints in the xAPI and xAPI profile specifications, was carried out. Furthermore, the recommendations were validated based on user testing of the technical solution that implemented the recommendations, including semi-structured pre-test and post-test interviews. This

---

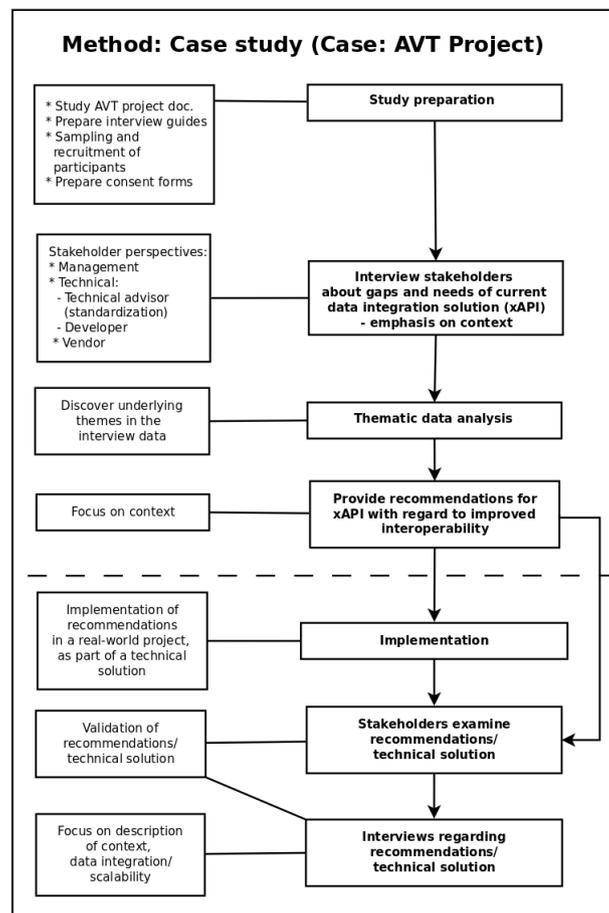
<sup>6</sup> Although there may be semantic differences in how the result structure is used, as mentioned in Samuelsen et al. (2021).

<sup>7</sup> <https://profiles.adlnet.gov/profile/313ca4e5-d59e-4b0a-866a-0ad98cc2d1b9> (retrieved April 1, 2023)

exploratory case study methodology has similarities with Design-Based Implementation Research (DBIR; Fishman et al., 2013), whose four key principles regard: 1) "persistent problems of practice from multiple stakeholders' perspectives" (Fishman et al., 2013); 2) collaborative design and iteration; 3) systematic inquiry for theory and knowledge building pertaining to learning and implementation; and, 4) system-level sustainable change (Fishman et al., 2013). The exploratory case study methodology incorporates some elements from the first three DBIR principles, including a focus on persistent problems of practice from stakeholder perspectives, design and iteration, and systematic inquiry that informs knowledge related to learning (e.g., regarding the expressibility of xAPI learning activity data) and implementation. The methodologies differ in that DBIR places more emphasis on creating scalable and sustainable change through implementation, while the case study is exploratory, and as such the case study could be part of an earlier stage of DBIR.

**Fig. 2**

Research methodology (adapted from Samuelsen et al., 2021<sup>8</sup>)



<sup>8</sup> Figure 2 has been adapted to reflect that a technical solution implemented the recommendations, and that the technical solution was employed within one real-world project as part of the case study.

## **Technical implementation**

In this section, the process of providing technical implementation related to the recommendations for interoperability and data integration, emphasizing context information and expressibility, is elaborated. Initially, information on how the recommended solution relates to the xAPI standard and the xAPI profile specification more broadly, and on how the solution was adapted for implementation according to xAPI and the xAPI profile specification, is provided. Next, information on the profile use case, including the context dimensions and properties that were included in the profile, is given. Thereafter, more implementation specific information related to the properties included in the profile is provided, as well as the rationale for 1) the way the properties were implemented according to the affordances of the xAPI profile specification, and 2) two extensions of xAPI constructs and concepts that were added to the solution. Finally, the process of automatically validating the profile for conformance with the xAPI profile specification, using tools, is briefly described.

### **A brief description of challenges and the technical solution**

Based on the solutions previously recommended at the conceptual level, Table 1 summarizes the technical solution, with aspects grouped according to the challenges identified in Samuelsen et al. (2021). If applicable, aspects of the technical solution are listed both at the general level, relating to the recommendations and how they could apply more generally to xAPI and the xAPI profile specification, and at the implemented level. In the latter instance, we have explored how the solution requirements can be expressed both using the developed xAPI profile (i.e., the school adaptivity profile) and using xAPI statements that conform to the profile.

**Table 1**

Challenges identified and the technical solution

Challenges identified (Samuelsen et al., 2021)	General technical solution	Implemented technical solution
<p>The distinction between ContextActivities and extensions appears artificial, and it is not always clear which to use.</p> <p>Extensions are flexible in how data can be registered and therefore could make it more difficult to integrate data.</p> <p>ContextActivities is not a good fit for all types of context data.</p> <p>Grouping of related activities in ContextActivities can be done within three different structures (<i>grouping</i>, <i>category</i>, or <i>other</i>). It is not clear how the three structures differ. The grouping structures are all very high-level.</p>	<p>The xAPI specification should be changed regarding the data model of the xAPI statement context, to permit context dimensions and their properties instead of ContextActivities with groupings, and extensions. Through a change to the xAPI profile specification it should consequently be possible to require the inclusion of context dimensions and properties in statements, for the appropriate use case/community of practice that defines a profile. Following, data typing and validation could be related to the modified xAPI profile, e.g., regarding concept granularity.</p>	<p>Use the current xAPI functionality <i>context extensions</i> to illustrate the 2-level hierarchy of context dimensions and their properties. The extension key is the name (represented with an IRI) of the context dimension, and the extension value is a JSON object that contains all the context properties with corresponding values. Since requirements related to extensions within the xAPI profile can be given, data typing and validation are possible, e.g., in terms of deciding if a property should be optional or required, and to ensure the property values follow a certain type or format.</p>
<p>The query capabilities of LRSs are seen as limited. The example given is that it is only possible to filter statements on contextual data that are instances of an activity type. Thus, to allow filtering of resources in AVT (without extra development work), resources were registered as activities, even if they were not really activities on the semantic level.</p>	<p>Query capabilities in xAPI should be altered within the xAPI specification to accommodate the modified context structures (context dimensions with properties solution) that is part of the technical solution.</p>	<p>Not implemented.</p>
<p>Concepts from the xAPI vocabulary are not sufficient to describe all data.</p>	<p>In addition to the currently available xAPI solution of adding new concepts to xAPI profiles, the xAPI profile specification should support profile inheritance. Enabling a profile hierarchy would allow for having a more generic profile for a use-case/community of practice, which could then be extended by different sub-communities. The more generic profile could have general terms that apply to everyone in the community, while profiles for sub-communities could add specialized vocabulary (e.g.,</p>	<p>Since profile inheritance is not supported, needed concepts (whether new or reused) are added in the one xAPI profile.</p>

	related to local conditions or practices). The profile inheritance could also apply to data typing and validation, for instance a more general profile only specifies which properties are available for a context dimension, while a more specific profile indicates if certain properties are required, with their data types and value requirements.	
The same vocabulary concept may be represented in different public xAPI profiles, which make up the xAPI vocabulary.	Challenge should be addressed through the profile curation/approval process level rather than a technical solution.	-
Tools generating data at multiple levels of granularity is a challenge, which may make it more difficult to meaningfully integrate data.	For individual profiles we need to be able to specify the type of data values. This functionality is available within the xAPI profiles specification.	For the context extensions used to specify context dimensions, we can specify granularity in an xAPI profile using the JSON schema standard, enabling JSON schema validation.
Difficulties in mapping real-world data to xAPI due to its assumptions.	For the general xAPI data model, which is part of the xAPI specification, the assumptions for each property should be made explicit and tested against the xAPI data through data typing and validation. The xAPI data model should also accommodate new needs as they are identified by the community (Samuelsen et al., 2021).	Related to data typing and validation of the xAPI data model, we use an xAPI statement validator. To accommodate new community needs (general technical solution), currently it is only possible to add additional properties to the xAPI data model on a case-by-case basis for some of the structures (e.g., context, Activity) through extensions. Which extensions should be included in an xAPI statement, and the extension sub-properties, can be specified in an xAPI profile using the JSON schema specification (included in the profile through each defined extension's inlineSchema or schema property).
Different tools may generate different numbers of statements for the same type of event.	For individual profiles, the types of data that are required for a statement representing an event and the pattern such statements may follow, can be specified. This functionality is available within the xAPI profiles specification.	xAPI profile statement templates allow us to specify a statement structure.

The openness and flexibility of xAPI allows data and relationships of the same type to be modeled in a myriad of different ways.	Data typing and validation of properties and property values can help alleviate the challenge of openness and flexibility, addressed through a xAPI profile. Profile vocabularies can also specify which vocabulary to use (Samuelsen et al., 2021).	Use of an xAPI profile to specify vocabulary, data typing and validation.
It may be challenging to correctly use concepts from the xAPI vocabulary.	Challenge should be addressed on documentation level rather than technical solution.	-

### The profile use case

To develop the profile for this research, i.e., the school adaptivity profile, we relied on the guidelines by ADL (Advanced Distributed Learning, n.d.-c). According to these guidelines it is important to identify the use case and requirements for which one would like to utilize xAPI, what should be tracked, and with which concepts this tracking can be achieved. The use case should then inform the profile development. In the following, the profile use case is further outlined.

The profile is informed by the AVT project, focusing on data relevant for adaptive learning. Currently there is no xAPI profile that explicitly addresses the adaptivity use case. The findings regarding what contextual information teachers would like to know (Morlandstø et al., 2019; Hansen et al., 2020) is important. As the use of context dimensions was one of the main recommendations for data integration and interoperability, a number of context dimensions and properties were identified and classified, primarily derived from the teacher interviews. Additionally, information that could serve as important input to an adaptive system that dynamically changes the learning resource and/or tool offered to the student was taken into account (e.g., the device and environmental context). These two contextual categories are included as learning may happen outside of the school boundaries, and they have been found to be important in previous research (Thüs et al, 2014; Lincke, 2020). Some properties related to the context dimensions were already defined as part of xAPI, for example within the context structure (platform and instructor properties), and as part of profile context extensions published on the profile server (including latitude and longitude properties<sup>9</sup>). Adding such properties to one of the context dimensions enabled explicitly signifying their belonging to a context dimension and their relationships to the other context dimension properties. Finally, contextual information related to the statement itself (i.e., profile and tag properties) and to the object parent was

<sup>9</sup> These properties are available as part of the TinCan Vocabulary: <https://profiles.adlnet.gov/profile/9596a646-dd44-45fd-92e5-e8cd1a5c6d66> (retrieved April 1, 2023).

also included. This was done to illustrate how this information could be modeled using the context dimensions and properties approach<sup>10</sup>, something that would be needed after the recommended removal of the contextActivities structure.

Table 2 shows the selected context information for the school adaptivity profile, modeled as context dimensions with corresponding properties. The unit of measure has been added to a number of the properties to clarify their meaning.

**Table 2**

Context dimensions and properties for the school adaptivity profile

Context dimension	Context dimension description	Context dimension properties
School/class context	Contains information about the school and class of the statement actor	school, school owner, grade, class, instructor
Platform context	Contains information about the platform, e.g., e-learning platform or LMS, and the relevant structures that might be used to organize content within the platform	platform, feide clientinfo, course, module
Statement context	Contains information about the statement, such as the profile the statement is structured according to/follows rules for, and tags (keywords) that pertain to the statement	profile, tag
Environmental context	Contains information related to the external environment of the learner, typically obtained through sensors	latitude, longitude, noise level dB (unit: decibel), linear accelerationX (unit: m/s <sup>2</sup> ), linear accelerationY (unit: m/s <sup>2</sup> ), linear accelerationZ (unit: m/s <sup>2</sup> )
Device context	Contains information about the device of the learner	connection type, effective connection type, screen width (unit: pixels), screen height (unit: pixels), battery level
Object activity context	Highly dynamic data for the learning object, which relates directly to the learner that is engaging in the activity	parent

<sup>10</sup> In the statement context dimension the tag property has the data type "string" rather than Activity.

Generally, for properties to be added to the profile context dimensions (Table 2), their value should change dynamically relative to the task/item on which the learner works. Properties with values that may be less dynamic in their nature, such as school, are added due to their relevance for reporting within an adaptive system. The properties identified within AVT relate to a Norwegian context, consequently there may be properties listed that would not apply in a similar context in other countries<sup>11</sup>. The object activity context includes only the parent of the learning object (Activity), since the parent of a learning object can change dynamically (e.g., if learning resources are reused). Static learning object information is not included as this type of information relates directly to the learning object itself (rather than the learner interacting with the learning object), and is addressed through other standards than xAPI (e.g., through "ISO/IEC 19788 Information technology - Learning, education and training - Metadata for learning resources" [International Organization for Standardization, 2024]).

### Profile implementation

For profile implementation, the information on how the recommended solutions to support interoperability and data integration can be implemented using xAPI and the xAPI profile specification (Table 1, column 3) was combined with information regarding the profile use case. Table 3 presents the context properties, grouped according to their respective context dimensions, with information on the specified data types and patterns (where applicable; thus, enabling data typing and validation), activity-types<sup>12</sup> (if applicable), and whether the properties are required. The data types Activity and Agent are from xAPI<sup>13</sup>, while the other types (e.g., string, number, array, and object) are from the JSON schema specification.

---

<sup>11</sup> If the recommended (general) technical solution of profile inheritance (see Table 1) was introduced in the xAPI specification, we could make a more generic school adaptivity profile that was extended by local sub-communities such as the AVT project.

<sup>12</sup> While IRIs are used to identify the activity-types, the IRIs pertaining to the school adaptivity profile and the AVT profile do not currently resolve, as the profiles have not yet been made publicly available.

<sup>13</sup> The Activity and Agent types were modeled in the profile, as part of the context dimensions, using JSON schema to enable data typing and validation.

**Table 3**

Context properties/data types (grouped according to context dimensions)

School/class context
school (Activity, activity-type: <a href="https://w3id.org/xapi/avt/activity-types/school">https://w3id.org/xapi/avt/activity-types/school</a> ) - required
school owner (Activity, activity-type: <a href="https://w3id.org/xapi/avt/activity-types/school-owner">https://w3id.org/xapi/avt/activity-types/school-owner</a> ) - required
grade (integer) - required
class (string, pattern [regular expression]: [A-Z])
instructor (Agent) - required
Platform context
platform (Activity, activity-type: <a href="https://w3id.org/xapi/school_adaptivity/activity-types/platform">https://w3id.org/xapi/school_adaptivity/activity-types/platform</a> ) - required
feide-clientinfo (Activity, activity-type: <a href="https://w3id.org/xapi/avt/activity-types/feide-clientinfo">https://w3id.org/xapi/avt/activity-types/feide-clientinfo</a> )
course (Activity, activity-type: <a href="http://adlnet.gov/expapi/activities/course">http://adlnet.gov/expapi/activities/course</a> )
module (Activity, activity-type: <a href="http://adlnet.gov/expapi/activities/module">http://adlnet.gov/expapi/activities/module</a> )
Statement context
profile (Activity - activity-type: <a href="http://adlnet.gov/expapi/activities/profile">http://adlnet.gov/expapi/activities/profile</a> ) - required
tag (array(string))
Environmental context
latitude (number, minimum: -90, maximum: 90)
longitude (number, minimum: -180, maximum: 180)
noise_level_db (number, minimum: 0)
linear_accelerationX (number)
linear_accelerationY (number)
linear_accelerationZ (number)
Device context
connection_type (string, enum: ["bluetooth", "cellular", "ethernet", "mixed", "none", "other", "unknown", "wifi", "wimax"] <sup>14</sup> ) - required
effective_connection_type (string, enum: ["slow-2g", "2g", "3g", and "4g"] <sup>15</sup> )
battery_level (number, minimum: 0, maximum: 1)
screen_width (integer)
screen_height (integer)
Object activity context
parent (Activity)

<sup>14</sup> Enum values have been gathered from Network Information API (<https://wicg.github.io/netinfo/#connectiontype-enum>).

<sup>15</sup> Effective connection type represents the measured network performance. Enum values have been gathered from the Network Information API, and while cellular connection types, they apply also for Wi-Fi and other non-cellular connections. An explanation of each value is given in [https://developer.mozilla.org/en-US/docs/Glossary/Effective\\_connection\\_type](https://developer.mozilla.org/en-US/docs/Glossary/Effective_connection_type).

The implemented solution was expressed through a number of constructs that are defined in the xAPI standard and the xAPI profile specification. To model context dimensions and accompanying properties and property values in the xAPI statements, xAPI *context extensions* were used. Thus, enabling the expression of a unified structure that accommodates a 2-level hierarchy of context dimensions having properties with values of a variety of possible data types.

Using an xAPI profile allowed us to define the context dimensions to include (by requirement or optionally) in an xAPI statement following the profile, and using a specific verb, i.e., *answered*<sup>16</sup>, which was demonstrated using *statement templates*. Requirements (or constraints) for individual *context extensions*, including their (sub)properties and values, were defined using JSON schema, with individual schema included using IRIs through the *schema* property. A number of properties were added for the context dimensions, along with information related to their value data types and value patterns.

The xAPI Activity was used as the construct for a number of the context property values within the proposed solution (i.e., when there exists a public IRI that uniquely identifies the value), allowing us to reuse a number of previously defined xAPI Activity types from the AVT profile and other profiles that had defined activity types that were of relevance. Metadata regarding the Activity *definition* was stored in the Activity id IRI, utilizing the hosted metadata solution. Primitive values are used for properties when there is no publicly available IRI to uniquely identify the resource. Two such properties containing primitive values were grade and class, represented with integer and string, respectively. Since there may be multiple tags related to an xAPI statement, this property takes a JSON array.

To demonstrate how statements could adhere to the profile, we developed an example xAPI statement. The example was partly based on an example made earlier in the AVT project (AVT, 2021); however, the structure and information were modified to conform to the profile developed for this research, i.e., the school adaptivity profile.

### ***Extension of xAPI constructs***

For the technical solution, we provided two extensions to xAPI, through emulating functionality. The extensions are related to: 1) the concept of hosted metadata; and 2) the construct of the xAPI Activity. Both extensions were introduced to enable consistent use of the hosted metadata solution. Statements using these extensions, with data described according to the functionality that is part of the technical solution, will not be rejected by LRSs. The xAPI standard, however, does not provide semantics to properly understand these extensions.

---

<sup>16</sup> The full IRI for the *answered* verb is "<http://adlnet.gov/expapi/verbs/answered>".

First, the concept of hosted metadata was extended to also apply for context extensions, meaning metadata is hosted in the Activity ids that exist within the context extensions values. Second, the xAPI Activity definition was extended to include data about the metadata IRI that uniquely identifies an object (Activity) within the domain of the administering/controlling organization, using the "authoritative\_iri" property. Using such a property could, for example, enable the Activity definition object to be populated according to this information. The property was implemented using (Activity) extensions.

### **Automatically validating the xAPI profile using tools**

To ensure the technical implementation conformed with the xAPI profile specification, two tools were used for profile validation<sup>17</sup>. The first tool is Data Simulator for TLA (DATASIM), which provides functionality to generate simulated xAPI data, where the xAPI profile that is input to the simulation process is validated (Advanced Distributed Learning, n.d.-d). The second tool is the xAPI profile server, providing an endpoint for validating profiles<sup>18</sup> (Advanced Distributed Learning, n.d.-b). To allow for JSON schema validation, the JSON schema that were included using IRIs in the profile were transformed by escaping quotation marks and included inline in the profile using the individual extensions' *inlineSchema* property. We initially experienced a case where entering newlines within the inline schema was accepted (validated) by DATASIM, but not by the xAPI profile server. After removing newlines from the JSON schemas in the xAPI profile, this issue was resolved.

### **Stakeholder validation**

The technical solution was evaluated through user testing, allowing people that are in a product's target audience to review and/or try out the product, and letting them evaluate the extent to which it meets specified usability measures (Rubin & Chisnell, 2008, p. 21).

### **Goals**

The overall objective of user testing was to assess the usability measures usefulness, effectiveness, and satisfaction for the technical solution. Usefulness relates to the degree a solution allows the users to reach their goals and assesses willingness to use the product. Effectiveness relates to the degree to which the product behaves in line with the users' expectations, how simple it is to use the solution and is often given as a quantitative measure. A part of effectiveness is learnability. Satisfaction relates to how users think about, feel about, and perceive the solution (Rubin & Chisnell, 2008, p. 4-5).

---

<sup>17</sup> The reason for using two tools was that they varied in the JSON schema versions used for validation.

<sup>18</sup> <https://profiles.adlnet.gov/api-info/validate> (retrieved April 1, 2023)

## Participants

Participant selection was conducted according to purposive sampling (Bryman, 2012, p. 418). As the participants needed to understand the xAPI data model, we recruited technical experts who had experience with xAPI data descriptions, thus they represented target users of the technical solution. Three participants were recruited, having worked within the AVT project as either technical advisors or as a developer for a vendor that contributed data to the project (see Table 4).

**Table 4**

Participants

Identifier	Gender	Perspective (AVT)	Work tasks in AVT (sample)
P1	Male	Technical advisor	Work related to vocabularies and the AVT xAPI profile. Examined how to represent context for xAPI activity data. Development of xAPI example statements for use by the vendors.
P2	Male	Technical advisor	Work related to vocabularies and the AVT xAPI profile. Examined how to represent context for xAPI activity data. Participated in developing the AVT example xAPI statements. Advised on tools and libraries for xAPI activity data storage and exchange.
P3	Male	Vendor, developer	Technical work on behalf of the vendor, including implementing the vendor's solution for transformation of activity data to xAPI and delivery of xAPI statements to the AVT project.

The participants that had functioned as technical advisors in the AVT project (P1, P2) had been involved in the first phase of the project (2017-2019). P3 was involved in data delivery to the project in 2022.

A key characteristic of the participant group is that they are users with highly specialized technical skills and extensive experience with xAPI, and could therefore be expected to go through the user testing based on materials (e.g., test instructions, documentation) without guidance from the test moderator.

## Study design

Materials were developed and piloted prior to the user testing. The materials included a data registration form that among other described user test tasks that would result in an xAPI statement that would be structured according to the school adaptivity profile, and pre-test and post-test interview guides.

A user test was designed comprising 1) a pre-test interview, 2) a testing session, and 3) a post-test interview. The user test was conducted to gain an indication of the technical solution's usability, according to the usability goals. The user test was designed as an assessment test, which enables evaluation of the usability of a solution's lower-level

functionality and aspects, and uncovering usability deficiencies, through users performing realistic tasks (Rubin & Chisnell, 2008, p. 34-35).

### ***Ethical approval***

The project was reported to the Norwegian Agency for Shared Services in Education and Research (Sikt) - Data Protection Services<sup>19</sup>, which assesses that the processing of personal information is legal based on the measures taken concerning privacy and research ethics. Participant consent was obtained through a signed consent form to collect data from audio recorded interviews and for their participation in the user testing tasks.

### ***Carrying out the user testing***

The user testing was conducted between November 23 and December 16, 2022. Data were collected from 1) pre-test interviews, covering qualitative data about participant background information; 2) testing session, i.e., quantitative performance data (behavioral measures) derived from user test tasks, to identify errors in task completion; 3) post-test interviews, covering qualitative data about the test experience and preference data regarding various aspects of the technical solution foundations and implementation. The interviews, which took place using a video conference platform, were conducted in Norwegian.

### ***Pre-test interviews***

Each user test session started with a pre-test interview activity. This was supported by the pre-test interview guide that contained questions about the background of the participants. The activity concluded with us giving the participants information about the technical solution that would be user tested and what the user testing would entail.

Upon interview completion, the participants were emailed the data registration form and either an anonymized xAPI statement obtained from the AVT project (for technical advisors) or an xAPI statement they had previously delivered to the AVT project (for the vendor). These emailed statements all represented the case of a learner answering a question in a math test provided by a digital tool (see the AVT section for more details on the xAPI format according to this case). Each participant received a different statement.

### ***Testing sessions***

The participants were asked to go through the user testing themselves, allowing them to do the test over several days, in their own environment, on their own equipment. The data registration form, detailing the user test, described 6 mandatory and 1 optional data

---

<sup>19</sup> <https://sikt.no/en/data-protection-services>

description tasks, which would result in a new xAPI statement. The first task involved filling in the statement's actor, verb, object and result structures, ensuring that the participants had a general understanding of xAPI, while the remaining tasks were focused on specifying context dimensions, properties, and values in accordance with the required value type/format. Additionally, the data registration form included materials that could support the execution of the user test tasks, including documentation regarding the technical solution (e.g., from Table 2 and Table 3) and an annotated version of the xAPI profile, a link to an xAPI statement validator<sup>20</sup>, a section for note taking during the tasks, e.g., regarding thoughts and opinions of the solution, and a section where participants could gradually fill in the xAPI statement that would result from completing the tasks.

Participants were asked to base their xAPI statement on the activity data they had been emailed. Structuring the data in accordance with the school adaptivity profile required changes to the data (e.g., in terms of structure and data types), and some additional data needed to be included in the xAPI statement according to fictitious values that would fit the required data value type/format. The participants were encouraged to complete the tasks within 7 days, and to email the completed xAPI statement. Upon receiving the email, we evaluated the user test and set up the post-test interview.

### ***Post-test interviews***

The post-test interview was supported by the post-test interview guide, which included relevant topics. The interview was related to the participant's user test, where participants were encouraged to bring their notes, allowing for an improved understanding of the participants' actions and any potential errors or issues. Furthermore, the interview contained questions about different facets related to the technical solution on a more general level and its implementation, allowing us to ascertain the strengths and weaknesses of the technical solution. These facets included the structuring of the contextual data (using a unified and hierarchical structure), the chosen context dimensions and properties, requirements for context dimensions and properties, and the hosted metadata solution. Finally, the interview inquired about profile inheritance, to assess if such functionality could potentially be valuable.

### **Data analysis and results**

Data were analyzed relating to the different parts of the user test, which involved assessing the completion of the required user test tasks, according to quantitative measures. For each of the six required tasks, 1 point was the maximum number of points that could be obtained,

---

<sup>20</sup> The data registration form linked to the xAPI statement validator available at <https://lrs.io/ui/tools/xapi-statement-validator/>.

leading to a maximum score of 6 for the completed user test. Each task had a number of subtasks, where every task except for the first involved filling out the context dimension with a number of adhering properties. For each task, we checked if the subtasks were completed according to the expectation. Correct completion of a subtask would yield 1 point, where the number of points were summed up for each task and divided by the number of subtasks, giving the task score. The post-test interviews were transcribed, and the transcripts were analyzed qualitatively according to topics, to identify the participants' thinking related to different facets regarding the more general technical solution and its implementation. Quotations, originating from the post-test interview, have been translated from Norwegian to English.

### ***Task completion***

A summary of the user test results for the first 6 tasks is shown in Table 5. P2 and P3 completed the optional seventh task correctly.

**Table 5**

User test results

Test #	Participant #	Tasks completed	Score (out of 6 possible points)
Test 1	P1	6	5.83
Test 2	P2	6	5.83
Test 3	P3	6	5.33

### ***Validation of recommendations and technical solution***

Information regarding the users' test experiences and their thoughts and opinions regarding the recommendations that serve as a foundation for the technical solution, and its implementation, derived from the post-test interview and further supported by participants' notes, are provided below. The findings are listed according to topics, where the 7 first topics stem from the post-test interview guide, while the final 2 topics emerged from the post-test interviews.

### **User test experience**

The user test instructions were generally understood by the participants, who found the tasks quite straightforward to go through, supported by a number of materials, leading them to create and submit an xAPI statement resulting from the tasks. In the one case where all the participants had chosen a different way to describe the data than what had been intended by the researchers, there was a discrepancy between the user test instructions and the constraints given as part of the technical solution (the relevant user test task asked that participants fill in a property that was not required to be filled in as part of the technical solution). As such, the user test instructions could have stated more clearly that in the case

where such differences are observed, the participants should follow the user test instructions. Additionally, one participant (P3) did not correctly fill in the profile that the statement was structured according to, which may be related to him being less familiar with the concept of an xAPI profile than the other participants. Finally, to further support the data description tasks, one participant (P2) suggested statement validation according to the profile and including the xAPI profile JSON schemas explicitly in the support materials.

### **Structuring of contextual data**

All participants expressed approval for the use of a hierarchical structure to classify context properties in accordance with context dimensions. The participants indicated that this structure, which is more explicit than the flat structure typically used in xAPI, adds to aspects such as understanding, readability, and cleaner organization of the properties, thereby promoting expressibility. In terms of the unified structure, the participants also generally agreed that it is preferable to spreading data across structures, mentioning aspects such as readability, understandability, and learnability, indicating that the unified approach could further support expressibility. At the same time, two of the participants (P2 and P3) expressed pragmatic views regarding data integration, suggesting that as an alternative to achieving integration through the unified and hierarchical solution, the different parties may alternatively follow the same rules for consistent data descriptions, or that the xAPI statements may be further processed to achieve integration.

### **Context dimensions and properties**

The participants indicated that 4 of the 6 context dimensions seemed appropriate to include based on the profile's focus on adaptivity in the K-12 domain. For the remaining 2 context dimensions, i.e., the "device" context and the "environmental" context, two of the participants (P1 and P3) indicated they were less certain regarding their inclusion. Here, P3 understood adaptivity in a somewhat different way than the broader understanding that had been the basis for the school adaptivity profile. While the school adaptivity profile included factors related to the learning environment, including device and environmental context dimensions, P3's understanding of adaptivity was that "if the student does not manage to successfully solve a task then he will get an easier task, and if he is able to successfully solve a task then he will get a more challenging task". Furthermore, P3 also highlighted that universal design of learning resources might reduce the need to adapt to these context dimensions. In terms of adding further context dimensions, P2 indicated that there may be other context dimensions that could support the goal of adaptivity, although he was uncertain of which. In general, P1 and P2 advised that the context dimensions that introduced new information (all except the statement and object activity context dimension)

should not be a part of the standard but should rather be included as needed for particular communities of practice.

The participants suggested possible improvements for the context dimensions:

- The platform dimension needs a better name, as it encompasses the properties of platform, feide-client-info, course, and module, and to avoid duplication of terms across context dimensions and properties (P1 and P2)
- The "parent" of the "object\_activity" context might belong together with course and module in the "platform" context, but it would depend on the circumstance (P3)
- The statement context dimension could be renamed to clarify its meaning and how its properties are related (P3)

The participants also suggested possible improvements for the properties - related to context dimensions:

- Choose a more international name for feide-clientinfo to adapt to the international K-12 adaptivity community (P2)
- Find a more fitting measure for movement than linear acceleration (P3)
- The profile property value (IRI) should explicitly clarify the profile version (P1)
- Add properties course "unit" and "deep link" used to navigate to a resource to the platform dimension (P2)
- Add properties "touch screen" (P2 and P3), and "user-agent" and "viewport" (P3) to the device dimension
- Add information regarding universal design and individual adaptation related to disability and special needs (P1)
- The grade property is ambiguous in its meaning and needs clarification (P1 and P3)

### **Requirements for context dimensions and properties**

Regarding the data typing and validation measures, the participants indicated on one hand that such measures may promote interoperability and data integration, but on the other hand they indicated that it is important that the measures must fit reality. The participants identified some properties, including "class" and "instructor", where the data types and format requirements might not fit exactly with reality. One participant (P2) cautioned also that customizing the solution too much for the Norwegian case might make the solution unusable by the international community. Another issue (brought up by P1) was that when creating the technical solution, it was unnecessary to reuse old data types from xAPI (e.g., the Activity data type). At the minimum, he indicated, it should be considered if the Activity could have a more generic name to signal its broader application area.

Further improvement suggestions regarding data types and formats:

- Tag property, which takes a list of string, needs to be standardized (P2 and P3)
- Allow for specifying more than one profile (P2)
- Numeric data types could have further restrictions, e.g., regarding decimal precision and ranges (P2)

There was also indication by the participants (P2 and P3) that when requiring context dimensions and properties, there may be a trade-off between interoperability (through consistent data descriptions) and adapting to real-world situations. P3: “It’s the usual challenge, the more things that are required, the more interoperability. [...] But then it gets more difficult to accommodate the real-world”. Another issue mentioned (by P1) is that requiring a lot of data to be present in all xAPI statements of a certain type would impact storage space and data transfer latency.

Further improvement suggestions regarding context dimensions and property requirements:

- It is better not to require environment and object activity context dimensions since their properties are not required (P2 and P3)
- The instructor property might not need to be required (P3)

### **Implementation of technical solution**

The participants commented on a number of functionality within xAPI that were utilized for implementation of the recommendations as part of the technical solution. Statement templates were used to require context dimensions. Some aspects mentioned by the participants included further use of such templates to also require statement properties (e.g., statement id), as an alternative to JSON schema definitions in specifying context dimension properties (as mentioned by P2), use of statement templates with profile patterns to reduce the length of statements within such a pattern (i.e., group of xAPI statements, when applicable, as mentioned by P1), and that while the statement templates increase human-readability there exist very few tools that may actually provide template validation for statements that are structured in accordance to a specific profile (P2).

The xAPI profile utilized xAPI extensions to represent the context dimensions. Within the extensions, individual JSON schemas specified the requirements for each of the context dimensions. One aspect mentioned (by P2) is that it could be stated more explicitly in the context extension IRIs that they are actually context extensions. The participants also had some varying inputs regarding the JSON schema. For instance, one participant (P1) thought it was an interesting way to extend the capabilities of xAPI, but noted that other schema languages (e.g., XML Schema Definition [XSD]) could be more expressive. Another participant (P2) stated that the JSON schema could enforce the use of JSON-LD compatible syntax, if the xAPI statements in the technical solution had been specified using JSON-LD

rather than JSON. Regarding including JSON schema in the profile through external IRIs with the "schema" property versus in the profile with the "inlineSchema" property, the participants had a preference to utilize external schemas, listing a number of reasons related to expressibility. At the same time, it was mentioned (by P2) that validation tools may provide better support when the schemas are included with "inlineSchema".

### **Hosted metadata**

The participants indicated approval for the hosted metadata solution, provided a stable infrastructure was used to serve the metadata and a versioning strategy was put in place, with two participants (P2 and P3) signaling they would generally prefer this solution over inlining data about Activities in the xAPI statements.

Some of the benefits mentioned regarding this solution include reduced statement length and consistent data descriptions (P2 and P3), and that it could make it easier to correct mistakes and filter the data (P3). Although the xAPI documentation hints at the possibility of deriving metadata from other formats, it does not provide implementation details for such a solution. As such, one participant (P1) alluded to the problem of potential data duplication across standards, and one participant (P2) suggested several approaches to hosted metadata that could be used with more than one standard (e.g., regarding learning analytics and learning resources), including using JSON-LD metadata. As a potential drawback, P2 cautioned that it might be difficult to understand the solution by those that would host the metadata. P2: "It might be hard enough for them to understand xAPI, so having hosted metadata [...] in the object IDs that they thought they would use, that would likely be a challenge". The participants perceived the "authoritative\_iri" property as potentially useful for hosted metadata, listing uses such as data provenance (P3) and retrieving updated metadata (P2).

### **Profile inheritance**

The participants generally expressed that profile inheritance, where one profile through inheritance can add all that is contained in another profile and then add its own specific properties, could be advantageous (e.g., in terms of catering to international communities and extending the applicability of an xAPI profile). However, the participants also highlighted different nuances related to inheritance, and different aspects that would need to be taken into account when considering such an approach. One aspect mentioned (by P1) is that even though one may not directly inherit/extend a profile, it is currently possible to reuse some of the xAPI concepts from another profile. Furthermore, it is possible through the xAPI profile specification to specify how concepts such as verbs and activity types relate to other concepts, since xAPI profiles inherit linked data concepts from the SKOS specification (as emphasized by P2). Additionally, P2 highlighted that inheritance is

different in JSON-LD than in object-oriented programming languages, having implications for how the concepts may be inherited/extended in practice.

### **Documentation**

Aspects related to the documentation of the technical solution were brought up during the interviews. At the level of the xAPI profile, both P1 and P2 indicated that more documentation could have been provided regarding the definitions and use of the context dimensions. As expressed by P1: “I was wondering if in the profile it would be possible to insert the definitions from the tables [Table 2 and Table 3]. It would have been useful.” In terms of documenting the semantics for the context dimension properties, P1 and P2 stated that JSON schemas could provide definitions for the individual schema properties. Additionally, P1 indicated that it would be good to include examples of property usage through the JSON schemas.

### **Linked data**

Both P1 and P2 highlighted inclusion of linked data technologies as a potential improvement for the xAPI specification and also for the technical solution. P1 and P2 suggested that it would be good to add a JSON-LD @context to the xAPI statements, which could uniquely identify the JSON-LD properties and clarify their meaning through online lookup, even though xAPI currently uses JSON rather than JSON-LD. Similarly, P1 and P2 stated, using linked data in statements would also allow the learning resources or activities to be referred to uniquely as linked data, providing additional context related to their meaning. Both P1 and P2 presented hosting metadata as linked data as an alternative approach to xAPI hosted metadata, P2 clarifying that the xAPI hosted metadata is limited (in terms of format and use case). In addition, P1 highlighted that JSON-LD is an RDF format, which means it can be imported with ontologies into a triple store, leading to more powerful and intelligent search capabilities than what will be available through the LRS.

### **Discussion**

Returning to the user test goals, we can now get an initial indication of the usability criteria of usefulness, effectiveness, and satisfaction. Regarding usefulness, the user test indicates that the technical solution allows the users to reach their goals (of describing contextual data with xAPI in a consistent manner across data sources), where the participants express that the use of context dimensions and properties, as part of an unified and hierarchical solution, add to aspects such as readability and understandability. Two participants express, however, that such usefulness can also be achieved presently through xAPI and the xAPI profile specification, if care is taken for data to be combined within and across sources (e.g., through following examples/templates for data description). Additionally, the participants

indicate support for data typing and validation measures in general, but caution that it is important that the data types and validation measures correspond to the real-world. Next, it is indicated that the effectiveness criteria is met, in that users were for the most part able to correctly understand how to utilize the solution (as indicated from the results on the user test), and also with participants expressing that based on the instructions and support materials it was mostly straightforward to go through the data description tasks. Finally, the participants indicated positive attitudes toward the technical solution at a general level, indicating satisfaction with the general solution that is based on the recommendations related to interoperability, data integration, and xAPI context descriptions. The participants, however, identified some room for improvements on the implemented level, where some of these improvements relate only to the technical solution (e.g., documentation and property requirements), while others relate also to xAPI, and its affordances, more generally.

### **The use of the xAPI Activity**

Related to the use of the xAPI Activity, whose semantics has been found to be problematic by some of the research participants, we advise considering if the name (Activity) could be made more generic, and furthermore, if its definition could be broadened and documented within the xAPI documentation. This would make it clear that this structure may be used for values not just related to the object of an xAPI statement, but also within the context of the statement.

### **Validation and LRS compatibility**

Some challenges were encountered for the profile validation, including different behaviors among the two tools that were used, i.e., DATASIM and the xAPI profile server. To foster mainstream adoption of xAPI, improvements could be made to the validation tools and capabilities offered. For instance, there needs to be mechanisms to ensure validators that validate according to the same parameters do not produce different results. For the latter aspect, inspiration could be gathered from a previous project that examined statement validation across LRSs, as a means to investigate practical interoperability (Downes et al., 2015).

Furthermore, related to the LRSs' that implement the xAPI standard, xAPI operates with three different conformance levels, i.e., SHALL (MUST), SHOULD, and MAY (IEEE, 2023c). In particular, the MAY level could lead to inconsistent behaviors among LRSs, indicating an option where the LRS developer is free to choose without any recommendation from the specification. One such example that we encountered when conducting the research presented in this paper was for the hosted metadata solution, where xAPI version 1.0.3 specified it as optional for the LRS to act as a metadata consumer that

resolves the hosted metadata IRIs (Advanced Distributed Learning, 2017). We tried this solution with the Learning Locker Open Source LRS<sup>21</sup> and found that the hosted metadata were not resolved. Regarding hosted metadata, the newer xAPI version 2.0 specifies that "if an Activity IRI is a URL, an LRS should attempt to GET that URL" (IEEE, 2023b). It is commendable that this functionality has been clarified in xAPI version 2.0 in terms of LRS conformance, but there are still several examples where the MAY conformance level applies. If the xAPI standard is to be implemented in an interoperable manner, where data may be integrated across multiple sources and exchanged among a variety of LRSs developed by different vendors, it would be beneficial for xAPI to further specify clearer guidelines.

### **Extensibility and broader applicability**

Aspects related to the extensibility and broader applicability of the technical solution were discussed during the post-test interview. Two of the participants brought up the need to separate between properties that are included in the standard and properties that are included for specific communities of practice. While we agree with the suggestion that it would not scale well to include all properties in the standard, it might be possible to include the more custom properties as part of context dimensions in profiles, while the more general properties could be made part of context dimensions in the standard. The separation between the standards and profiles could be further explored by a number of relevant stakeholders. Here, the Caliper specification (1EdTech, 2020) could serve as inspiration by looking at its separation between properties that are required for all Events<sup>22</sup> and properties that pertain to specific Caliper profiles.

Another aspect expressed was that some of the property names could be made more generic or internationalized, to accommodate a broader adoption of profiles. Finally, the participants were generally positive to the use of profile inheritance, where one base profile could be inherited by relevant sub-communities (e.g., to accommodate cultural or national subtleties). While the participants indicated that such a solution could include a base profile that is inherited, meaning it is contained in the inheriting profile, further aspects of such a solution would need to be worked out, to assess if the suggestion is feasible both on a conceptual and an implementable level.

### **The use of JSON-LD**

The participants discussed the potential benefits of using JSON-LD for xAPI statements in the technical solution, and more generally for the xAPI specification, as this approach

---

<sup>21</sup> <https://github.com/LearningLocker/learninglocker>

<sup>22</sup> "A Caliper Event is a generic type that describes the relationship established between an actor and an object, formed as a result of a purposeful action undertaken by the actor at a particular moment in time and within a given learning context" (1EdTech, 2020).

would allow the use of linked data technologies. Concerning the unified and hierarchical structure that has received positive feedback in the user test, it would still be possible to define it using JSON-LD since JSON-LD relies on JSON which allows for nested data structures at multiple levels. Currently it is only the xAPI profile specification, not the xAPI specification, that supports JSON-LD. While there exists an xAPI ontology, the xAPI community reports that there are major issues with the ontology<sup>23</sup>. Various research has been carried out related to xAPI ontology development (e.g., Vidal et al., 2015; De Nies et al., 2015; Vidal et al., 2018), although it does not appear that results from these projects have been adopted explicitly into the xAPI ontology. If moving to a linked data solution for the xAPI specification, the xAPI community should look into this previous research. Utilizing JSON-LD for the xAPI specification could have a number of possible advantages, which were emphasized by the participants, including enhanced query capabilities in triple stores, hosting metadata that may pertain to different standards, and reducing xAPI statement length, thus potentially increasing expressibility through more consistent descriptions. For linked data, data typing and validation constraints would typically be defined in languages such as Shapes Constraint Language (SHACL), and RDF schema (RDFS), allowing for the use of RDF built-in data types that are generally more expressive than JSON schema (Allemang et al., 2020). On the other hand, the JSON schema specification, utilized for the technical solution, could also play a role in ensuring xAPI statements are according to the requirements, especially for developers that are familiar with JSON but not with linked data.

### **xAPI Extensions**

The use of extensions, such as context extensions, may present a challenge to interoperability due to the openness with which they can be defined (Bakharia et al., 2016; Samuelsen et al., 2021). Here, it should be noted that the choices to use xAPI extensions to represent context dimensions and properties, and to extend the existing concept of the xAPI Activity, were made to adhere to the existing functionality and constraints of xAPI when implementing the general technical solution. As such, use of extensions allowed for stakeholder exploration of the recommendations while also clearly specifying data description constraints with the JSON schema specification (a must in terms of interoperability for adopters of the technical solution) and keeping conformance with xAPI and the xAPI profile specification. Furthermore, the technical solution presented in this paper can be considered a "proof-of-concept" more than a ready-made solution, since adopting it as is would require that existing xAPI data are formatted according to the school adaptivity profile. Thus, if measures from the technical solution such as context dimensions

---

<sup>23</sup> <https://github.com/adlnet/xapi-ontology/issues>

and properties were to be included in xAPI in the future, we advise that they be introduced as native constructs rather than extensions, thereby allowing all adopters to utilize them in a standardized way.

## Conclusion and future work

This paper addressed two research questions related to the implementation and evaluation of recommendations for enhancing xAPI context descriptions and expressibility that were identified in previous research (Samuelsen et al., 2021).

In response to RQ1—*how can the recommendations for enhancing xAPI context descriptions and expressibility be implemented through a technical solution?*—the recommendations for enhancing xAPI context descriptions and expressibility were implemented as part of a technical solution through the creation of a new xAPI profile for the K-12 adaptive learning domain, where an accompanying xAPI example statement illustrates data description according to the profile. The technical solution incorporates various aspects, including a unified and hierarchical context model that is exemplified with categorization of context according to the adaptive learning domain, emphasizing measures for data typing and validation.

In response to RQ2, *how does the technical solution support technical experts in describing learning activity data from multiple data sources for LA data integration?*, technical experts participating in user testing of the technical solution expressed that the solution supports them in describing learning activity data for LA data integration consistently across sources. As such, the user test participants generally indicated approval of the unified and hierarchical structuring of context, as represented through context dimensions and properties, emphasizing that it can add to aspects related to expressibility. The participants, however, indicated pragmatic views that consistent data descriptions can alternatively be achieved through other means such as post hoc data processing. Furthermore, the participants indicated general support for data typing and validation measures to support data integration, although cautioning that these need to follow real-world constraints. The participants also indicated approval for the use of hosted metadata to promote consistent data descriptions. Related to the usability criteria assessed for the technical solution, the user testing generally indicates that the usefulness and effectiveness criteria are met. Additionally, the participants indicate satisfaction regarding the solution at a general level, while also pointing out potential for improvement at the implementable level.

The findings of this study provide evidence that the technical solution is feasible and effective in supporting xAPI data integration and interoperability through promoting expressibility, focusing in particular on the K-12 adaptivity case. The value contribution of this study is improved xAPI data integration through the promotion of consistent data

descriptions across multiple sources. As such, this study has implications for evidence-based practice and adaptive learning, where improved integration of data from multiple sources enhances the outcomes of LA. For example, in the context of K-12 education, the following scenario that relates to the AVT project illustrates how the technical solution could be applied in real-world educational settings: In Oslo, Norway, schools (grades 1-10) have access to a variety of digital tools, including tools for mathematics learning. Furthermore, the municipality students go through several obligatory assessments, delivered through digital platforms, in subjects including maths. Upon student interactions with the math tools and platforms, and their accompanying learning resources, the tool and platform vendors all generate xAPI activity data that are structured according to the technical solution (e.g., following the unified and hierarchical context structure). The generated data are continually fed into a LA system, which integrates the data in a Learning Record Store. Through analyzing the student data that spans across time, tool/platform and institution, the LA system provides functionality pertaining to adaptive learning, including dynamic provision of learning resources in math based on student progress.

Interoperability and data integration relate to LA scalability. As such, measures utilized in the technical solution (e.g., regarding the hierarchical and unified structuring of contextual information), could be further explored for inclusion to the standard by the xAPI community, as a means to promote scalable LA, thereby breaking down the silos that act as a barrier to LA without having to rely on time and resource-intensive ad hoc or post hoc processing of the data. Furthermore, the stakeholder validation results highlight the potential of including JSON-LD for both the technical solution and the xAPI specification (e.g., to provide additional semantics to properties and as a cross-standard compatible approach to host metadata).

We acknowledge that there are limitations to this research. While focusing on implementing the recommendations related to interoperability, data integration, and xAPI context descriptions as part of the technical solution, we did not address and implement all of the recommendations, due to the affordances and constraints provided by the current xAPI and xAPI profile specifications, and the research situation. For instance, we do not directly address the need for enhanced query capabilities in xAPI; and the solution does not include xAPI profile patterns, used to specify the ordering of allowed xAPI statements, since the use case of school adaptivity is very broad, meaning a lot of different sequences could potentially be allowed. Furthermore, the usability of the technical solution has been evaluated using technical experts from only one case, the AVT project, with a limited number of participants. While the technical experts responded positively to the technical solution, the technical solution has not yet been implemented as a part of an adaptive learning solution in the K-12 domain, which would be needed to generate the real-world data necessary to evaluate its impact on adaptive learning with involvement of stakeholders

such as teachers. Finally, the device and environment context dimensions, while having foundations in previous research, have not been evaluated by domain experts within education. Similarly, the categorization of context properties into context dimensions, and the data types and validation measures, have not yet been validated by educational domain stakeholders.

As future work, the technical solution should be evaluated across multiple case studies, to ensure its applicability and effectiveness in diverse settings. As such, the solution should be evaluated by a greater number of technical experts; and furthermore, the context data model should be evaluated by a broader group of stakeholders, having domain expertise within education, teaching and educational technology.

#### **Abbreviations**

API: Application Programming Interface; AVT: Activity Data for Assessment and Adaptation; DATASIM: Data Simulator for TLA; DBIR: Design-Based Implementation Research; IRI: Internationalized Resource Identifier; JSON-LD: JSON for Linking Data; LA: Learning Analytics; LRS: Learning Record Store; RDF: Resource Description Framework; SKOS: Simple Knowledge Organization System; xAPI: Experience API.

#### **Acknowledgements**

The authors wish to thank the technical experts that participated in the user testing for their valuable contributions.

#### **Authors' contributions**

This paper is a part of the PhD project conducted by JS, where BW was her main supervisor and WC was her co-supervisor. WC and BW assisted in planning and writing. All authors read and approved the final manuscript.

#### **Authors' information**

Jeanette Samuelsen, PhD, currently works as a senior advisor ICT and is also affiliated with the University of Bergen, Norway. Her research interests include learning analytics, educational technology standards, data integration and interoperability.

Weiqin Chen is a professor at Oslo Metropolitan University and an adjunct professor at the Centre for the Science of Learning & Technology (SLATE), University of Bergen, Norway. Her current research interests include human-centered artificial intelligence, digital accessibility and learning analytics.

Barbara Wasson is a Professor and Director of the Centre for the Science of Learning & Technology (SLATE), University of Bergen, Norway and Co-director of the new national AI Centre for the Empowerment of Human Learning (AI LEARN). Her current research interests include human-artificial systems, hybrid intelligence, learning analytics, and data literacy.

#### **Funding**

This research has been supported by a University of Bergen PhD stipend at SLATE and funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 856954.

#### **Availability of data and materials**

To protect the privacy of the participants, the data cannot be shared.

#### **Declarations**

#### **Competing interests**

The authors declare that they have no competing interests.

#### **Author details**

<sup>1</sup> Centre for the Science of Learning & Technology, University of Bergen, Norway

<sup>2</sup> Department of Information Science & Media Studies, University of Bergen, Norway

<sup>3</sup> Oslo Metropolitan University, Oslo, Norway

Received: 25 June 2024 Accepted: 2 October 2025

Published online: 1 January 2027 (Online First: 16 March 2026)

## References

- 1EdTech (n.d.). *Caliper analytics*. <https://www.imsglobal.org/activity/caliper>
- 1EdTech (2020). *Caliper analytics specification*. <https://www.imsglobal.org/spec/caliper/v1p2>
- Advanced Distributed Learning. (n.d.-a). *xAPI profile server authoring guide: Authoring guidance*. <https://adlnet.gov/guides/xapi-profile-server/authoring-guide/Authoring-Guidance.html>
- Advanced Distributed Learning. (n.d.-b). *xAPI profile server*. <https://profiles.adlnet.gov/profiles>
- Advanced Distributed Learning. (n.d.-c). *xAPI profile server: xAPI profile guidelines*. <https://profiles.adlnet.gov/help#resourcestop>
- Advanced Distributed Learning. (n.d.-d). *Data simulator for TLA (DATASIM)*. <https://adlnet.gov/projects/datasim/>
- Advanced Distributed Learning. (2017). *xAPI specification: Part two - Experience API data*. <https://github.com/adlnet/xAPI-Spec/blob/master/xAPI-Data.md#parttwo>
- Advanced Distributed Learning. (2018a). *xAPI profiles specification*. <https://github.com/adlnet/xapi-profiles>
- Advanced Distributed Learning. (2018b). *xAPI profile specification: Part Two - xAPI profiles document structure specification*. <https://github.com/adlnet/xapi-profiles/blob/master/xapi-profiles-structure.md#part-two>
- Advanced Distributed Learning. (2021). *xAPI specification*. <https://github.com/adlnet/xAPI-Spec>
- Allemang, D., Hendler, J., & Gandon, F. (2020). *Semantic web for the working ontologist: Effective modeling for linked data, RDFS, and OWL* (3rd ed.). ACM. <https://doi.org/10.1145/3382097>
- AVT (2021). Eksempler på kall mot og respons fra leverandørenes aktivitetsdata-API. <https://github.com/KS-AVT/avt/blob/AVT1/eksempler.md>
- Bakharia, A., Kitto, K., Pardo, A., Gašević, D., & Dawson, S. (2016, April). Recipe for success: Lessons learnt from using xAPI within the connected learning analytics toolkit. In *Proceedings of the 6th International Conference on Learning Analytics & Knowledge* (pp. 378–382).
- Bryman, A. (2012). *Social Research Methods* (4th ed.). Oxford University Press.
- Cooper, A. (2014). *Learning analytics interoperability: The big picture in brief*. Learning Analytics Community Exchange. Retrieved April 1, 2023, from <https://web.archive.org/web/20160508150324/http://laceproject.eu/publications/briefing-01.pdf>
- De Meester, B., Lieber, S., Dimou, A., & Verborgh, R. (2018). Interoperable user tracking logs using {linked data} for improved learning analytics. In *Call Your DATA Proceedings of the XIXth International CALL Research Conference* (pp. 29–31).
- De Nies, T., Salliau, F., Verborgh, R., Mannens, E., & Van de Walle, R. (2015). TinCan2PROV: Exposing interoperable provenance of learning processes through experience API logs. In *Proceedings of the 24th International Conference on World Wide Web* (pp. 689–694).
- Dey, A. K. (2001). Understanding and using context. *Personal and Ubiquitous Computing*, 5(1), 4–7.
- Downes, A., Shahrazad, A., & Smith, R. (2015). *Sharing between LRSs: A collaborative experiment in practical interoperability* [White paper]. <https://xapi.com/wp-content/uploads/sites/3/2015/03/whitepaper.pdf>
- European Commission. (2017). *New European Interoperability Framework*. [https://ec.europa.eu/isa2/sites/isa/files/eif\\_brochure\\_final.pdf](https://ec.europa.eu/isa2/sites/isa/files/eif_brochure_final.pdf)
- Fishman, B. J., Penuel, W. R., Allen, A.-R., Cheng, B. H., & Sabelli, N. (2013). Design-based implementation research: An emerging model for transforming the relationship of research and practice. *Teachers College Record*, 115(14), 136–156.
- Griffiths, D., & Hoel, T. (2016). *Comparing xAPI and caliper* (*Learning Analytics Review*, No. 7). LACE.
- Hansen, C.J.S., Wasson, B., & Belokry, G. (2020). *Teacher's need for information*. Internal report: Unpublished.
- IEEE. (2023a). *xAPI about*. <https://opensource.ieee.org/xapi/about>
- IEEE. (2023b). *9274.1.1 xAPI base standard for LRSs*. <https://opensource.ieee.org/xapi/xapi-base-standard-documentation/-/blob/main/9274.1.1%20xAPI%20Base%20standards%20for%20LRSs.md>
- IEEE. (2023c). *xAPI Base Standard Overview*. <https://opensource.ieee.org/xapi/xapi-base-standard-documentation/-/blob/main/9274.1.1%20xAPI%20Base%20Standard%20Overview.md>
- International Organization for Standardization. (2024). *Information technology for learning, education and training – Metadata for learning resources* (ISO Standard No. 19788-1:2024).
- Jovanović, J., Gašević, D., Knight, C., & Richards, G. (2007). Ontologies for effective use of context in e-learning settings. *Journal of Educational Technology & Society*, 10(3), 47–59.
- Kitto, K., Whitmer, J., Silvers, A. E., & Webb, M. (2020). *Creating data for learning analytics ecosystems*. Society for Learning Analytics Research (SoLAR). [https://www.solaresearch.org/wp-content/uploads/2020/09/SoLAR\\_Position-Paper\\_2020\\_09.pdf](https://www.solaresearch.org/wp-content/uploads/2020/09/SoLAR_Position-Paper_2020_09.pdf)
- Lincke, A. (2020). *A Computational Approach for Modelling Context across Different Application Domains* (Doctoral dissertation, Linnaeus University Press). <http://urn.kb.se/resolve?urn=urn:nbn:se:lnu:diva-93251>
- Morlandstø, N.I., Hansen, C.J.S., Wasson, B., & Bull, S. (2019). *Aktivitetsdata for vurdering og tilpassing: Sluttrapport*. SLATE Research Report 2019-1. Centre for the Science of Learning & Technology (SLATE). ISBN: 978-82-994238-7-8

- Oates, B. J. (2006). *Researching information systems and computing*. SAGE publications.
- Rubin, J., & Chisnell, D. (2008). *Handbook of usability testing: How to plan, design and conduct effective tests*. John Wiley & Sons.
- Samuelsen, J., Chen, W., & Wasson, B. (2019). Integrating multiple data sources for learning analytics—review of literature. *Research and Practice in Technology Enhanced Learning*, 14(1). <https://doi.org/10.1186/s41039-019-0105-4>
- Samuelsen, J., Chen, W., & Wasson, B. (2021). Enriching context descriptions for enhanced LA scalability: A case study. *Research and Practice in Technology Enhanced Learning*, 16(1). <https://doi.org/10.1186/s41039-021-00150-2>
- Schmitz, H. C., Wolpers, M., Kirschenmann, U., & Niemann, K. (2011). Contextualized attention metadata. In *Human Attention in Digital Environments* (pp. 186–209).
- SoLAR (2025). *Reimagining Learning Analytics*. <https://www.solaresearch.org/wp-content/uploads/2025/06/Reimagining-Learning-Analytics-V3-002.pdf>
- Thüs, H., Chatti, M. A., Greven, C., & Schroeder, U. (2014). Kontexterfassung, -modellierung und -auswertung in Lernumgebungen. *DeLFI 2014-Die 12. e-Learning Fachtagung Informatik*.
- Thüs, H., Chatti, M. A., Yalcin, E., Pallasch, C., Kyrlyuk, B., Mageramov, T., & Schroeder, U. (2012). Mobile learning in context. *International Journal of Technology Enhanced Learning*, 4(5-6), 332–344.
- Vidal, J. C., Rabelo, T., & Lama, M. (2015). Semantic description of the Experience API specification. In *2015 IEEE 15th International Conference on Advanced Learning Technologies* (pp. 268–269).
- Vidal, J. C., Rabelo, T., Lama, M., & Amorim, R. (2018). Ontology-based approach for the validation and conformance testing of xAPI events. *Knowledge-Based Systems*, 155, 22–34.
- Wasson, B., Morlandstø, N. I., & Hansen, C. J. S. (2019). *Summary of SLATE research report 2019-1: Activity data for assessment and activity (AVT)*. Centre for the Science of Learning & Technology (SLATE). <https://bora.uib.no/handle/1956/20187>

### Publisher's Note

The Asia-Pacific Society for Computers in Education (APSCIE) remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

***Research and Practice in Technology Enhanced Learning (RPTEL)***  
is an open-access journal and free of publication fee.