Learning Analytics for Open Learning Environments:
Connection to 21st Century Skills

Sokratis Karkalas[1], Alisa Lincke[2], and Marianthi Grizioti[3]

[1] University of Derby, Derby, UK s.karkalas@derby.ac.uk
[2] Linnaeus University, Växjö, Sweden alisa.lincke@lnu.se
[3] Educational Technology Lab, National Kapodistrian University of Athens, Athens, Greece mgriziot@eds.uoa.gr

Abstract. This paper presents the design and development process of an innovative learning analytics tool tailored to address the challenge of generating analytics for diverse, constructionist, open learning tools. The paper outlines the preparatory phase, which informs a co-design component aimed at eliciting data requirements and establishing a shared conceptual framework among educators regarding the monitoring of 21st-century skills using open learning tools. Through this process, common understandings and agreed-upon metrics for assessing skill cultivation were identified. Subsequently, the paper delineates how these insights were translated into functional and technical specifications for the development of a learning dashboard. Finally, a report is given on the results of a preliminary evaluation, giving promising indications that the designed tool effectively addresses the identified challenges. This paper contributes to the advancement of learning analytics by offering a systematic approach to designing tools that support the cultivation of 21st-century skills in diverse learning environments.

Keywords: Learning Analytics · Requirements Elicitation · 21st-century Skills · Open Learning Environments · Exploratory Learning Environments

1 Introduction

Current international education agendas and directives underscore the imperative of digital transformation in education, advocating for a shift towards a trans-disciplinary, inclusive, and skill-oriented approach. Emphasis is placed on cultivating digital competences and emerging 21st-century skills. Contemporary educational strategies aimed at fostering these skills integrate interactive and constructionist learning media, fostering dynamic learning environments. However, this integration complicates instructional design, presenting a multifaceted and challenging task. Within this landscape, Learning Analytics (LA) plays a central role in enhancing instructional design and optimizing teaching and learning processes. In this context a typical top-down implementation of LA would neglect the nuanced needs of such environments without early-stage involvement from educators. While existing approaches involve stakeholders in the development of LA systems, challenges persist, especially in the critical early stages. One significant challenge is the varying levels of awareness among stakeholders regarding the potential of LA, which can hinder their effective engagement in the development process. To address these challenges within constructionist environments and 21st-century skill development, this study proposes the co-design, development, and evaluation of a customisable LA dashboard. This dashboard incorporates input from teachers regarding the collection, analysis, and visualization of data generated from students' engagement with various tools. The paper aims to present a structured methodology for the design of a customisable visualization dashboard, deriving implications for conceptual models of 21st-century skills to make LA meaningful for end-users.

2 Literature Review

The integration of digital technologies into educational practices has transformed the way learning experiences are delivered and assessed [5, 9]. Interactive and constructionist learning environments, which encourage active engagement, collaboration, and exploration, have become increasingly prevalent [21]. However, the complexity of these environments presents unique challenges for instructional design and assessment. Traditional methods of evaluation may not adequately capture the diverse forms of learning and engagement facilitated by these environments, necessitating the need for more evidence-based approaches such as Learning Analytics (LA).

LA can offer a holistic view of the learning process, capturing a wide range of data including student interactions with learning materials, performance on assessments, and engagement patterns [3, 17]. By analyzing this data, educators can gain valuable insights into student learning behaviors, identify areas for improvement, and tailor instructional strategies to meet individual needs. This can help educators monitor student progress in real-time, providing timely interventions and support when necessary as well as summative feedback after the activities are completed. Moreover, LA enables revisiting learning designs and informed redesign adjustments to improve effectiveness in response to how designs are perceived by learners [12, 16].

In the context of 21st-century skills development, which emphasizes critical thinking, creativity, collaboration, and digital literacy, LA plays a crucial role in assessing and fostering these competencies [1]. By analyzing student interactions with digital tools and resources, LA can provide valuable feedback on the acquisition and application of these skills [6, 6]. Moreover, LA can inform the design of learning experiences that promote the development of 21st-century skills, facilitating a more dynamic and adaptive approach to education.

Despite its potential benefits, the successful implementation of LA requires collaboration and engagement from all stakeholders, including educators, students, administrators, and policymakers. A top-down approach to LA implementation may overlook the nuanced needs of diverse learning environments, highlighting the importance of early-stage involvement from educators in the development process. By adopting a co-design approach, which incorporates input from teachers in the design and development of LA tools, we can ensure that these tools are tailored to the specific needs and contexts of open learning environments [2, 22].

Learning Analytics offers a promising avenue for enhancing instructional design, optimizing teaching and learning processes, and fostering the development of 21st-century skills. By leveraging data analytics techniques and adopting a user-centered design approach, we can develop innovative LA tools that support the cultivation of these essential competencies in diverse learning environments.

3 Context

This project took place in the context of a large EU funded project - ExtenDT2 - focused on exploring the fusion of emerging technologies with existing constructionist learning environments, coupled with design thinking methodology, to enhance educational practices [18]. To facilitate experimentation with these technologies, we developed an innovative learning platform as a web-based learning ecosystem enabling seamless integration and interoperability of diverse learning environments. These environments vary in architecture, application programming interfaces, communication protocols, and data formats. However, within this platform, they function cohesively, offering dynamic synthesis of engaging learning activities spanning a wide array of 21st-century skills.

At the core of this platform there are interactive constructionist learning environments, fostering knowledge acquisition through exploration. These environments can be enhanced dynamically with automated support and adaptability. As learners engage with these activities, the system captures and analyzes their interactions, providing valuable insights for both learners and educators. These insights serve as formative and summative feedback for learners, aiding in self-awareness of their learning progress and refinement of learning strategies. Educators can utilize this data to assess and refine their instructional designs, fostering iterative improvement.

While this platform presents compelling learning opportunities, it also poses significant challenges, stemming from the diversity and exploratory nature of the learning process. Integrated learning tools include MaLT2 (a programming environment for creating and tinkering with 3D dynamic graphical models), SorBET (a tool for authoring classification games), ChoiCo (a tool for authoring choice-driven simulation games), and GearsBot (educational robotics).

4 Methodology

This section outlines the systematic approach employed to address the objectives given in section 1. It provides a detailed account of the procedures, techniques, and tools utilized throughout the design process. The methodology adopted follows user-centered design (UCD) principles [19] aimed at uncovered needs, goals, tasks, preferences, challenges, and behaviours of end-users and stakeholders and effectively transform them into technical and functional specifications for the development of a learning analytics tool. The basic principles behind this approach involve focus on users, iterative process, multidisciplinary collaboration, early and continuous user involvement and empirical evaluation. The methodology involves the following components:

4.1 Selection of Learning Activities

UCD emphasises the importance of involving stakeholders early and continuously throughout the design process. This typically involves conducting user research, gathering feedback on prototypes, and engaging users in co-design activities to ensure that their needs and preferences are adequately addressed. This first component is related to the latter. In the context of this project we implemented a series of requirements elicitation workshops with teachers to explore what type of information they find important when students interact with exploratory learning tools with regard to 21st century skills. This was based on the Repertory Grid Technique (RGT) [20]. The workshops took place at the National and Kapodistrian University of Athens (NKUA) in June (Malt2) and November (SorBET, ChoiCo) of 2023. Further details about these workshops are given in [10]. In the first part of these workshops, participants are presented with a simplified scenario in which they assume the role of teachers utilizing a specific tool for a classroom activity. The aim is to ensure that all participants share a common understanding of the data generated by the learning tool throughout the learning process. This exercise facilitates the establishment of a uniform level of awareness regarding the semantics of the data, enabling participants to identify any gaps and introduce new, potentially valuable data elements. The facilitators are responsible to resolve possible misconceptions and make sure the same level of understanding is achieved at the end of this session. This presupposes that the facilitators are equipped with adequate level of understanding themselves before engaging with participants. This is an important factor that can influence significantly the effectiveness of this part. To address this issue we went through an elaborate process of analysing existing and well tested learning activities for each tool from old repositories. These are existing scenarios for activities based on these learning tools, that have been used in the classroom successfully and there is available documentation about misconceptions, common problems, landmarks, typical solutions and other important aspects of the learning process. The outcome of this process was the best candidate learning activities for each tool. These activities were then used to prepare facilitators for the workshops. The selected learning activities were the following: The activity for the MaLT2 tool is called "squares to cubed". It provides students with a cube net model created by a Logo procedure and asks them to modify the code so that the cube net can fold into a full cube [14]. The activity for the ChoiCo tool is called "CT-chef" and asks the students to play a simulation game about running a restaurant with healthy food and then modify it to improve its performance [7][4]. The activity for the SorBET tool is called "App-game" and asks students to play and extend a classification game about popular computer applications and their common purpose of usage [8][5].

Rationale behind the Structure of Action Indicators: As explained in 4.1 facilitators need to be aware of the particularities of the learning tools as well as the data generated by them during activities. In this section we are presenting, as examples, two learning tools with central role in the project: ChoiCo [15] and SorBET [8]. These are web-based applications that allow the design and play of digital games by integrating a set of interconnected computational affordances. ChoiCo integrates a map-based editor, an interactive database and block-based programming, while sorbet integrates a game scene, an interactive database and block-based programming. Both applications support two modes for the users: a) the "play mode", where they can play or test a game as players with limited access to the game affordances e.g. in ChoiCo they can only see a representation of the data of a selected record from the database but not modify them and b) the design mode, where they can modify and create new game elements using the full functionalities of the integrated affordances e.g. in ChoiCo they can modify all elements of the game data in the interactive database. In the logging process we aimed to capture a) the role under which the student interacts with the tool (i.e. player or designer) and b) the different uses of the offered affordances. To achieve this, the logging messages for ChoiCo and SorBET tools are structured as follows:

- **id**: an integer variable determining the id of the relevant affordance e.g. in ChoiCo there are 3 coding editors and this id determines which of the 3 generated the event
- **type**: a string variable with the affordance that actions were performed on. It can have one of the following values: playmode (to determine that the user was interacting as a player), map_editor, database, codespace (these three values determine that the user was interacting as a designer)
- **event**: a string variable with the name of the event that is related to the element (e.g. 'addField', 'modify_point').
- **state**: any information related to this event including a) the current state of the related affordance or the game progress in case of playmode events e.g. the total number of database fields at the time of the event, b) information of the user activity that triggered the event e.g. the name of the new field that the user added and triggered the event and c) the times this event has been triggered since the start of the activity
- **timestamp**: the time of event trigger in Unix timestamp

For example an event from SorBET, triggered when the user, as a game designer, modifies the name of a column in the database that represents a game category

[4] http://etl.ppp.uoa.gr/choico/?CTChef_Eng
[5] http://etl.ppp.uoa.gr/sorbet/?AppGame

could reveal the following: Through the state variable we could see that the game, at the time of the event, had X categories in total and that the student changed the name of the category 'Mamals' to 'Fish'. Regarding the learning process, this indicates that the student probably decided to use more focused categories and not so general ones like the initial game had (Mamals). This can also be considered as a landmark for the activity since it indicates an understanding of the classification model of the game and how the game categories are represented in the database.

Examples of Activities: In the following ChoiCo activity, students are asked to first play a 'half-baked game' about having a balanced diet and then improve it. The initial game has by design some intentional errors in the values of some of the choices, aiming to trigger students to discuss the game topic and correct them in the design mode. For instance, the consequences of the point 'ice cream' are not consistent with all the other similar points.

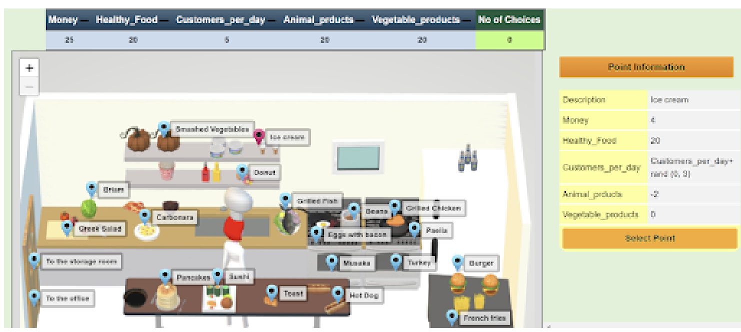


Fig. 1: A game in ChoiCo about making balanced food choices

The teacher expects students to play the game several times, explore all the available points and then switch to edit mode and start modifying the game database. For this specific activity, the focus is on the consequence values that are represented in the database, rather than the game rules in the codespaces or the game scene. Thus the teacher indicates the landmarks shown in the first column of table 1 and they can be correlated with the logging activity shown in the second column.

4.2 Exploration of Learning Activities

In the first part of the RGT workshops, participants are given as input a learning scenario and a full list of events associated with the respective tool. The source for this list was the tool documentation. The goal in this initial segment of the workshop, is to ensure uniform awareness among participants regarding the data

Table 1: Landmarks and Events

Landmark	Event Logging Activity
Exploration of available choices as players	(The event ‘point selection’ has been triggered at least 20 times AND The event ‘point selection’ has been triggered for at least 10 different points) OR (The event ‘game over’ has been triggered at least 3 times with score greater than 13)
Testing and debugging	The event ‘switch mode’ has been triggered at least 5 times
Experimentation with game data	The event ‘change_value’ has been triggered at least 15 times OR The event ‘add_field’ has bee triggered at least 2 times
Detection and correction of inconsistencies	pointID: 14 and 22 (these are the points with the inconsistent values)

generated by the tool throughout the learning process. The aim is to establish a common, shared understanding of the data semantics and empower participants to identify and introduce any new, potentially valuable data elements that may be missing. The scenario that is given as a point of reference is inevitably an element that influences the discussion around the data generated during the activity. This data is expected to be a proper subset of the full list of the events given and is also expected to have some activity-specific semantic nuances. It is important that the facilitators are very well prepared for that part to ensure cohesion and consistency of the semantics used in the workshop. To address this need we employed a tool called AuthELO.

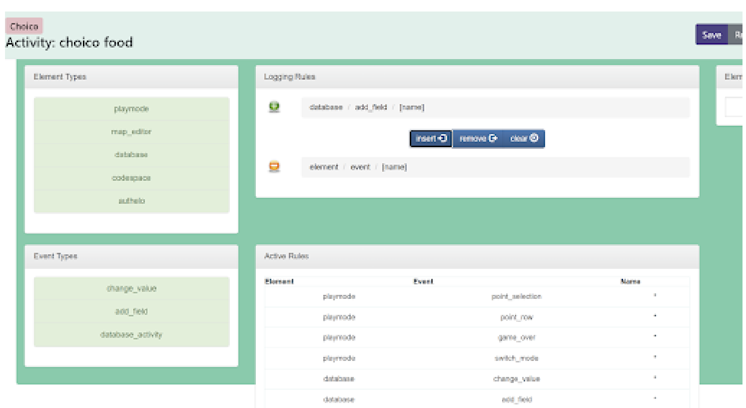


Fig. 2: Logging Rules

AuthELO [11, 13] is an existing, established and well tested tool that can be used to configure user activity logging rules and rules that dictate how automated feedback can be generated based on these logs. We used AuthELO to configure the learning tools to generate all available events and then asked the facilitators to do the activities as students through AuthELO. This workshop took place in early June 2023 at NKUA with three participants. All the participants were experienced learning technologists with different backgrounds (primary school teacher, ICT and maths teacher). The participants spent 30 minutes for each activity - tool, including a 5-10 minute discussion / reflection.

AuthELO is designed to operate as an example-tracing tutor. It allows the user to do an activity as a learner and displays in real-time user activity indicators generated by the tool related to that activity. This allows the user to map much easier the actions performed on elements in the learning environment to events generated by the tool and understand better their context specific nuances. The feedback we received from the facilitators for this was very positive. They reported that doing the activity themselves and seeing what is being generated in terms of events in real time streamlines the familiarisation process and provides a more exact depiction of what the actual data representation is in relation to the contextual semantics of the activities.

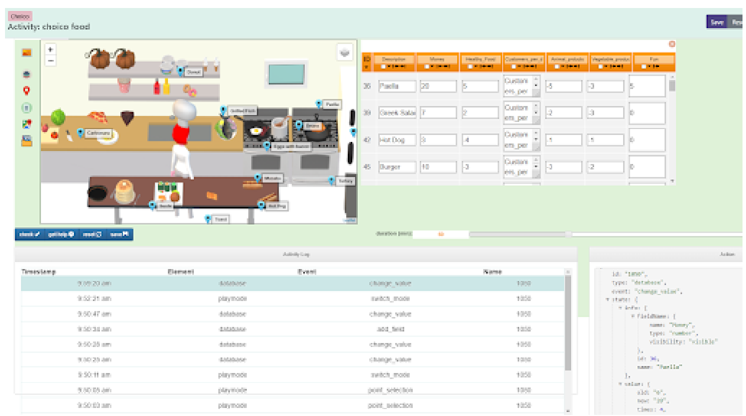


Fig. 3: Action Indicators

4.3 Elicitation of Data Requirements and Emerging Concepts

The outcome of the two previous components are used as input for this part. This is the series of workshops employed to uncover and analyze teachers' personal constructs, to serve as the cognitive framework through which we interpret and understand what is meaningful and useful in terms of data for the given activities. As described in [10] by utilizing this methodology, our goal was to systematically and comprehensively understand stakeholder perceptions, preferences, and constructs. This, in turn, allowed us to derive evidence-based, well-informed, and meaningful user-centered design specifications for a learning analytics tool tailored to the specific context of learning. To achieve this, we conducted a series of workshops with teachers to elicit requirements. These workshops aimed to explore what information teachers consider important when students interact with exploratory learning tools in the context of developing

21st-century skills. Through this process, we identified various concepts associated with 21st-century skills and translated them into tool-specific indicators of learner interactions. The main concepts identified include motivation, experimentation, understanding, interaction with technology, and originality and are consistent across all three tools used in the study. As illustrated in figure 4, each concept is linked to one or more 21st-century skills and accompanied by a list of tool-specific events that demonstrate how learners engage with the tools during learning activities. In this context, we can consider these concepts as an additional variable or dimension in the generated data, providing a categorisation perceived by educators. These categories can be mapped to specific skills and corresponding learner actions. These insights formed the foundation of a design specification, informing the development of a customisable learning analytics tool suited for open learning environments.

Fig. 4: Data Design for SorBET. (A) Key common concepts identified through RGT associated with (B) specific 21st-century skills and (C) tool-specific events

4.4 Definition of Technical Specifications

The following methodology was followed to translate the outcomes of the RGT into technical specifications for the development of the learning analytics tool:

- **Understanding of RGT results**: Reviewing concepts, skills, action indicators and their interrelationships as identified in section 4.3. Concepts are second-order variables in this analysis. These are the actual variables deemed worth monitoring by teachers. The values given to them are composite and should be generated dynamically as a function of the first-order action indicators specified in the RGT analysis. In this part a distinction was made between action indicators being available directly in the data and indicators that need to be generated as aggregate, derivative values from the data.

- **Mapping Action Indicators to Elements / Events**: The first-order action indicators considered in the previous step, are associated with events being generated when actions are performed on specific elements in the learning tools (e.g. move the camera or slider, execute the code, change properties of an item). Some of those indicators correspond to count-based events which quantify various learner actions, such as the number of times a student executes a procedure in MaLT2, or selects a point during the game in ChoiCo, or the number of correct / wrong classifications in a SorBET game. In this step, all of those action indicators were mapped to the the actual tool-specific element / event combination.

- **Quantifying Concepts**: The concepts considered in step one are still qualitative data that need to be quantified. These are second-order variables and thus their values should depend on the respective first-order action indicators. In this part certain algorithms were considered as to how this translation should be made so that it allows easy manipulation (authorability) by teachers. The algorithm prevailed was the composite index value (score) as a weighted sum of first-order action indicators [4]. This is easy to comprehend by users and easy to represent in authoring tool user interfaces. In a composite index where multiple variables are combined with different weights, the sum of the weights should be equal to 1 or 100%. This guarantees that the composite index reflects the relative importance of each variable in the overall measurement. Each weight represents the proportion of influence that the corresponding variable has on the final composite score, in this case the concept.

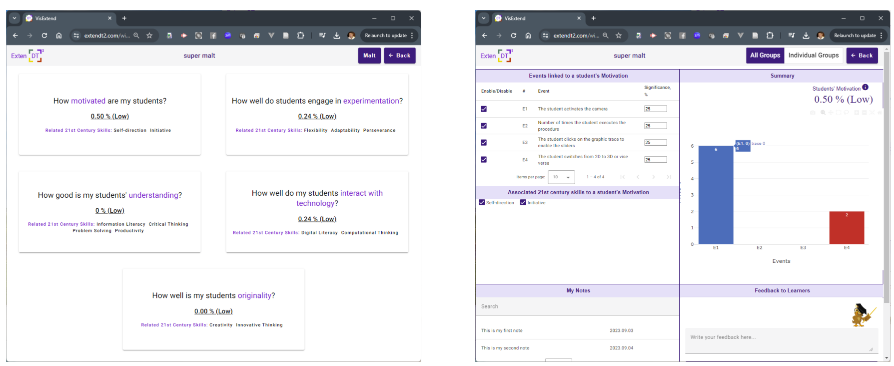
- **Designing Authorability**: In this part the feedback collected from the RGT component was qualitatively considered to determine the affordances of the learning analytics tool with respect to the level of authorability. The following requirements were identified: (a) a teacher should be able to see the overall score for each concept (e.g., motivation, experimentation, etc.); (b) a teacher should be able to select a construct and configure it by enabling / disabling the respective action indicators and specifying their significance level between 0 and 100%; (c) a teacher should be able to see the elements through simple visualizations at different levels of granularity (group or classroom level).

- **Selecting Visualisations**: Simple bar charts and matrix-like visualizations were selected due to their simplicity, expressiveness and analytical power.

- **Integration with the ExtenDT2 platform**: The tool was designed to be developed as an external component and integrated with the the ExtenDT2 platform in a loosely coupled manner through a REST (Representational State Transfer) interface. The design objective here was to allow for maximum versatility, autonomy and adaptability to different deployment settings.

4.5 Development of the Prototype

The prototype was developed using the Angular 16 (TypeScript) framework[6] with the Plotly[7] and ng2-charts[8] visualisation libraries. It consists of two main components: services (for loading and pre-processing the LA data) and visualisations (for visualising the processed LA data). The business logic of the LA is implemented in the former. This involves loading and translating the data, aggregating the events, and calculating composite index scores for concepts.



(a) Concepts (b) Concept Details

Fig. 5: Learning Analytics Tool

4.6 Evaluation of the Prototype

Early assessment of the prototype by stakeholders resulted in highly positive feedback. The implementation was found to closely match teachers' expectations regarding essential aspects to monitor during the learning process. Moreover, users found the interface intuitive, both in design and navigation.

5 Conclusion, Future Work

In this study, we have presented a systematic approach to the design and development of a customisable Learning Analytics (LA) tool tailored to address the challenges of generating analytics for diverse, constructionist, open learning environments. Through a co-design process involving educators, we elicited data requirements and established a shared conceptual framework for monitoring 21st-century skills using open learning tools. The data requirements derived

[6] https://angular.io/
[7] https://plotly.com/javascript/
[8] https://valor-software.com/ng2-charts/

from the design phase were effectively transformed into functional and technical specifications for the development of the LA dashboard. These specifications guided the implementation process, leading to the creation of a prototype that integrates input from teachers regarding the collection, analysis, and visualisation of data generated from students' engagement with various tools. An early evaluation of the prototype by stakeholders yielded very positive feedback. The implementation was found to be well-aligned with teachers' perceptions of what is valuable to monitor from the learning process. Additionally, the usability of the interface was found to be intuitive in terms of design and ease of navigation. This study contributes to the advancement of learning analytics by offering a structured methodology for designing tools that support the cultivation of 21st-century skills in diverse learning environments. By incorporating input from educators throughout the design and development process, we ensure that the resulting LA tool meets the specific needs and contexts of open learning environments. Moving forward, further refinement and validation of the prototype will be conducted through iterative testing and evaluation with a wider range of stakeholders. Additionally, future research efforts will focus on exploring the scalability and generalisability of the LA tool across different educational contexts and settings.

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