Towards a Learning Analytics Platform for Supporting the Educational Process

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Abstract— **In this paper, we present the vision of an open source learning analytics platform, able to harvest data from different sources, including e-learning platforms and environments, registrar's information systems, alumni systems, etc., so as to provide all stakeholders with the necessary functionality to make decisions on the learning process. The platform's architecture is modular, allowing the introduction of new functionality or connection to new systems to collect needed data. All data can be analyzed and presented though interactive visualizations to find correlations between metrics, to make predictions for students or student groups, to identify best practices for instructors and let them explore 'what-if' scenarios, to offer students personalized recommendations and personalized detailed feedback, etc. Our objective is to inform and empower all stakeholders to improve the learning experience.**

Keywords— E-learning platform, Learning analytics, Personalized recommendation, Semantic Integration, Visualization

I. Introduction

Nowadays, a great portion of the students-instructors activity and interaction is performed through online systems. To perform their tasks students, instructors, managers and policymakers use a multitude of tools, such as Learning Management Systems (LMS), Virtual Learning Environments (VLE), Personal Learning Environments (PLE), but also Registrar Information Systems and Course Evaluation Systems (CES). Much of the daily student life has become digital, with an aim to simplify tasks and improve the learning experience. During their studies, students leave traces of their progress and interactions in a variety of places: an e-learning platform may keep logs of their daily presence, exams taken, wiki posts, podcasts viewed, etc.; a registrar system records the courses taken and their grades; a CES holds the students' opinion towards the courses and their instructors, and so forth.

These traces can be exploited to enable all stakeholders to analyze the learning process and take appropriate action. For example, it is of the essence for a student to be informed that s/he is lacking strength in specific parts of a course and receive personalized recommendations on ways to overcome the difficulties. Similarly, instructors may assess the impact of their teaching methods and identify student groups that need a different teaching approach. A manager may detect weaknesses in the curriculum structure, while a policy maker may view shortcomings in the institution's strategy. However, at present, data that could be processed to extract the essential information is spread across diverse systems, while some useful data are not being recorded at all.

To this end, we envision an open source learning analytics platform, able to harvest data from different sources, including e-learning platforms (such as LMS, VLE, PLE, Massive Open Online Courses-MOOC), registrar's information systems, CES, podcast platforms, alumni systems, etc., in order to offer all stakeholders the necessary information and functionality to make decisions on the learning process. For example, the platform will be able to process data, cluster student groups, perform statistical analyses such as statistical significance tests and correlations, make predictions, offer early identification of groups at risk or of high impact students that can positively influence classmates and to present curriculum evolution along with data indicating the impact of previous choices. From an end-user perspective, functionality will be provided through easy to use interfaces with interactive visualizations, allowing users to control both which information is processed and the way this information is presented. The platform's architecture will be modular, allowing the introduction of new functionality or the connection to new systems to collect useful data. The platform will also be able to connect to instances of the same platform hosted by different learning organizations to exchange data, in a fashion securing anonymity and seeking informed user consent. The platform will encompass an ontology, which will support the processes of (a) translating the data retrieved from various sources into a single unified target schema and (b) driving the process of accessing data stored at the unified schema, in a meaningful and user task-centric fashion.

The rest of this paper is organized as follows: section II presents related work, while section III focuses on the stakeholders of the envisioned platform and their goals, as well as the real-world information systems from which the necessary data are retrieved. Section IV presents the platform architecture and discusses issues related to the platform operation, and finally section V concludes the paper and outlines future work.

II. Related Work

According to [1] "learning analytics is an emerging field in which sophisticated analytic tools are used to improve learning and education." (page 2)… "learning analytics are focused on building systems able to adjust content, levels of support and other personalized services by capturing, reporting, processing and acting on data on an ongoing basis in a way that minimizes the time delay between the capture and use of data. Thus (…), learning analytics seeks to combine historical and current user data to predict what services specific users may find useful now" (page 4). Our approach adopts the definition in [1] and uses the generic term learning analytics to refer to the exploitation of students' data for the improvement of teaching and learning.

Being in its infancy [2], the field of learning analytics still faces a number of problems. Existing learning analytic tools seem to have some usability problems, since teachers find them hard to use [3], while existing learning analytics tools also face privacy problems [4]. In addition, many attempts have focused on static analysis of student data, meaning that the instructors can only see comparisons predefined by systems developers [3]. Our approach attempts to directly target these problems, since it aims at highly usable interfaces that use visualization techniques for the effective interaction with data. In addition, the dynamic character of the learning processes will be reflected in the design of the platform that will allow multiple comparisons of different data, taking into account privacy issues.

The envisaged platform aims to advance the state of the art from past attempts in the field, like exploratory Learning Analytics Toolkit" (eLAT) [3] and E-Learning Web Miner (EIWM) [5], since it is targeting large student data. In addition, there have been works in efficient data mining [6], usable interfaces [7], and attempts to provide learner specific information to the instructors [8]. Our approach will incorporate existing findings and progress towards the development of a platform with a highly usable interface that will provide information about students' personal learning characteristics, allowing multiple comparisons of data and using effective visualization techniques. It aims to cater not for a single user group of the learning process (learners, instructors, managers/policy makers), as current systems do, but for all of them in tandem; the same raw data, processed and presented differently, will be of interest to multiple parties for different reasons. By specifying standards for data interchange between data providers and the learning analytics platform, the envisioned platform will be able to integrate data from the multitude of systems available at the participating institutions and serve as a basis for future expansions. In addition, we will not only focus in one given academic setting but will also allow the cross-cultural, cross-departmental, and cross-subjects comparisons in large scale.

III. Learning Analytics for Supporting the Educational PROCESS: the Real-World Case

Education is a complex process involving numerous stakeholders with diverse interests. These stakeholders include students, instructors, managers and policy makers, with each group having a separate perspective and needing different services. The educational process is supported by a multitude of electronic systems, including LMSs, VLEs, PLEs, registrar systems and so forth. Each system maintains a portion of the information about the education process and therefore is unable on its own to synthesize the "big picture" of the stakeholders' activities and needs, and offer the necessary services. In the following, we will elaborate on the stakeholders and their needs. We will also present in more detail the real-world information systems that can be used as data sources for the envisioned system.

A. Stakeholders and Offered Functionality

The envisioned platform aims to cater for the needs of all involved stakeholder groups, adopting a user-centered approach. In this context, the following stakeholder groups are recognized:

Student: a learner who attends an educational program. The major concerns of a student are to monitor her progress, gaining insight where she is lacking background and/or expertise, get recommendations for elective courses (where available) based on past performance, set alerts or reminders. The envisioned system will provide the student with a set of visualizations and metrics for displaying progress, either individually or in comparison to other students, for providing help in managing learning classes as well as gaining insight where s/he is lacking background. The student will be also able to express her goals, at a varying level of specificity, starting from coarse grain (e.g. professional area) to specific learning objectives (e.g. be able to read and write files programmatically). To formulate recommendations for the student, the system will take into consideration the student's cognitive and learning styles [9], as well as her goals. These styles have been found to have a significant impact on her effectiveness in a particular course [9]. To support this aspect of the learning process, the system encompasses personalization and profiling functionalities. Even if cognitive and learning style information is not directly available from an external source, the system can assess a student's cognitive and learning profile by analyzing behavior and performance data and/or presenting the student with relevant tests (e.g. MBTI test, [10]). If students elect to share their profiles with their instructors, the instructors will have the possibility to offer additional, more focused recommendations. In this respect the envisioned approach for improved learning experience offers guidelines on possible strategies that can help instructors in accommodating for student groups with varying cognitive and learning styles.

Instructor: personnel involved in teaching, including teachers, faculty, teaching assistants, etc. The instructor's main concerns regarding her courses are the improvement of the course syllabus and material as well as the assessments of her students' progress, including the identification of students/student groups at risk [11].

It is common for instructors to perform simple statistics: what percentage of the students failed, what was the average grade, sometimes they even check whether the students' grades follow a normal distribution. With current systems and practices, pattern discovery in the student results is not easy, if at all possible, since only few information dimensions are available (e.g. only student grades). Unifying the wealth of information into a single, consolidated repository, the envisioned system will provide new potential to instructors, such as clustering students into subgroups according to common characteristics (e.g. learning style), and perform statistical functions on the data collected, find correlations and early identify students at risk. The instructor will also be able to view data related to the students' activity and evaluate their ability in exploiting digital tools or collaborating with other students. While the system will be able to offer personalized recommendations, it will include all the necessary provisions for preserving privacy and anonymity of the people to which the data are related. For instance, an instructor will not be able to correlate individual students to learning styles (unless the student has released this information), relate evaluation sheets to submitting students and so forth. By being able to cluster the students into groups under different dimensions (e.g. learning profile) and by encompassing information on how different teaching strategies affect students of various learning profiles [12], instructors can explore "what-if" scenarios, for instance to project whether the adoption of a different teaching style would lead to decreased drop-out rates or better student performance.

The system will also help the instructor assess the success of the course's learning material and activities. For instance, the instructor is not limited in just viewing how many times a podcast has been played, but can also access details like the portions of the podcast (re)played and employ visualizations to identify patterns and discover correlations to clusters of student groups. This can help the instructor to pinpoint the portions of the material that are useful or abstruse and act accordingly.

Instructors often seek information on how other colleagues organize their courses. The platform can collect anonymized macroscopic data from other installations of the same platform (or compatible ones). To facilitate discovery of similar courses, search would be performed not only on title, but also on learning objectives, course and other ECTS (European Credit Transfer and Accumulation System) description fields. The system makes explicit any differences between grading systems, to facilitate comparisons among courses. Instructors may have access to aggregate assessments of the other courses, view overall student performance, see what learning material, online resources and assignments are used. If an instructor finds that a particular search produces interesting results, she may decide to share it as a template ready for other instructors to try at their courses. Instructors can choose if they want to make available data on their courses for use by other installations, and up to what detail.

Finally, by maintaining a history of the collected data, the system can present metrics and visualizations which facilitate the analysis on how different changes in the course (e.g. amount of exams given, teaching hours) have affected students' performance.

Managers and policy makers: managers include personnel involved in management of instructors (for example head of department, deans, etc.), whereas policy makers are people that can set a plan pursued by the institution and its groups (for example, institution's board, local or central government). Users in these stakeholder groups are expected to operate at a broader level, examining not only macroscopic data of individual courses, but the structure and performance of a curriculum as a whole. They may associate data regarding student enrolment in specializations with information from the alumni platform to view their current employment statistics and analyze their employment prospects; examine the curriculum content against recommendations published by scientific bodies (e.g. [13]), or examine if the learning outcomes of the curriculum meet the needs of current and projected market developments (e.g. which skills are needed in the market, which are the market trends and prospects of specific areas in the next years). Being able to collect data from a variety of sources covering the whole spectrum of academic activities, the platform is able to provide a comprehensive view of the current status and opportunities for future development, offering the functionality to view and analyze data for identifying strengths and weaknesses in current curricula.

B. Education-related Information Systems as Data Sources

As stated above, the educational process is nowadays supported by a multitude of electronic systems, including LMSs, VLEs, PLEs, registrar systems and so forth. Each of these systems maintains a *vertical fragment* of the information about the education process, i.e. information related to a specific set of activities. The envisioned system will retrieve data from the individual systems and integrate them into a comprehensive and semantically rich schema, which will synthesize the "big picture" of the educational process and will serve as a basis for providing the necessary information to stakeholders. R2RML (http://www.w3.org/TR/r2rml/) is a candidate tool for implementing this integration. In particular, the following information systems have been identified for contributing data into the unified schema:

Learning environments. These include all types of software systems through which instructors publish learning material that is subsequently disseminated to the students and used by them. Various forms of learning environments are used, such as LMSs, PLEs, VLEs, with varying features; however all types of systems can offer data regarding the description of the course, its learning outcomes, the instructor's material and the type of each material (e.g. document, presentation, exercise, video), the students enrolled in the course and the material that each student accessed. Depending on the system and the material type, more information may be available, such as the learning goals set by the student or the learning process chosen by her (in PLEs), the portion of the video played, the results of self-assessment tests, home assignments and their grades etc. Preferences recorded by students in the systems (e.g. preference towards audible material) could be also of use.

Registrar Information Systems. Registrar information systems provide the "official" information for courses, instructors and students, including the courses available and their descriptions (including teaching hours and ECTS grades), the instructors teaching each course, the enrolled students and their grades. Typically, a registrar information system maintains the whole history of course-to-instructor assignments, syllabi changes and students' performance, hence it is a valuable source of information for inferring how specific parameters –such as the teaching style and the grading method have influenced the students' performance.

Course Evaluation Systems. Course evaluation systems provide the students' view regarding the teaching process of courses. Users rank, among others, the quality of the course content, the instructor's overall teaching performance, assignments and laboratories, textbooks, additional material and so forth. While these data can be used in isolation to evaluate and improve the course, combined with the teacher's and student's profiles, the student's performance and the educational material usage information, they can offer valuable insight on the effect that aspects of the learning process can have on different groups of students, and therefore assist in identifying specific means that can be used or actions that can be taken to further improve the course's effectiveness.

Alumni systems, social and professional networks. These information systems can be used to track the graduates' careers. This information, combined with the traces of each graduate's record within the learning organization as a student can help in identifying how decisions in the learning process (e.g. choices of elective courses, choices of essay or thesis subjects) influence the work prospects in different areas; these results can then be used to assist the students with their choices regarding the learning process, as well as managers and policy makers in improving (or retargeting) the curriculum. Alumni systems, being developed and operated by the learning institutions, have the advantage of higher customizability; on the other hand, professional networks (e.g. LinkedIn) can typically host structured knowledge on the members' career paths, skills and education, making this information directly available and exploitable.

Published curricula and employment agencies. The curricula offered by learning organizations generally have a two-fold mission: (a) to provide sound and comprehensive knowledge on the learning domain(s) covered and (b) to equip the students with suitable knowledge and skills, so as to prepare them for their professional life. The developments on the knowledge to be offered are generally compiled into curriculum structures by scientific bodies or administrations (e.g. [13][14]), while market trends regarding the requested skills can be harvested from various sources, such as employment agencies or even classified advertisements. Managers and policy makers can use these information, so as to better design the curriculum structure, taking into account the curriculum goals.

Learning models and teaching/learning methods. Besides the content of the curriculum, which describes *what* is being taught, the way that this content is communicated and perceived by students (i.e. *the how*) is of high importance. Learning models and teaching/learning methods are continuously surveyed by scientists and practitioners, and both existing practices as well as developments that will emerge should be made available to the platform. While there currently are no repositories maintaining structured information about learning models and teaching/learning methods, this information can be sourced from scientific works, practice/experience reports, as well as recommendations of pedagogical bodies [15], codified in a structured and machine-processable format and made available as a distinct repository to the platform.

IV. SYSTEM ARCHITECTURE

A. Overall Architecture

Figure 1 illustrates the overall architecture of the proposed platform. The architecture comprises of five horizontal and one vertical layer. Each horizontal layer provides platform-specific functionality, with higher-level layers providing higher levels of abstraction and being able to build on top of the functionality provided by lower-level ones; on the other hand, the vertical layer contains architecture building blocks that are cross-cutting, which means they may be applicable to and used by architecture building blocks in one or more of the horizontal layers. The functionality of the layers and their modules are discussed in the following paragraphs.

B. Data Sources and Harmonization Layer

Data sources supply the information needed by the platform (curricula, usage data etc.), however the formats employed may vary significantly. To this end, each data provider will be able to plug in the system by including a wrapper facility, i.e. a piece of software through which the provider (a) describes the data it provides (b) publishes the data handling methods it supports and (c) makes the data handling methods available. Appropriate metadata, for formulating the descriptions of data and data handling methods should be also provided. The

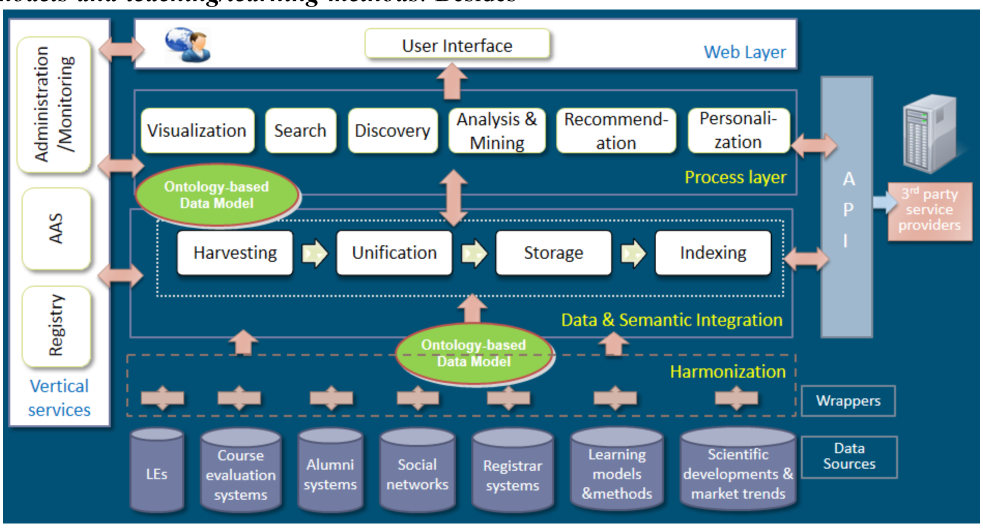

Figure 1. Platform architecture

metadata will include provisions, among others, for security and privacy.

Wrappers are responsible for aligning the diverse schemas of the harvested data to the platform data model, which is ontology-based; effectively thus, data harvested from a source provide the instances/slot values for a subgraph of the ontology-based data schema. This transformation is based on a set of rules, which are part of the wrapper's configuration. After this transformation has been performed, this data is stored within the platform's data repository and integrated into it.

C. *Data and Semantic Integration Layer*

The Data and Semantic Integration Layer includes all the necessary facilities for unifying the information gathered from the data providers and formulating a comprehensive and efficient data store, supporting the functionalities available to the users. To this end, the following operations have been adopted for this layer:

a) Harvesting, i.e. the collection of data published by registered providers, typically performed periodically. All data are tagged with their source and time of retrieval, enabling thus provenance tracking and offering the capability for maintaining historical information about the collected data.

b) Unification, i.e. integration of the data sets retrieved from providers, to form an integrated and coherent database.

c) Storage, which creates a local, persistent copy of the collected data, appropriately transformed to fit the ontology-based platform data model.

d) Indexing, i.e. the creation of structures, such as data cubes, to efficiently support operations on the data, e.g. drilling and clustering.

D. *Ontology-Based Data Model*

The envisioned platform, stores the data in an ontology-based schema. Using an ontology-based schema allows for supporting incorporation of explicitly stated formal semantics, inclusion of constraints for meaning, consistency and integrity and promotes schema understandability by humans. Schema understandability is considered particularly important in the context of the platform, so that humans can navigate across and drill down into information stored in the schema and formulate ad-hoc queries (instructors and policy makers/managers are the two stakeholder groups that are bound to use these functionalities). As noted above, indexing mechanisms built into the data and semantic integration later create specialized structures to ensure high performance when accessing and querying data stored into the ontology-based data model.

E. *Process Layer*

The process layer implements the functionality which is specific to the proposed platform. This functionality includes:

a) *Searching*, allowing users to find data of interest. Through the search mechanisms, users will be able to query the metadata stored in the data layer, expressing thus their queries using semantic criteria. An example query would be "learning efficiency for Pedagogics courses in Europe".

b) *Discovery*, permitting users to browse the platform's ontology-based data model to locate items of interest. All dimensions supported by the metadata will be available to the users to facilitate their navigation to the target information. For instance, a user could employ the "Metrics" dimension to select the "learning efficiency" metric, then use the "Course" dimension to choose "Pedagogics" and finally employ the "Geographic region" dimension to designate her interest in the European continent.

c) *Analysis and Mining*, through which users can analyze the available data and search for interesting patterns therein. For instance, an instructor may analyze her courses' data to identify which learning styles perform better and which need additional support, or seek for patterns regarding the association of her students' performance and their background knowledge. Data mining and dimensionality reduction techniques can be used to drive the analysis and mining processes, while techniques for receiving and handling both explicit and, especially, implicit user feedback (e.g. how long a user spends with a specific learning asset, the interaction pattern with the asset, the possible bookmarks or ratings created during the experience) will be also incorporated. The survey in includes a number of mining methods which can be used.

d) *Recommendation*, providing users with suggestions about their tasks in learning process (e.g. a student may receive recommendations on ways to overcome the difficulties, while instructors may receive recommendations on which is the most suitable material for different groups of students). The recommendation module will cater for providing these recommendations, by matching the situations at hand against the information stored in the data layer, and choosing the similar situations that have led to the best results. Recommender system techniques, such as collaborative filtering, can be employed to this end.

e) *Visualization*, enabling users to view graphical representations of data and concepts, leveraging the comprehensibility, allowing the perception of emergent properties that were not anticipated, facilitating understanding of both large-scale and small-scale features of the data, promoting hypothesis formation (to be later confirmed or rejected through analysis and mining), and even exposing problems with the data or the ways it has been collected. The platform will provide pre-configured (but configurable) dashboards, offering users immediate access to indicators typically used by the user group they belong to.

f) *Personalization*, through which the offered behavior, functionality and content of the platform are tailored to the needs and desires of its users. For instance, the instructor of a specific course will be most targeted to gaining insight on the performance of her students and locating material related to her courses, while the designers of a departmental curriculum have a different set of needs, related e.g. to the up-to-dateness and the coherency of the curriculum, as well as its suitability for the target student population.

The platform's process layer functionality will be made available both through the platform interface layer and through standardized APIs, enabling the offering of this functionality through third party applications.

F. The Web Layer

At the Web layer, the platform will be deployed in a form of a portal, offering its users the ability to sign in the platform and subsequently access all services available at the process layer. Standard portal development techniques, such as realizing distinct functionalities as *portlets* to modularize the implementation process, will be followed to this end.

G. The Vertical Services Layer

The Vertical Services layer encompasses functionalities that cross-cut the horizontal layers, which are:

a) Administration/Monitoring. This functionality allows for inspecting the status of the platform and the resources it manages, as well as taking the necessary actions to allocate resources, federate with other platforms, define data usage policies and so forth. Note that the federation aspect raises important research issues regarding the cross-cultural, cross-departmental, and cross-subjects analysis of collected data, which will be tackled in both the data model and the analysis & mining module.

b) Authentication and Authorization Services (AAS). This functionality supports user signing in the platform and is also used internally by the platform modules to determine whether the user currently signed in is allowed to perform the requested operations and/or access specific data.

c) Registry. The registry module records the resources available to the system, including data providers as well as processing and storage facilities. Processing resources may be used for carrying out the processing-intensive tasks, such as data mining, while storage facilities can be exploited for storing the platform data.

V. Conclusions

In this paper we have presented the vision of an open source learning analytics platform which can be used by all stakeholders involved in the educational process to analyze the current situation and plan their future activities. The platform sources information from existing systems currently being used to support different aspects of the educational process, and integrates them into a comprehensive ontology-based schema; information within this schema can be analyzed and mined, and also used for formulating recommendations to the users; additionally, users can navigate, search and visualize this information, while personalization techniques are used to reduce information overload and facilitate users' work.

The complexity of the educational process and the extent of the features offered by the platform render indispensable the existence of a set of guidelines to all stakeholders, regarding both (a) how the platform should be used to maximize the benefits from its functionality (b) which additional information and/or structural changes should be attached to curricula and courses, so that they can provide the information needed for the analytics to be effective (c) how offered metrics can be exploited (including the highlighting of proper and improper interpretations of available analytics) and (d) how results from the analysis process can be used to improve courses and curricula. The formulation of this set of guidelines, together with the finalization of the data model and the development of the platform services, are the core of our future work.

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