# Using Linked Data in Learning Analytics

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Learning Analytics has a lot to do with data, and the way to make sense of raw data in terms of the learner's experience, behaviour and knowledge. In this article, we argue about the need for a closer relationship between the field of Learning Analytics and the one of Linked Data, which in our view constitutes an ideal data management layer for Learning Analytics. Based on our experience with organising the "Using Linked Data in Learning Analytics" tutorial at the Learning Analytics and Knowledge conference, we discuss the existing trends in the use of linked data and semantic web technologies, in general in education and in Learning Analytics specifically. We find that the emerging connections between the two fields are still, at the time of writing, much less prominent than one would expect considering the complementary nature of the considered technologies and practices. We therefore argue that specific efforts, somehow materialised through the tutorial and the work in the LinkedUp support action, are needed to ensure the realisation of the potential cross-benefits that combining Learning Analytics and Linked Data research could bring.

## 1. Introduction

Learning Analytics is about the processing of data about learners and their environments for the purpose of understanding and optimising learning (see for example Ferguson, 2012). A lot of both the research-oriented and the practical work in this area is dedicated to the methods employed for collecting, analysing, mining or visualising such data in relation to various levels of models of learning, from the basic information models used to structure the data, to the cognitive models that are expected to be reflected in the learners activity patterns found in the data.

Here however, we focus on a different aspect of the Learning Analytics process, which, while not necessarily core to the research in this area, is fundamental and too often overlooked: data management. It is indeed our view that Learning Analytics introduce specific challenges with respect to the management of the data sources used, specifically related to the issues that: 1- Learning Analytics processes can be applied in a wide variety of different contexts and domains, all having their own approaches to data management and to the modelling of information; 2- Learning Analytics might require to combine and connect various data sources from different origins, through trying to gain insights on the connections between very different aspects of the learning experience and the learner's context; and 3- The whole Learning Analytics process requires raw data, information sources and background knowledge at different stages (in input, to enrich core data, to support interpretation, etc.) in a way which might not always be anticipated a priori. These specific issues with data management for Learning Analytics lead to requirements that can only be addressed by state-of-the-art data management approaches: the ability to flexibly bring and interconnect all sorts of heterogeneous data sources into the process of analytics.

This naturally brings us to consider Linked Data (Heath and Bizer, 2011) and Semantic Web technologies (Domingue et al., 2011) as a candidate data management layer for Learning Analytics. Indeed, the basic idea of Linked Data is to use the architecture of the Web to share, distribute and interconnect data from various origins into a common, online environment. It is based on the basic principle that raw data objects are identified and accessible, similarly to webpages, through Web addresses (URIs), that deliver the information in a structured, processable and linkable way. Since one of the major challenges in this approach is the requirement to handle the wide heterogeneity of the data being presented, Semantic Web technologies, especially related to ontology representation and engineering, aim at providing web-enabled, reusable and connected common vocabularies making such distributed, linked data exploitable across origins and domains (Suárez-Figueroa et al., 2012).

Linked Data principles and technologies have been very successful in the last few years, especially as a base approach for the publication of open data on the Web. They have been adopted by government agencies in several countries (prominently, in the UK and the US) for transparency and public information purposes, by cultural heritage institutions such as libraries and museum to provide more processable and integrated information about their collections (see the Europeana project for example), by companies in publishing (for example at Nature, or Elsevier), broadcasting (for example at the BBC[1]), or retail (for example at BestBuy[2]). As we will see later in this paper, there is a growing trend in the use of Linked Data specifically for education, with especially universities making their public information (academic programmes, research outputs, facilities, etc.) available as linked data on the web (see LinkedUniversities.org).

[1] See for example http://www.bbc.co.uk/blogs/internet/posts/Linked-Data-Connecting-together-the-BBCs-Online-Content

[2] See for example https://bbyopen.com/announcing-bbyopen-metis-alpha-best-buy-product-catalog-semantic-endpoints

Here, we summarise the current uses of Linked Data in Learning Analytics, based on our experience with organising the "Using Linked Data in Learning Analytics" tutorial at the LAK 2013 conference. While the major part of the tutorial was dedicated to the description of basic techniques for integrating linked data in a Learning Analytics process and in analytics tools in general, another component giving us insight into the potential for cross-fertilisation between the two fields is the LAK Data Challenge : A competition for the development of analytics applications based on exposing, through linked data principles and technologies, the literature on Learning Analytics and educational data mining. We therefore specifically look into the variety of entries to the challenge and how they demonstrate the way in which Learning Analytics can benefit from using Linked Data.

## 2. What is Linked Data?

The foundation of the Web is that it is a network of documents connected by hyperlinks. Each document is identified by a Web address, a URI[3], and might represent a document which content is encoded using a standard, universally readable format (most commonly HTML[4]). Following this, the simplest way to describe Linked Data is that it is about using these same principles of the Web architecture not only for documents, but also for data. The foundation of Linked Data is therefore that data objects on the Web are identified, similarly to documents, by URIs. The representation of the data—i.e. the information associated with a data object— is then represented by Web links, which can themselves be characterised by URIs. This makes it possible to represent information in such a way that it is materialised as a graph, where nodes are URIs or literal data values (strings, numbers) and the edges are links between them.

For example, a university like The Open University publishes information about the courses it offers through its website, as well as using linked data. It achieves that through assigning to every course a dedicated URI that acts both as an identifier for the course on the Web, and as a way to address information about this course. For example, http://data.open.ac.uk/course/aa100 is the URI for the course with code AA100, which is an undergraduate (level 1) course in Arts and Humanities, entitled "The arts past and present". Through the links between this URI

[3] Uniform Resource Identifier http://www.w3.org/Addressing/

[4] Hypertext Markup Language http://www.w3.org/html/

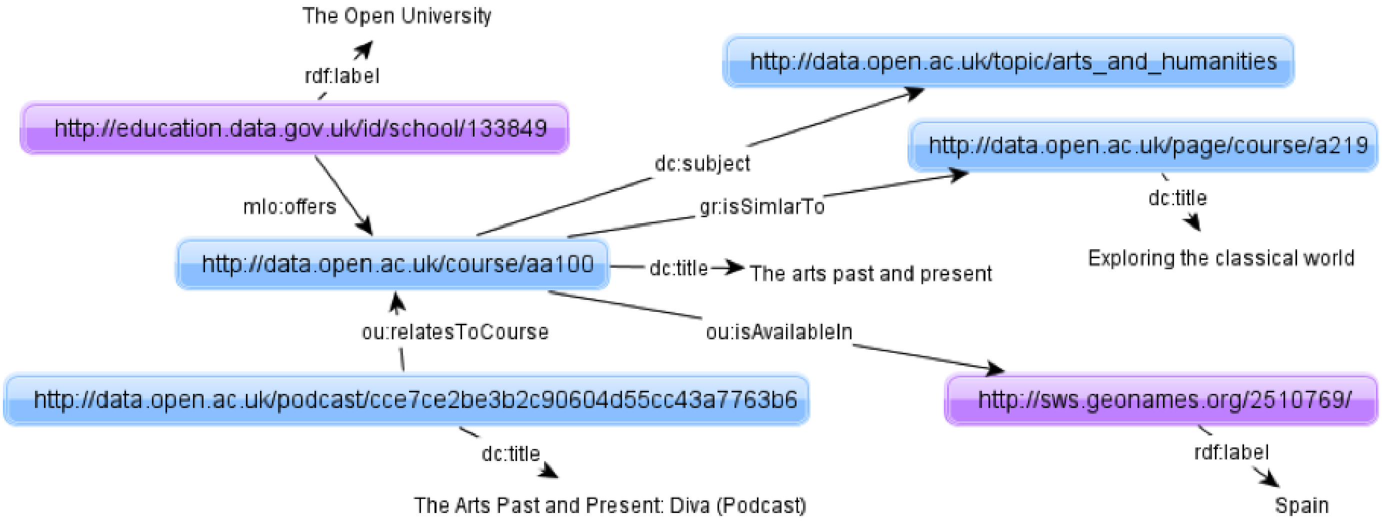


Figure 1: Extract from the linked data graph around the "AA100 – The arts past and present" course at the Open University.

and others, information about this course is being represented regarding the topics and description of the course, where it is available, how it is assessed, what course material and open educational resources relate to it, etc. (see Figure 1). While most of the other data objects it relates to are also identified by URIs within the domain of the Open University, it is important to remark here that it links to other data sources, such as the UK government's information about the Open University or information provided by the Geonames platform about the countries in which the course is available. This demonstrates how, from these basic principles, information originating from widely different systems and sources can be seamlessly integrated.

Following the base principles described above, the most basic technology employed to implement linked data is a web-enabled, graph-based data representation language: **RDF** (Resource Description Framework). RDF is in principle related to XML, but dedicated to the representation of graphs where nodes are URIs or literal values, and edges are links labelled by URIs. It has different syntaxes, including an XML-based one, but also others based on listing the triples *[subject, predicate, objects]* forming the links in the data[5].

Another important component of the technological stack for linked data is the one of **vocabularies**. Indeed, an important aspect of linked data (and, further, of the semantic web) is that data should be shareable and reusable in a common way across sources and systems. To address that, languages such as RDF-Schema and OWL (the Web Ontology Language) allow one to define the types of objects that can be encountered in the data (e.g. Course, Person, Country, etc.), as well as the types of relationships that connect these types of objects (e.g. location, title, employer, author, etc.) Without going into the details (which are out of the scope of this article), these languages are based on database schema representation and knowledge representation formalisms, adapted to the Web and the principles of linked data (i.e. so that every type or relation has a URI and a Web addressable definition).

Finally, another important element of linked data is the way in which, still relying uniquely on the basic mechanisms of the Web, the data can be consumed. As we already mentioned, URIs on linked data can be requested to obtain RDF (most often in its XML syntax). When more flexibility is required, many of the existing linked data sources offer data endpoint using the standard querying language and protocol for RDF/Linked Data: SPARQL. Briefly, SPARQL is both a query language made explicitly to fit the graph data model of RDF, and a Web protocol dictating the way in which a SPARQL endpoint should be accessed and queried on the Web. For example, the query:

[5] See http://www.w3.org/TeamSubmission/n3/, http://www.w3.org/TR/turtle/

```
select distinct ?course ?title where {

?course a <http://purl.org/vocab/aiiso/
schema#Module>.

?course <http://data.open.ac.uk/saou/
ontology#isAvailableIn>
<http://sws.geonames.org/2328926/>.

?course <http://purl.org/dc/terms/subject>
<http://data.open.ac.uk/topic/computing_
and_ict>.

?course <http://purl.org/dc/terms/title>

?title

}
```

returns the courses (URIs and titles) in computing and ICT offered by the Open University and that are available in Nigeria, when executed on the Open University's SPARQL endpoint[6]. Accessing such a SPARQL endpoint does not require any specific API or library, but is achieved using standard HTTP requests. The query above can therefore also be shared via a standard Web link [7].

## 3. The state of Linked Data in education

There is a growing base of open educational content being made available online, both in education-specific resource repositories and in general information sources of relevance to learning and teaching (see for example Hyln, 2006). Having such content accessible and discoverable on the web has a significant potential impact on the way education is delivered and received. Information consumed by educational environments can take many different forms, beyond the base material for teaching and learning (including for example repositories of research articles and descriptions of educational facilities), and the open exposure of such data following the principles of open, linked data is expected to make educational information easier to address, aggregate and reuse for various purposes.

Accordingly, linked data principles are increasingly being adopted by educational institutions in different contexts. Indeed, institutions and initiatives have started using these approaches to expose open data of educational relevance. These include universities, schools and research centres (see LinkedUniversities.org), government agencies (see for example education.data.gov.uk), and projects around specific domains (see for example mEducator). Usage of such data sources is slowly starting to emerge in collective resource gathering and intelligence (Heath et al., 2012), recommendation (d'Aquin et al., 2012) and other areas related to education (d'Aquin, 2012).

In (d'Aquin et al., 2013), we described how, as part of the LinkedUp Catalogue of Datasets for Education, we collected and analysed datasets that explicitly reference education and are exposed as linked data. We obtained 146 datasets (RDF graphs) from 22 different SPARQL endpoints. Some datasets originate from universities (e.g. data.open.ac.uk, data.southampton.ac.uk, data.aalto.fi); others from publication repositories (e.g. data.nature.com, dblp.l3s.de), government agencies and standardisation bodies (e.g. education.data.gov.uk), or as the output of specific projects (e.g. meducator.open.ac.uk, data.organic-edunet.eu). All together, the datasets use 588 different types and 719 relations. [8]

While the numbers above do not, by themselves, give us much insight into the current state and growth of linked data in education, they show that, even at this early stage, initiatives are being formed that try to individually exploit the benefits of linked data to expose information of educational relevance. More importantly, as discussed in details in (d'Aquin et al., 2013) and shown through the graphs of Figure 2, each of these initiatives constitutes a contribution to a growing network of data on the Web, which can be used for educational applications, and especially Learning Analytics.

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[6] http://data.open.ac.uk/query

[7] http://data.open.ac.uk/query?query=select%20distinct%20%3Fcourse%20%3Ftitle%20where%20%7B%0A%20%20%20%20%3Fcourse%20a%20<http%3A//purl.org/vocab/aiiso/schema%23Module>.%0A%20%20%20%20%3Fcourse%20<http%3A//data.open.ac.uk/saou/ontology%23isAvailableIn>%20<http%3A//sws.geonames.org/2328926/>.%0A%20%20%20%20%3Fcourse%20<http%3A//purl.org/dc/terms/subject>%20<http%3A//data.open.ac.uk/topic/computing_and_ict>.%0A%20%20%20%20%3Fcourse%20<http%3A//purl.org/dc/terms/title>%20%3Ftitle%0A%7D

[8] The list of datasets analysed and their statistics are available from http://data.linkededucation.org/linkedup/catalog/analysis/1.0/

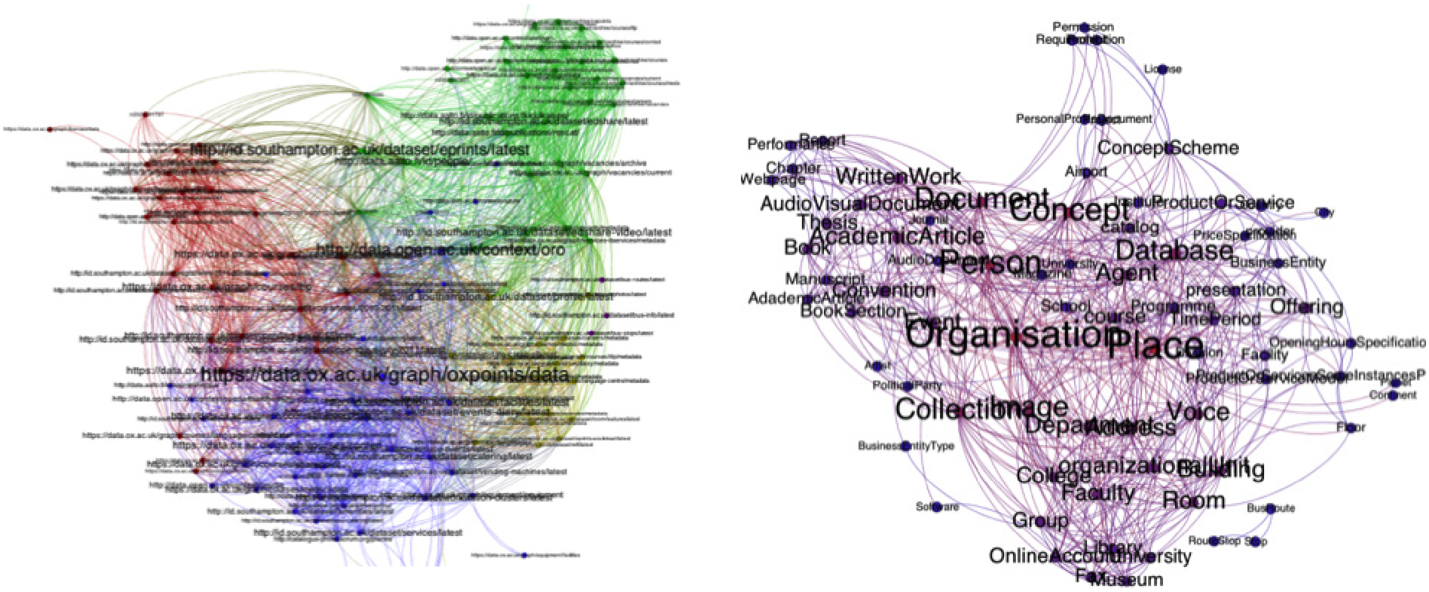


Figure 2: Network formed by the 146 analysed datasets based on their sharing of common (aligned) types of objects in the data, and network of (aligned) types based on their co-occurrence in the education-related datasets.

## 4. Use of Linked Data in basic analytic tools

One of the key objectives of the "Using Linked Data in Learning Analytics" tutorial was, beyond providing participants with a basic overview of linked data and of the technologies to manipulate linked data as described above, to show how linked data could be used to create analytics, as a source of information. This represents the most elementary use of linked data in Learning Analytics: as an input to a data processing and analysis workflow. The following sections will give more details about the way linked data can be employed beyond this simple use case.

The main point to emphasise here however is how linked data technologies are meant to be used primarily for the publication of data in such a way that these data can be easily processed and reused by others, for a variety of purposes. A number of tools have therefore already included basic linked data import/export function, making it possible to very easily (in a few minutes) create simple data mash-ups, to visualise or explore data available from various data sources. For example, through a dedicated extension, SPARQL queries can be executed in R, making it possible to statistically process available sources of information. The pie chart shown in Figure 3 was for instance created based on a small number of simple commands in R, relying on the SPARQL endpoint of the Open University. Another tool that includes the possibility to query linked data endpoints through SPARQL is Gephi, which is commonly used for network analysis. Based on this feature, and relying on linked data-enabled repositories of research publications such as the ones available from various universities (e.g. at data.southampton.ac.uk), it becomes easily achievable to create appealing and insightful visualisations of the networks formed by co-authorship of research publications in different institutions.

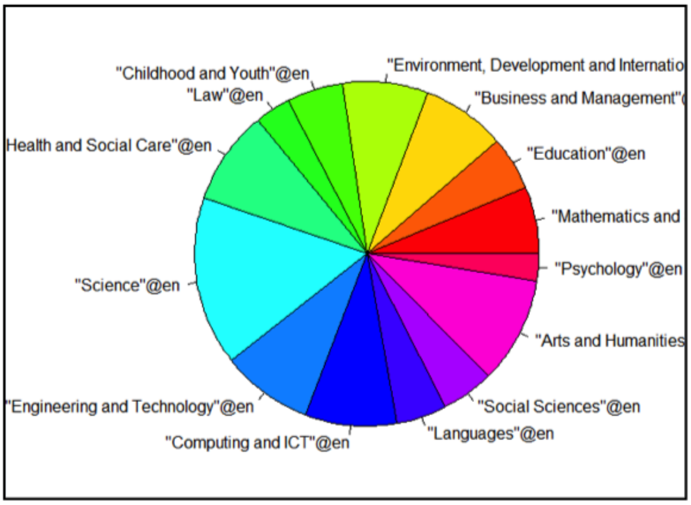


Figure 3: Pie chart showing the distribution of the courses (in number of modules) in the top level topics at The Open University, created in a few lines with R.

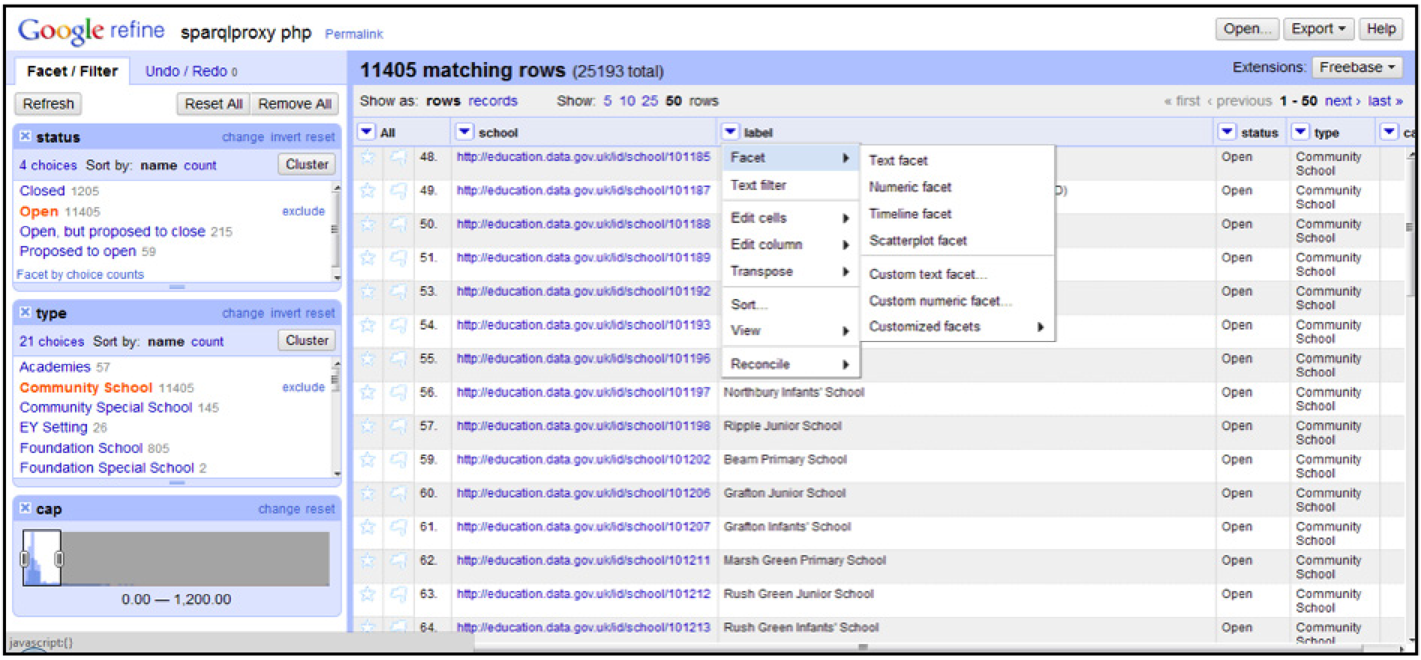


Figure 4: Facet-based exploration of data about UK schools and educational institutions in OpenRefine. The data was obtained through a SPARQL query to education.data.gov.uk.

Taking a step back from dedicated tools, an important aspect of linked data technologies is that they are made to be flexible, especially with respect to the format and representation of the data (graph data models being the most generic data representation paradigms). Many of the SPARQL endpoints available nowadays can provide results not only in the XML or RDF formats, but also in forms that can be used by many commonly available tools. These include JSON and tabular formats such as CSV (Comma Separated Value). If not directly available from the endpoint, such formats can also be obtained from simple services such as SPARQL proxy, themselves relying purely on Web protocols and on the flexibility of the linked data standards. On this basis, it therefore becomes a relatively simple task to import data from linked data sources into common tools such as Microsoft excel, or as shown in Figure 4, into OpenRefine for exploration, visualisation or further processing.

## 5. Linked Data in the LAK Data Challenge

While the previous sections introduce some of the simple techniques that can be employed to use linked data in a Learning Analytics process, the purpose of the LAK Data Challenge (as part of the "Using Linked Data in Learning Analytics" tutorial) was to demonstrate how the availability of data on the Web can lead to innovative uses in analytics.

As described on (Taibi and Dietze, 2013) the LAK Dataset was created and published as linked data to include information about the current literature in Learning Analytics and educational data mining. It contains in a structured form the metadata and full-text of research papers published in two editions of the Learning Analytics and Knowledge conference (66 papers) and in five editions of the International Conference on Educational Data Mining (239 papers), as well as 16 articles published in the Journal of Educational Data Mining and 10 articles from a special issue of the journal of Educational Technology and Society on Learning and Knowledge Analytics.

The basic idea of the Challenge was to request entries that would demonstrate innovative ways to explore, analyse and gain insight from these data. Eight entries were selected to be presented at the tutorial, which are described briefly below, and in more details in the respective papers from the LAK Data Challenge proceedings.

1. A Dynamic Topic Model of Learning Analytics Research (Demtl et al., 2013): This entry proposes visual analytics of the topic dynamics in the Learning Analytics and educational data mining literature. The dataset is processed using probabilistic, dynamic topic mining algorithms, and visualised using a web-based browsing tool called D-VITA.

2. Socio-semantic Networks of Research Publications in the Learning Analytics Community (Fazeli et al., 2013): This entry proposes network visualisations and analysis with the aim to support the researchers and practitioners in the Learning Analytics community in finding authors and papers that are relevant for their own interests.
3. Linked Data based applications for Learning Analytics Research (Maturana et al., 2013): This entry proposes end-user applications based in linked data (as implemented in the GNOSS platform ) to support the exploration of the Learning Analytics and Educational Data Mining literature, in relation to other resources available (through linked data) on the platform.
4. Paperista: Visual Exploration of Semantically Annotated Research Papers (Milikic et al., 2013): This entry presents a visualization and exploration tool, called Paperista, which presents the topics found in the Learning Analytics and Educational Data Mining literature in multiple views, thus allowing users to observe and interact with topics and understand their evolution and relationships over time.
5. Analysis of the Community of Learning Analytics (Nawaz et al., 2013): This entry presents trends in the Learning Analytics community in terms of authors, their affiliation and geographical location. It tries to identify the most influential authors, institutes, and countries, as well as collaborations among authors, institutes, and countries.
6. Cite4Me: Semantic Retrieval and Analysis of Scientific Publications (Pereira Nunes et al., 2013) This entry presents the Cite4Me Web application, which focuses on providing innovative search, visualization, retrieval and recommendation of scientific publications from the LAK dataset and related interlinked resources.
7. Visualizing the LAK/EDM Literature Using Combined Concept and Rhetorical Sentence Extraction (Taibi et al, 2013): This entry aims to demonstrate the use of natural language processing technology in analysing the papers from the LAK Dataset thematically, using Edge Betweenness Clustering combined with sentence extraction using the Xerox Incremental Parser's rhetorical analysis.
8. Ontology Learning to Analyze Research Trends in Learning Analytics Publications (Zouaq et al., 2013): This entry shows how ontology learning tools can be used to reveal the central research topics that are tackled in the published literature on Learning Analytics and educational data mining, as well as the relationships between these research topics.

Interestingly, amongst the three winning entries (3,6 and 8), the two first were the ones that most strongly exploited the principles of linked data, by connecting to other sources of information. Indeed, they demonstrate how analytics can be produced that not only exploit the core data given in input, but are also enriched with background information from other, linked datasets. However, beyond the merits of individual entries, it is really in the variety of techniques and purposes demonstrated in the different submissions that the interest of the LAK Data Challenge lies. Indeed, it shows that the approach employed by linked data technologies to propose data in a flexible, easily reusable way can make one rather simple dataset to generate many different views and insights into the practices and interests of a given community.

## 6. Linked Data in Learning Analytics research

Generally, Learning Analytics is still an emergent field, and is evolving into a fundamentally multi-disciplinary area, marrying computing techniques, pedagogy theories, learning design and cognitive understanding of the learning process. While closer to a mature research area, with especially many practical applications, linked data (and more generally the Semantic Web) is also not yet considered a mainstream technological field. Therefore, while the connection between the two research areas appears quite natural (as illustrated for example by the mention of "Semantic Web and Linked Data" in the topics of the Learning Analytics and Knowledge conference's call for papers), we can only observe preliminary and anecdotal initiatives truly bringing them together. Indeed, in each of the three editions of the Learning Analytics and Knowledge conference, very few papers use keywords such as semantics, semantic web, linked data or ontologies.

However, besides the "Using Linked Data in Learning Analytics" tutorial, a workshop co-located with the LAK 2012 conference also had for objective to explore the connections between the two fields, with mostly researchers in 'technology-enhanced learning' discussing and demonstrating the use of linked data tools and techniques in their research. One critical issue here however is the ability for linked data and semantic web specialists to explain and demonstrate both the benefits and also the practices of the technology to a community (Learning Analytics) which is making a conscious effort not to focus on technology-related issues. Papers such as (d'Aquin and Jay, 2013) illustrate this, showing how linked data sources can be brought into the Learning Analytics process, by contributing background information to the interpretation of patterns discovered in core educational data. It shows an application to student enrolment data and sequence mining where the availability of linked data from the considered university makes it possible to obtain such background information on various aspects of the courses, therefore providing as many views on the discovered patterns. For such approaches to become more employed however would require both for educational linked data to become more commonly available, in scales much larger than what is described in Section 3, but also for the Learning Analytics community to gain a greater awareness of the technological approaches, techniques and tools at their disposal.

## 7. Conclusion

As discussed at the beginning of this article, we believe that there is a strong connection, and a strong potential for cross-fertilisation, between the fields of Learning Analytics and Linked Data. Linked Data has been maturing into a standard, commonly employed set of technologies in situation where publishing data openly online in a way that naturally integrates with other sources of information is of key importance. While many successful examples of applications of these technologies have emerged recently in different areas, key issues remain to be addressed by research on semantic web technologies that require more robust and user oriented scenarios as testbeds. Learning Analytics on the other hand is at a much more early stage in its development and is especially concerned right now with the connection between the technological aspects and the aspects of the practice and theory of education. In the further development of the field, i.e. as Learning Analytics becomes better understood and much more mainstream, the most obvious relationship with linked data is that Learning Analytics processes can rely on semantic web technologies as a robust and adequate underlying technological layer, and therefore focus on the higher level considerations of analysis, modelling and interpretation. As shown through the examples in the tutorial and this article, this is very much achievable today, with many tools and systems supporting the management and manipulation of data according to the linked data standards. The main obstacles to this happening more widely and commonly than it is now are that, first, data should be available that are relevant to Learning Analytics scenario and that can be exploited through linked data principles, and second, that Learning Analytics practitioners, who may not have a strong focus on technology, need to gain sufficient awareness and proficiency in these technologies to create and manipulate such data. Many initiatives have emerged recently and are forming into a trend in relation to the exposure as linked data of information about education and learning. The LinkedUp support action in particular is building a linked data-based catalogue of data endpoints of relevance to education (as described earlier in this paper). Stronger connections between the two fields, facilitated by events such as the "Using Linked Data in Learning Analytics" tutorial are needed to tackle the second issue.

Besides the straightforward connection that Learning Analytics can rely on Linked Data as a technological layer, there is a possibly more interesting scenario in which Learning Analytics becomes a driver for research in semantic web and linked data technologies. Indeed, Learning Analytics is a naturally challenging application area for such technologies. It relies on many heterogeneous sources of information that need to be made available in an integrated and accurate way to practitioners in education for them to gain understanding of the information possibly hidden in the data, while not being themselves experts in data technologies. Heterogeneity, one of the key issues for linked data, here appears at different levels: data is available in different formats, modelled differently, with different granularities and scale (both in space and time), etc. The aspect of usability is also an important issue in linked data technologies, and beyond simple usability, the ability to extract meaning out of raw data is an essential component of semantic web research. In other words, there is an opportunity, currently barely emerging, for Learning Analytics to become such a challenging application domain that it drives innovation and the development of the underlying technology.

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