LEARNING ANALYTICS APPLIED TO CURRICULUM ANALYSIS

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LEARNING ANALYTICS APPLIED TO CURRICULUM ANALYSIS

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Abstract

Learning analytics deals with the development of methods that harness educational data sets to support the learning process. One of the major subtasks of learning analytics is to determine the efficacy of a curriculum. In this paper contribution, the authors propose a generic curriculum analytics framework that can act as a useful guide for understanding the key dimensions that have to be considered when applying analytics in curriculum analysis and evaluation. The paper then describes a case study where the curriculum analytics framework has been applied to understand the gaps and strengths of an existing IS curriculum.

Keywords: Curriculum Analysis, Learning Analytics, Curriculum Design, Data Models, Text Analytics, Frameworks

I. INTRODUCTION

Curriculum analysis unpacks the three education components namely the intended outcomes, content, and the learning activities with a purpose to evaluate how the individual components fit together in terms of consistency and alignment. It allows educators to analyze the strengths and weaknesses of the curricula in terms of all the three components. Furthermore, the analysis aims to justify the curriculum choices and assumptions, and it can be performed at the program level or at a specific course level. In order to better understand the curriculum in greater details, analysis can be further classified into three categories; impact analysis, design analysis and policy analysis [Janson & Reddy, 2013].

The main objective of curriculum analysis is to improve the teaching and learning experience. In order to achieve these goals, several tasks are identified under the umbrella of curriculum analysis; assess alignment between program level outcomes and course level outcomes, determine whether the outcomes have been achieved, identify the gaps between the outcomes and assessments, identify strengths which can be further built upon, identify blind spots, study the impact on job opportunities, verify alignment with industry skills requirements, demonstrate the worth of the curriculum to different stakeholders [Lena & Minna, 2009], and lot of similar tasks which fall under the same umbrella of curriculum analytics. These tasks share not only similar objectives but also similar datasets and stakeholders. Therefore, we need a common framework that defines different components applicable across all tasks related to curriculum analytics. Traditionally, curriculum analysis has been mostly a manual process which is tedious and painstaking work. However, the emergence of analytics techniques that leverages vast amounts of data sets to gain insights from the data which is both structured and unstructured has opened new possibilities for analysing the curriculum. This new capability, analytics technology, plays a major role to automate many stages and tasks of the curriculum analysis process and therefore emerges as another integral component of the framework.

In this paper, we propose a generic curriculum analytics framework based on four dimensions; stakeholders, objectives, data, and techniques. The framework intends to be a guide as much as a descriptor of the problem zones. It provides a standard starting point for the community of stakeholders to consider the soft (competencies or objectives) and hard (data or techniques) components related to the analytics (Greller & Drachsler (2012). In the second part of the paper,
we evaluate this framework on one of the curriculum analytics design analysis tasks, “analysing curriculum using competencies”. The case study aims at curriculum design analysis using course competencies, where analytics has been applied in understanding the gaps and strengths of an existing undergraduate core curriculum; Bachelor of Science (Information Systems Management) degree program BSc (ISM), offered by the School of Information Systems (SIS).

The rest of the paper is organized as follows. In Section II, we discuss some related work. We define the curriculum analytics framework in Section III. In Section IV, we present a case study that leverage analytics framework and we conclude in Section V.

II. RELATED WORK

Curriculum and Curriculum Analysis
The Webster Dictionary defines curriculum as the courses offered by an educational institution or; a set of courses constituting an area of specialization. The term applies to studies required for graduation or to all of the courses offered in a school. A number of education researchers have also attempted to define their own versions of curriculum. For example, Posner describes the common concepts around curriculum to include [Posner, 2004]:

- Scope and sequence, which is a document that lists a series of intended learning outcomes, with the role of guiding both the instructional and evaluation decisions
- Syllabus, or plan for an entire course, with elements of both the ends and means of the course
- Content outline, which is sufficient only if the sole purpose of education is to transmit information, without having to consider objectives
- Standards, which describe what the student is able to do, and processes aimed at achieving the learning outcomes
- Textbook, or a guide to both the ends and means of education
- Course of study, with the concept of a journey through the educational program
- Planned experience, actually comprising all experiences planned by the school

[Hoover, 2010] prescribes that a curriculum has three key components- the intended outcomes, what is taught, and the manner of implementation. At the program level, the intended outcomes map to program learning outcomes, what is taught maps to the program structure comprising courses and other learning experiences such as internship, and manner of implementation maps to the various learning activities and assessments that the students experience during the program. At the course level, the intended outcomes map to the course level learning outcomes, what is taught maps to the course structure with detailed concepts, theory and hands-on-practice, and manner of implementation maps to the learning activities and assessments the students experience within a specific course.

Curriculum analysis unpacks these components with a purpose to evaluate how the individual components fit together in terms of consistency and alignment [Janson & Reddy, 2013]. The analysis also aims to justify the curriculum choices and assumptions. There are a number of benefits in doing the curriculum analysis that aim to improve the curriculum namely, assess alignment between program level outcomes and course level outcomes, determine whether the outcomes have been achieved, identify the gaps between the outcomes and assessments, identify strengths which can be further built upon, identify blind spots, study the impact on job opportunities, verify alignment with industry skills requirements and demonstrate the worth of the curriculum to different stakeholders. [Janson & Reddy, 2013] propose three types of curriculum analysis; impact analysis, design analysis and policy analysis.
Impact analysis aims to study the effects of the curriculum in terms of the external impact. The key question that the analysis attempts to answer is “What difference is the curriculum making?” To answer this question, one requires a clear understanding of the program outcomes, and expected results. For example, the impact analysis aims to understand if the curriculum is relevant, to identify parts of the curriculum that need to be strengthened, and to identify parts that need to be removed.

Design Analysis aims to study the curriculum in terms of standards and design principles. For example, a curriculum could be analysed in terms of the learning principles defined in the Blooms taxonomy or curriculum design models such as Tylerian model or even post-modern curriculum models [Koo Hok-chun, 2002].

Policy analysis aims to study the relevance or relationship of a curriculum to a broader set of social or educational policies. For example, if the government education ministry adopts proposals for competency-based curriculum in information systems, a particular school may want to assess its curriculum in terms of the new criteria with a purpose to get its curriculum accredited by the government body.

Analytics and Application in Learning and Education

“Analytics is the discipline that applies logic and mathematics to data to provide insights for making better decisions” [Kart, et al., 2013]. It includes methods such as data mining, text mining, linguistics, statistics and machine learning. As a first step, the target data is cleaned and processed. In the second step, data is modelled and mined using principled algorithms. Finally, analytics is applied to gain valuable insights from the results. [Kart, et al., 2013] classify four different types of analytics namely descriptive, diagnostic, predictive and prescriptive. Descriptive analytics is directed at answering the question “What happened?” by querying historical data. The results of the queries provide insights and are used by decision makers, who apply their judgment and experience to make decisions. Diagnostic analytics attempts to answer the question “Why did it happen”. In order to answer this question, one has to further dive deep into the results delivered by descriptive analytics. Predictive analytics uses the historical data in combination with algorithms and occasionally external knowledge to determine the probable future outcome of an entity or new data point behaviour, and thus giving room for recommendations. Prescriptive analytics not only anticipates what will happen and when it will happen, but also why it will happen and how to make it happen. Analytics has been applied in learning and education under the umbrella terms of “learning analytics” and “educational data mining”.

Learning analytics (LA) is concerned with leveraging the vast amounts of data sets available in the education setting in order to better understand student engagement, progression and achievement [Johnson et al., 2011] and [Lockyer & Dawson, 2011]. Such data can come from various sources, for example, student information systems provide data pertaining to student academic background, demographic information as well as their academic plans, academic feedback and academic results. Learning Management Systems (LMS) provide data pertaining to student learning activities such as the resources accessed, interactions with peers and teachers, and their online learning activities. Using this wealth of data, learning analytics provides opportunities to analyse and gain valuable insights in order to actively intervene in the academic process to assess academic progress, predict future performance, and spot potential issues. Another closely related field of educational data mining (EDM) focuses on the application of data mining techniques such as clustering, classification, and associate rule mining to support the learning process [Romero & Ventura, 2010]. Though these two fields are closely related, LA goes beyond data mining techniques and includes other methods, such as statistical and visualization tools or social network analysis (SNA) [Chatti et al., 2012].

III. CURRICULM ANALYTICS FRAMEWORK
On one hand, learning analytics has been widely used in admissions, fund-raising efforts on several campuses, and monitoring student performance in online learning and identifying at-risk students. On the other hand, very few attempts have been made to apply it to assess curricula [The New Media Consortium, 2011]. Nevertheless, a number of education researchers have attempted to study and analyse curriculum using traditional methodologies. For example, evaluating and documenting the alignment between curriculum standards and assessments, using methods such as sequential development, expert review, and document analyses [Webb, 1997]. [La Marca et al., 2000], [Porter, 2002] [Resnick et. al., 2003]. However, these traditional methods are majorly manual and do not fully leverage the automated analytics techniques that are presently available. More recently, educationists have started exploring how analytics can be applied to curriculum analysis. For example, [Monroy et al., 2014] presented a strategy to incorporate learning analytics into the design and evaluation of online science curriculum by addressing how the curriculum is used by teachers and students, and how the data collected can be used to evaluate the effectiveness of the curriculum. [Lockyer & Dawson, 2011] emphasized the need to bring together learning analytics and learning design in order to effectively use data from learning management systems and online platforms to help facilitate post-delivery reviews and reflections for supporting curriculum and course redesign. [Souza, 2013] proposed an embedded assessment approach to curriculum mapping and data collection on student learning outcomes achievement. This research helps to understand the alignment between program outcomes, course level outcomes, and assessments within a specific course. Longitudinal reports across the different courses help to map the frequency of questions related to each course and program level outcomes [Souza, 2013]. The output helps to analyse the percentage of questions asked at the knowledge, application, and synthesis levels of the Bloom’s Taxonomy. Based on the data analysis changes are recommended to assessments within a course.

In spite of the above projects, several research questions pertaining to how learning analytics can be applied to the impact, design and policy analysis of the curriculum largely remain unclear and unanswered. Therefore, to help better understand how analytics can be applied to curriculum analysis, we present a curriculum analytics framework (see Figure 1). This framework is adapted from the generic framework for learning analytics proposed by [Chatti et. al., 2012].

![Figure 1: Curriculum Analytics Framework](image)

As shown in Figure 1, the four dimensions of the proposed curriculum analytics framework are:
- **Stakeholders:** “The audience targeted by the analysis.” Stakeholders are either the beneficiaries of the process or the suppliers of the data. The beneficiaries are meant to act upon the outcome of the analysis. In certain cases both the groups can be same.

- **Objectives:** “The purpose of the analysis.” The main objective of curriculum analytics is to unveil the hidden information from the data and aid the stakeholders in the decision making process. The newly discovered information acts as a supporting evidence to such decision making.

- **Data:** “The data that is gathered, and managed for conducting the analysis.” Analytics takes advantage of available educational datasets from different learning management systems and other sources of academia. Linking such available datasets would facilitate the analysis, recommendation and prediction tasks related to curriculum analytics.

- **Techniques:** “The techniques that are used in conducting the analysis.” A variety of technologies can be applied in the development of analytic applications that support the objectives of the curriculum analytics stakeholders. Through these technologies one can generate tailored information to the stakeholders.

Curriculum analytical framework can come in handy in at least three distinct situations, namely impact analysis, design analysis and policy analysis as discussed below.

Recall that **impact analysis** aims to study the external effects of curriculum in terms of the “difference” it makes to the students when they complete a specific course or the entire program. The key stakeholders are students, prospective employers, alumni, course manager, and curriculum managers. The objectives include study of impact analysis tasks such as alignment of program outcomes with industry skills frameworks, alignment between skills requirements of recently passed alumni and the program outcomes, and alignment between instructor assessment and student self-assessment of skills. Such analysis will help to identify specific competencies or program outcomes that the students lack, and therefore lead to amend a course or group of courses (e.g. foundation courses). The data for impact analysis includes program outcomes, course competencies, and survey results of alumni and employers. The techniques include data models, descriptive statistics, text mining, and visual analytics.

Recall that **design analysis** is internally focused study that aims to analyse the curriculum mainly from the perspective of alignment with learning theory models, and alignment of learning activities, outcomes and assessments. The key stakeholders are internal and include course managers, curriculum managers, instructors, and students. The objectives include the study of design analysis tasks such as alignment between Blooms Taxonomy of knowledge and the curriculum, study of the progression of competencies across the different years, alignment between program outcomes and course specific competencies, alignment between course specific competencies and assessments, alignment between content and learning activities, social network analysis of student projects across the curriculum, and student sentiment analysis. The data for design analysis includes course assessment requirements, student work, student performance results, project groupings, program outcomes, course specific competencies, learning theory models, and in course student surveys. The techniques include descriptive statistics, visual analytics, data models, text mining, data mining, scoring and ranking methods, segmentation/clustering, and natural language processing.

Recall that **policy analysis** is an external focused study that the aims to analyse the curriculum mainly from the perspective of alignment with government or accreditation board requirements. The key stakeholders include government representatives, professional bodies, course managers, and curriculum managers. The objectives include the study of policy analysis tasks such as alignment between national qualifications framework and curriculum, measurement of student outcomes to satisfy accreditation body requirements (e.g. ABET or AACSB), and alignment with professional bodies skills framework. The data for policy analysis includes national qualifications framework, program outcomes, course specific competencies, and student performance results. The techniques include descriptive statistics, visual analytics, data models, text mining, data mining, and natural language processing.
In the next section, we present our case study that describes our attempts on performing design analysis of the curriculum by mapping the curriculum analytics framework on an existing Information Systems curriculum.

IV. Case Study - Analysing Competencies to Discover Curriculum Insights

We applied the curriculum analytics framework for the task of analysing the competencies to discover curriculum insights [Gottipati & Shankararaman, 2014]. The case study aims at the problem of analysing the curriculum at the design level. The approach we take here is to map the competencies of all the courses in the curriculum against the learning taxonomies to discover the structure of the curriculum on the cognition and progression dimensions. This discovery aids in finding the gaps, and therefore supports the curriculum designers in the decision making process of re-structuring the curriculum or improving the courses within the curriculum. Table 1 shows the mapping of four dimensions of the curriculum analytics framework as applied to the case study.

Table 1: Framework dimensions integrated in to the case study

<table>
<thead>
<tr>
<th>Framework dimensions</th>
<th>Case study components</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objectives</td>
<td>Curriculum structure analysis (design analysis)</td>
</tr>
<tr>
<td>Stakeholders</td>
<td>Curriculum manager/developer, Course manager, Instructors</td>
</tr>
<tr>
<td>Data</td>
<td>Learning outcomes and competencies, Learning theory taxonomies, Curriculum structure</td>
</tr>
<tr>
<td>Techniques</td>
<td>Data models, descriptive statistics, visual analytics</td>
</tr>
</tbody>
</table>

Case Study Problem Description

To formally define our problem, we first introduce a few basic concepts.

Competency: "Competencies are defined as the knowledge, skills and abilities in the context of a specific domain (object-oriented application development, cloud computing, etc.) that enable a student to take an effective action or make sound decisions" (Passow, 2012). For example, “Create the business process model for a given real world scenario” is a competency defined in the information systems domain.

Cognition level: Skills in the cognitive domain revolve around knowledge, comprehension, and critical thinking on a particular topic. Bloom categorized cognitive domain into 6 cognitive levels [Bloom, et al., 1956]. For example, given the competency, “Create the business process model for a given real world scenario”, the cognition level is “creating”.

Progression level: Progression level describes how individuals progress through various levels in their acquisition of competencies [Dreyfus & Dreyfus 1986]. Though there are two versions for the model with five and six levels respectively, the three main levels play major role in tracking the progress of the learners; awareness, proficiency and mastery [Judith et al. 2008]. For example, given the competency, “Create the business process model for a given real world scenario”, the progression level could be “mastery”.

Problem Description: Curriculum manager, courser manager and instructors play a major role in continuous improvement of a curriculum. However, for improving the curriculum it is important to analyse the competencies of the curriculum (subsumes courses) to discover insights. Such discovery aids the stakeholders in the decision making process of re-structuring the curriculum or improving the courses. In brief, analysing competencies at curriculum level has several advantages. Firstly, it aids in understanding the overall design of the curriculum in terms of supporting the progression along the various levels in achieving the competencies. It allows us to study the progression levels of mastering a competency from first to the final year of the program. For example, if the first year programming course lays undue emphasis on advanced thinking
skills, it can be moved to the advanced level of the curriculum. Secondly, it helps in discovering any discrepancies, blind spots or gaps in the program, and provides pointers for improving the curriculum. For example, if the analysis cognitive skill is never addressed in the entire program, this becomes evident and appropriate action can be taken. Thirdly, it helps in recommending the competencies for a new course. For example, when introducing a new course, an analysis of competencies across existing courses will help in identifying the required competencies for the new course such that the overall coverage of competencies and their progression levels is well designed. In this case study, we focus on analysing curriculum using competencies.

Manual analysis of course competencies in a curriculum can be a tedious and painstaking effort due to three main challenges. Firstly, even in a small curriculum, the total number of competencies can reach few hundred. For example, in our dataset of 14 courses, we have 578 competencies in total. Secondly, the competencies are verbose in nature and often multiple competencies are combined into a single statement. For example, the competency statement, “Create and evaluate the business process model for a given real world scenario” consists of two competencies; “Create the business process model for a given real world scenario” and “Evaluate the business process model for a given real world scenario”. Thirdly, competencies tend to evolve, especially in technology curriculum where changes happen every two to three years. Hence, there is a need for automated curriculum analysis framework that handles verbosity and generates the statistics/analytics to aid the educationist in the decision making process.

Solution Methodology

In this project, we propose a framework based on cube models [Khairuddin & Khairuddin, 2008], Bloom’s taxonomy [Bloom, et al., 1956], Dreyfus' model of skill development [Dreyfus & Dreyfus 1986], learning outcomes framework [Ducrot et al., 2008] and exploratory data analysis (EDA) [Cook & Swayne, 2007] to discover the impacts of courses' competencies on the curriculum. In the first step, we design a cube model that integrates the learning outcomes (subsumes competencies), Bloom’s cognitive domain (cognitive functionality) and Dreyfus’ competency level development levels (progression functionality) as shown in Figure 2.

In the second step, given a list of competencies expressed by the instructors, the competency cube is sliced and diced to generate the competencies that are aligned cognitively and progressively respectively. To determine cognition levels, Bloom’s action verbs [Krathwohl, 2002] are used. A simple text search is executed on each competency to discover verbs for every cognitive level and the competency is aligned to the corresponding cognitive level. In this process, if multiple verbs are found, the competency is aligned to multiple competencies. For example, “Create and evaluate the business process model for a given real world scenario”, consists of two cognitive functions; Creating and Evaluating. Therefore, the competency is aligned to both the cognitive levels. The competencies will also be categorized and aligned by progressive levels. In the above example, the competency will be aligned to the progression level, “Mastery”. In the third and final step, exploratory data analysis (EDA) is executed on the course information (year, term, level, etc.) and on the processed competencies to generate the statistics
on overall curriculum. EDA is a popular descriptive statistics technique and is useful in summarizing the data using various graphical techniques such as box plots, line graphs, bar graphs, etc. Such detailed visuals aid the educationists to analyse the curriculum and make decisions. In summary, cognition statistics aids in analysing the curriculum by cognitive levels, while progression statistics aids in analysing the curriculum by progressive levels.

**Dataset**

For our experiments we used the undergraduate core curriculum courses from School of Information Systems. The course coordinators for each course provided the list of competencies (raw competencies) and their mapping to program-level learning outcomes. We collected the competency lists, year, term and level (foundation or advanced) information for 14 courses of the core curriculum. Initially, there were 398 raw competences and after applying the alignment method, Step 2 of Figure 2, the total number of aligned competencies increased to 578.

**Experiments and Results**

Recall that applying EDA on competencies which are cognitively aligned yields the curriculum analysis by cognitive levels. Figure 3 shows the curriculum cognitive analysis by year. We observe that year 1 (Y1) courses majorly focus on remembering and applying. Y1 courses such as software foundations and data management are introductory courses that are technical in nature and are designed to emphasize learning by application component. Y2 courses majorly focus on understanding and applying. At the same time, they introduce mastery by creating or developing new products. Software engineering course is one of the examples where the students are required to implement a software product. Y3 courses mainly focus on mastery (creating and evaluating) while also testing the users’ remembering capability. For example, architectural analysis contributes majorly to mastery and creating products.

We then evaluate the impact of competencies on curriculum by term. Figure 4 shows the curriculum cognitive analysis by term. We observe that term 1 courses focus on awareness by remembering and in contrast, term 2 courses focus on mastery by creating. Both the terms emphasize applying as the curriculum is mainly based on business application of technology.

Finally, we evaluate the impact of competencies on overall curriculum at various cognitive levels. Figure 6 shows the average cognitive analysis on all the courses. We observe that, in general the...
curriculum gives importance to remembering, understanding, applying and creating. Evaluating and analysing components are at a very low importance, less than 10%. This is clearly an aspect where the curriculum manager needs to intervene and make decisions regarding how the evaluating and analysing components can be further strengthened.

Recall that applying EDA on competencies which are aligned progressively yields the curriculum analysis by progression levels as shown in Figure 7. We observe that, proficiency appears to be centred across the curriculum. Mastery appears to be similar to proficiency except for it has lower number of competencies (mean is lower). Awareness has excess variation. Some courses gave major emphasis on awareness while others don’t. Detailed analysis was performed at the course level for understanding these gaps which we skip in this paper.

V. CONCLUSION

Our research is an on-going effort on curriculum analysis that explores better ways of unpacking the three components of a curriculum. The purpose of the effort is to study the alignment between these components, identify the gaps, and propose further refinement of the curriculum and courses. In this context, learning analytics has opened up new opportunities for conducting curriculum analysis. The analytical techniques help to automate the overly manual process of curriculum analysis. In this paper, we have presented a framework for curriculum analysis and show how this framework has been applied to design analysis to understand the gaps and strengths of an existing undergraduate IS curriculum. The case study generated quantitative results for analysing the insights and gaps in the curriculum. The framework opens new directions of research in curriculum analysis; measuring the alignment of learning activities within a course and across the curriculum with the outcomes, assessments and learning theory taxonomies is useful for educators; measuring the curriculum design and industry skills or requirements impacts the students' placements; understanding students’ feedback plays an important role for the curriculum improvement which can be addressed by the sentiment analysis methods etc., Future work will be aimed at addressing these areas.

VI. REFERENCES


ABOUT THE AUTHORS

Dr. Swapna Gottipati is an Assistant Professor of Information Systems (Education) at the School of Information Systems, Singapore Management University. Her research interests include text analytics, natural language processing, information extraction, opinion mining, machine learning and social networking. Her main focus is to enhance data mining models while she applies her research findings to software, education, security and mobile applications. Prior to joining SMU, she worked as a consultant for banking, financial and mobile projects, where she designed, developed and supported various software systems.

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