International Journal of Computer Information Systems and Industrial Management Applications.
ISSN 2150-7988 Volume 3 (2011) pp. 594-601

Implications for Learning Analytics Tools: A Meta-Analysis of Applied Research Questions

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***Abstract*: Educators are in need for powerful Learning Analytics tools in order to improve the effectiveness of their courses and to enhance the performance of their students. In order to design such tools, knowledge about teachers' interests and research activities is required. In this paper, we present the results of a meta-analysis of case studies described in the conference proceedings of the approved German eLearning conference "Deutsche eLearning Fachtagung Informatik" (DeLFI). By answering the following two questions: 'What research questions are teachers asking for improving Technology-Enhanced Learning?' and 'Which methods do teachers apply to answer their research questions?', our aim is to help TEL researchers generate indicators which can be used as a basis for Learning Analytics tools.**

***Keywords*:** Technology-Enhanced Learning, Higher Education, Learning Analytics, Educational Data Mining, Requirements Analysis, Improving Teacher Support**.**

I. Introduction

With the establishment of Technology-Enhanced Learning (TEL) in higher education, a new research field, called Learning Analytics, is emerging and awakening interest of educators. As the number of teaching scenarios at universities where Learning Management Systems (LMS) and other tools are integrated into the learning process is increasing, many educators ask questions about the effectiveness of TEL and wonder how teaching can further be improved [1]. Masses of data are collected from all kinds of student actions, such as, solving assignments, taking exams, online social interaction, participating in discussion forums, and extracurricular activities.

"Learning Analytics is the use of intelligent data, learner-produced data, and analysis models to discover information and social connections, and to predict and advise on learning" [2]. It can allow schools and universities to take action. However, the technology to deliver that potential is still very young and research on understanding the pedagogical usefulness of Learning Analytics is still in its infancy [3].

Another possible way for individuals to achieve more knowledge on the improvement of teaching is to establish Action Research in TEL. Hinchey defines Action Research as "a process of systematic inquiry, usually cyclical, conducted by those inside a community rather than outside experts; its goal is to identify action that will generate improvement the researchers believe important" [4:p7]. The Action Research methodology has become increasingly popular and has been well developed in education, specifically in teaching at universities and schools in many countries around the world [5]. It enables teachers themselves to investigate and evaluate their work [6]. Thereby, teachers learn more about their teaching and are enabled to improve their personal teaching skills [4].

Example studies on TEL scenarios can demonstrate that results of Action Research activities might unexpectedly show that former assumptions and hypotheses about learning and usage of materials cannot be verified and didactics have to be changed to motivate more students to learn more continuously and achieve better assessment results [7].

Although Action Research might reveal information worth knowing, teachers still face difficulties, deterring them from integrating Action Research activities into everyday practice. A pre-eminent barrier is the increase in workload, originating from additional organizational tasks; e.g., teachers might have to collect, integrate and analyze raw data of log files of their LMS [7]. This process can be time consuming and error prone. Those teachers who are motivated to evaluate their teaching therefore wish for computer-based assistance, preferably on a continuous basis [17]. The field of Learning Analytics promises to satisfy these needs of educators in the near future. Yet, usable Learning Analytics toolkits for teachers are still missing in current LMS.

By comparing Learning Analytics and Action Research some parallels become apparent. In particular, the aim of improving teaching methods through cyclical investigations connects both attempts. We expect that a conjunction of both approaches will bring profit for future research on TEL. For this reason, in the remainder of this paper, we will use the term Learning Analytics and Action Research interchangeably.

It is a current goal at RWTH Aachen University to enhance its university-wide used learning and teaching portal L²P [8] with user-friendly tools for Learning Analytics. In order to design such tools that should not require extensive expert knowledge to be run and to be interpreted successfully, first of all, knowledge about teachers' interests and research activities has to be gained.

Hence, the leading questions of this investigation are: What research questions are teachers asking for improving TEL? And which methods do teachers apply to answer their research questions?

The present investigation contributes to research on quality improvements in technology-enhanced teaching and learning by gathering, analyzing, and classifying already documented, practically oriented research questions of educators. Its scope is limited to the analysis of case studies described in the conference proceedings of the approved German eLearning conference "Deutsche eLearning Fachtagung Informatik" (DeLFI), which can be considered as representative for the present technology application in German teaching scenarios. The paper proceeds as follows: In section 2 we will discuss related works. Section 3 will briefly describe the methodology of a qualitative meta-analysis of case studies, which was conducted to answer the two questions: What research questions are teachers asking for improving TEL? And which methods do teachers apply to answer their research questions? In section 4 we will examine and discuss the findings of this literature analysis, i.e., inspect which research questions already have been asked and which methods have been applied in a specific German community of researching teachers. The results may be used to draw the requirements and inform the design of future Learning Analytic tools. In the concluding section 5 we summarize the main results of this study and outline plans for future work.

II. Related Work

There are some tools that are already used by some teachers and students in courses of higher education to evaluate and improve TEL scenarios. At RWTH Aachen University, e.g., students are asked to answer paper-based or online questionnaires to evaluate each of their courses each term. These surveys are managed centrally through EvaSys [9]. Some teachers additionally create and pass out supplementary surveys such as one-minute-papers [10] or short online surveys during the semester, because they need more specific information more quickly. For this purpose, they might use survey functions integrated in a LMS or free survey software available online, such as SurveyMonkey [11]. Some LMS, such as Moodle [12] or the learning and teaching portal L²P of RWTH Aachen [8], also provide reporting functions for student tracking. These tools enable teachers to access all or small fragments of log file data or sometimes even visualizations that give an overview on specific parts of usage data.

The results of a meta-analysis [13] show that research activities similar to Learning Analytics are described in several case studies. Some of these studies are not only accompanied by methods of log file analysis, but are also initiated by web site monitoring and learner tracking functions or direct analysis of log files. Furthermore, Mazza and Dimitrova state: "Although qualitative analysis of discussions provides deep insight into social aspects in distance classes, it is usually laborious and time consuming. Instead, by using suitable visualization techniques, quantitative analysis can be performed to discover general tendencies and phenomena about social aspects of students as well as to highlight parts of the interaction for further qualitative analysis." [14:p281]. This demonstrates the relevance of tools for Learning Analytics besides evaluation tools for conducting qualitative research. Currently, however, the built-in student tracking functionalities in most LMS are not satisfactory [1]. Accordingly, the analysis of logs of student-computer interaction has led to the development of the research field of Educational Data and Web Mining (EDM) [15]. EDM research brings forward knowledge about the effects of TEL on learning processes through discovering coherencies in large amounts of data related to learning, and therefore, it can be used to better understand students and the settings which they learn in [16]. According to Siemens, however, Learning Analytics is broader "in that it is concerned not only with analytics but also with action, curriculum mapping, personalization and adaptation, prediction, intervention, and competency determination" [2].

Yet, usable EDM or Learning Analytics tools for teachers that support cyclical research activities are still missing in most current LMS. Romero et al. state that "[…] data mining tools are normally designed more for power and flexibility than for simplicity. Most of the current data mining tools are too complex for educators to use and their features go well beyond the scope of what an educator might require." [17:p369]. If tracking data is provided in LMS, it is often incomprehensible, poorly organized, and difficult to follow, because of its tabular format. As a result, only skilled and technically savvy users can utilize it [18]. But even for them it might be too time consuming. Moreover, unnecessary personal information of students can be observed by teachers or even fellow students, i.e., data privacy issues are ignored in the design of most LMS [19]. Other deficiencies of reporting tools are related to usability and clarity as well as completeness of the delivered results, such as the lack of possibilities to integrate results of online questionnaires with data from logs.

Several researchers have tried to solve some of these problems in the last decade. Mazza and Dimitrova, e.g., presented the tool CourseVis [18,20], which has been built as an extension of the course management system (CMS) WebCT at the Faculty of Communications Sciences of Lugano. Its design is based on the results of a survey, which revealed that instructors need information on social, cognitive, and behavioral aspects about their students when running distant education courses with a CMS. CourseVis uses multidimensional web log data and renders it graphically. The resulting visualizations can be inspected by teachers to get a better understanding of what is happening online in their courses. Evaluations that focused on effectiveness, efficiency, and usefulness have shown that the graphical representations of CourseVis helped instructors to quickly and more accurately grasp information of students [18,21]. Furthermore, it was noted that the visualizations would help instructors to identify students that might become potential drop-outs. The authors conclude therefore: "Many of these diagnostic activities would be tedious and cognitively demanding when the tools provided in traditional CMSs are used. This suggests that the effectiveness of CMSs can be improved by integrating [Information Visualization] techniques to generate appropriate graphical representations, similar to those produced in CourseVis." [18:p138]. As a

follow-up, the successful visualization principles of CourseVis have been implemented with another graphical interactive tool for student monitoring, called GISMO [14, 22, 23]. It has been built as a plug-in for the LMS Moodle in the context of a project funded by the European Union.

Even though there are approaches to support teachers in their ongoing evaluation and improvement activities, not all challenges have yet been solved. Examples include integration with other LMS and integration of diverse data sources, minimizing the time delay between the capture and use of data, consideration of data privacy issues, protection of students' identities and prevention of data misuse, enabling data exploration and visualization manipulation based on individual research interests, providing the right information to the right people right away, and investigating which captured variables may be pedagogically meaningful. An overview of future Learning Analytics challenges is also given in [3].

Many teachers are motivated to evaluate their courses and they already have research questions related to their teaching in mind. Yet, most monitoring and reporting tools found in current LMS are designed to collect, analyze, and visualize data in a static tabular form that was predefined by system developers. Teachers face the difficulty that appropriate and usable Learning Analytics tools, which help them answer their individual questions continuously and efficiently, are missing in prevalent LMS, since most of the work in the area of Learning Analytics is conceptual [3].

Requirements for developing such dedicated systems can be collected by analyzing interests and needs of the target group in more detail. The following sections examine and discuss the research interests of teachers and draw conclusions for the design of future Learning Analytic tools.

III. Methodology

What research questions are teachers asking for improving TEL? Which methods do teachers apply to answer their research questions? To answer these questions, a qualitative meta-analysis of case studies was conducted. Instead of quantitatively synthesizing the outcomes of various studies related to the same topic, this specific meta-analysis was geared towards the broad collection and analysis of different research questions across a variety of case studies in TEL.

The meta-analysis was limited to case studies described in the conference proceedings of the approved German eLearning conference "Deutsche eLearning Fachtagung Informatik" (DeLFI). The five topical conference proceedings of DeLFI 2005 to DeLFI 2009 can be considered as representative for the present technology application in German teaching scenarios. An analysis of the articles of these proceedings clarifies different, applied research questions and research attempts as well as accumulated experiences and investigation results. Relevant studies were chosen by the following three criteria which are based on principles of Action Research:

- application of new technologies and media within the scope of higher education,
- evaluation of the effects of this application,
- indications that educators themselves examined their teaching scenarios on the basis of self-put research questions.

Using these criteria eighteen articles relevant for answering the first two research questions were determined, including [7,24-40]. The articles' research questions and methods relevant for the analysis were collected, generalized, and duplicates were reduced with the aim of creating a clear and manageable body of material.

IV. Findings

The underlying goal of the meta-analysis is to draw the requirements and inform the design of future Learning Analytic tools that support easily understandable user interactions and interfaces. This section presents, categorizes and discusses the related questions as well as addresses the benefits of the findings for further developments.

For answering the first research question of the present study a broad collection and analysis of different research questions across a variety of case studies in TEL was sought after. Through the analysis of the DeLFI proceedings, 96 questions were collected. Almost half (47) of the questions were explicitly stated in one of the articles that fulfilled the choice criteria mentioned above. The other half (49) of implicit questions was extracted from other statements in the same articles. By using the more general term 'learning offering', instead of, e.g., a specific implementation of a LMS or a learning module, like a lecture recording, a podcast, a wiki or an interactive quiz or game, several question could be consolidated and, thus, the number of questions was decreased. The number of questions was reduced even further by joining very similar questions with regards to content.

The remaining 86 questions were analyzed and related to the following six categories A-F, which are related to the methods and tools that have to be used mainly to investigate them:

(A) qualitative evaluation (valuation / acceptance / purpose of usage / learning style)
(B) quantitative measures of use / attendance (frequency / intensity / time period / length / continuity)
(C) differentiation between groups of students (gender / age / learning style / field of study / etc.)
(D) differentiation between learning offerings (content / type / interactivity / features / etc.)
(E) data consolidation (relations / comparisons / correlations / proportions / etc.)
(F) effectivity (performance ratio / learning outcome)

Cat.	Question	Methods used	Ref.
A, B	How do students learn with the learning offerings?	questionnaire, log file analysis	[17] [26] [31]
A	Are students learning in groups or all by themselves? Do students like building groups?	questionnaire	[31] [22]
A, B	Which interests do students have?	log file analysis	[20]
A	How did the students like the learning activity?	online-questionnaire, interview	[32]
A	How difficult/easy is it to use the learning offering?	questionnaire	[31]
A, (B)	How do students like/rate/value specific learning offerings? How satisfied are students with the learning offerings?	questionnaire, online-questionnaire, log file analysis	[21] [26] [33]

A	How do the students like the structure of the learning offering?	questionnaire	[31]
A	How do the students rate the personal gain in knowledge?	online-questionnaire, interview	[32]
A	How informative was the learning activity for the students?	online-questionnaire, interview	[32]
A, (B, E)	How useful and relieving are students perceiving specific learning offerings (in comparison)? Are specific learning offerings suitable for learning?	(online-) questionnaire, log file analysis	[21] [24] [31]
A	How useful do students rate the learning offering?	questionnaire	[31]
A, (B)	Are students still motivated to use the learning offering for learning, after having used it? Would they recommend the use of the learning offering in other courses?	online-questionnaire, interview, questionnaire	[31] [32] [33]
A	What are students' intentions of using specific learning offerings?	online-questionnaire, log file analysis	[21]
A	Which strengths, weaknesses or possibilities for improvements do students detect?	online-questionnaire	[24]
A	Why do students appreciate the learning offering?	online-questionnaire, interview	[32]

Table 1. Examples of research questions that are mainly related to category (A) 'qualitative evaluation'.

Research questions that are related to the category (A) 'qualitative evaluation' (see, table 1) are asked for exploratory purposes. They are used to explain observation results and often concerned with sub questions of the overall questions 'How are students learning with the learning offerings?' and 'Why do they like learning this way?'. Most times, questions of category (A) are investigated by qualitative methods, such as (group) interviews with students or qualitative and quantitative surveys, because the required information is usually not available through analysis of e-learning systems data bases and log files. A downside of this form of evaluation is the time that is needed to analyze the outcomes. Also, surveys are often conducted at the end of a course. Therefore, the results can only be used to improve the learning scenario in the following run. An alternative to overcoming this hurdle could be to offer collaborative rating features, which allow students to immediately rate and evaluate TEL content, features, and activities on a predefined scale based on predefined criteria while a course is still running.

Cat.	**Question**	**Methods used**	**Ref.**
A, B	Are students learning online?	unknown	[17]
A, B	Are students using specific learning offerings at home or mobile?	questionnaire, log file analysis	[26]
A, B	Are students printing learning materials?	unknown	[17]
A, B	When and how long are students learning? When and how long are students accessing specific learning offerings (during a day)?	questionnaires (on previous knowledge), log file analysis	[22] [19] [20]
A, B	How often do students use a learning environment (during a week)?	questionnaires (on previous knowledge), log file analysis	[19] [20]
A, B	How often do students attend lectures/class?	online-questionnaire, log file analysis	[21]
A, B	Are there specific learning offerings that are not used at all?	questionnaire, log file analysis	[26]
A, B	How intensely is the learning offering used for preparation of exams?	questionnaire	[31]
A, B	When do students use the help function?	log file analysis	[20]
A, B	Which features are important to the students?	questionnaire	[31]
A, B	Which tools do students use?	questionnaire, log file analysis	[26]

Table 2. Research questions mainly related to category (B) 'quantitative measures of use/attendance'.

Research questions that mainly fall into the category (B) 'quantitative measures of use and attendance' (see table 2) can be used to test hypotheses by measuring properties by numbers and statistics. Questions of this category could be investigated by using quantifiable data from surveys and/or log files.

Research questions that also fall into the category (E) 'data consolidation' (see, table 3) investigate correlations, proportions and comparisons. They are often asked with the underlying goal to extract new knowledge about teaching and learning processes and patterns by combining data from different sources. Therefore they are always related to other categories as well.

Cat.	**Question**	**Methods used**	**Ref.**
A, B, E	How does the use of the learning offering influence the students' motivations?	questionnaire	[33]
A, B, E	How many (percent of the) learning modules are students viewing? Do students read/watch/listen to all or parts of the learning material?	questionnaires, log file analysis	[19] [20] [26]
A, B, E	How much effort does this learning activity take compared to other learning activities?	online-questionnaire, interview	[32]
A, B, E	To which extent does the use of the learning offering ease the learning of a specific subject?	questionnaire	[33]
A, B, E	Which didactical activities facilitate continuous learning?	questionnaire, log file analysis	[7]
A, B, E	Which effects do specific learning offerings have on collaborative learning processes?	questionnaire	[27]
A, B, E	Which learning offerings are preferably used to prepare or reinforce lecture-topics?	questionnaire, log file analysis	[7]
B, E	How do learning offerings have	questionnaire,	[7]

	to be provided and combined with support to increased usage?	log file analysis	
A, B, E	Which support offerings are accepted, due to students' reflection on their proficiency level?	questionnaire, log file analysis	[7]
B, D, E	How high/low is the usage of learning modules (materials or functions) compared to all the other offerings?	log file analysis, questionnaire, eye tracking	[25] [20] [29]
A, B, E	Which teaching activities increase learning activities (e.g. attendance in online discussions)?	observation, group interview, log file and discussion analysis	[18]

Table 3. Examples of research questions that are related to category (E) 'data consolidation'.

The lists of research questions in tables 1-3 show that teachers already have various questions about the designs and usage of learning offerings, the students' learning behaviors and correlations between objects of teaching and learning as well as outcomes. According to these questions, their intentions could be to find out how well the learning offerings are designed, to learn more about the needs of all or a specific group of students, or to better understand learning processes in general. Having these intentions, the research objects would be the learning offerings, the students and their properties and behaviors, or causal relationships, dynamics, correlations and differences among the elements and processes of a learning scenario. Also, some questions are related to one another or have to be specified to be able to answer them.

Cat.	**Question**	**Methods used**	**Ref.**
C, E	By which properties can students be grouped?	log file analysis	[20]
C, E, F	Do students of all cognitive learning styles profit in equal measure?	tests on learning styles and knowledge-gain	[30]
A, C, E	Do native speakers have less problems with the learning offering than non-native speakers?	questionnaire	[31]
B, C, D, E, F	Is the performance in e-tests somehow related to exam grades?	questionnaire, log file analysis	[7]
B, C, D, E, F	How do those low achieving students profit by continuous learning with e-test compared to those who have not yet used the e-tests?	questionnaire, log file analysis	[7]
B, C, D, E, F	How effective is the use of serious games in correlation to cognitive learning styles?	test on learning styles, tests on knowledge-gain	[30]
B, C, E	How high/low is the number of the actual users in correlation to the potential target group?	log file analysis	[20]
B, D, E	Are students using specific learning materials (e.g. lecture recordings) in addition or alternatively to attendance?	online-questionnaire, log file analysis, attendance-statistics	[21]
B, D, E	Are there differences in usage between specific groupings of learning offerings (e.g. between materials with or without exercises)?	log file analysis	[23]
B, D, E	Will the access of specific learning offerings increase if lectures and exercises on the same topic are scheduled during the same week?	questionnaire, log file analysis	[7]
A, C, D, E	How is the acceptance/preference of specific learning offerings differing according to user properties (e.g. previous knowledge)?	questionnaire, log file analysis	[22] [25]

Table 4. Examples of complex research questions that are related to several categories.

Table 4 shows that such research questions can become rather complex, so that it might be difficult for teachers to find answers without having supporting data mining systems that present results in an understandable format. The table presents examples of research questions that can be related to the categories (C) 'differentiation between learning offerings', (D) 'differentiation between groups of students' according to gender, age, language, learning style, field of study, etc., and (F) studying 'effectivity' including the learning outcomes. We consider these questions as particularly important for teachers to be able to become sensible to aspects of diversity and to generate new knowledge that goes beyond common summarized information on usage patterns which is typically extracted from log file analysis. Hence, teachers especially need supporting functions to investigate these questions to improve their teaching methods that take into account the diversity of students, because different students have different needs. Moreover, data must be interpreted carefully while being used for evaluations as, e.g., students that show the same learning behavior still cannot be supposed to have the same learning style or the same level of knowledge [14]. Further data must be taken into account to assure the quality of the evaluation results. Learning Analytics could "enable teachers and schools to tailor educational opportunities to each student's level of need and ability" [3:p28].

Which methods did teachers apply to answer their research questions? Besides evaluating collected answers to qualitative and quantitative questionnaires online, the perception as well as the reflection of learning and teaching processes can be augmented through continuous, integrated usage data acquisition and visualization. The findings in tables 1-4 reflect these declarations. The most prominent methods for data collection were (online) surveys, which were named to be used in 12 of the 18 examined studies (~66,6%), and log files, which were named in eight of the studies (~44,4%). Other methods mentioned were observations, group interviews, counting attendance to classes, eye tracking, and analysis of exam grades. Also, in nine investigations (50%), both or more methods were applied in parallel to compare and verify the empirical results.

Hinchey states that “any action research project requires several practical steps” [4:p52]. The first step she specifies is “developing a question”, followed by the tasks “formulating a research plan”, “systematically collecting data”, “analyzing the data”, “developing and implementing an action research plan”, “recording the project in writing”, and “sharing the study with others”. Her suggestion of beginning a project with the development of research questions demonstrates that educators should have their own questions and hypothesis in mind when starting to use monitoring and reporting tools, looking for answers and explanations. Yet, most monitoring and reporting tools found in LMS are designed to collect and analyze data in a tabular form that was predefined by system developers. Learning Analytics tools should support teachers by collecting, integrating, and analyzing data of different sources as well as by providing a step-by-step guidance including semi-automated processes, instead of just presenting large tables of data. Current reporting tools of common LMS, such as Moodle or L²P, do not particularly support users in forming their own questions as well as developing and sticking to a research plan. Yet, teachers should be able to choose from a flexible and extendable set of research questions. The system should guide the user throughout the research process, help him or her form the questions, recommend and provide appropriate methods for data collection, integrate data from different sources, and support its collaboratively organized analysis. Such a Learning Analytics tool could, e.g., provide extendable lists of supported research questions and suitable qualitative as well as quantitative methods for data collection, visualization and analysis.

V. Conclusion

Since independent and individual realizations of evaluative practices should be standard for everyday lectures at universities, well-proven Learning Analytics methods should now find their way into the tool sets of educators. More knowledge about and a focus on essential research questions and methods could help to reduce the complexity of EDM and Learning Analytics systems. The present investigations shows that teachers already have various questions about the designs and usage of learning offerings, the students’ learning behaviors and correlations between objects of teaching and learning as well as outcomes. We can use these findings to generate indicators that could, e.g. be presented in interactive dashboards, which help teachers quickly to evaluate and improve their teaching.

Our goals are to develop new processes and tools aimed at facilitating awareness and reflection for improving teaching and learning and to integrate these processes and tools into the practice of teaching and learning. Based on the results of the described meta-analysis of research questions our future research will focus on developing usable, interactive tools that systematically guide teachers in applying adequate Learning Analytics processes on TEL scenarios.

The next steps will be to design, develop and evaluate a prototype for an exploratory Learning Analytics tool that is exemplarily integrated into the LMS of RWTH Aachen University. The focus of this prototype will be on supporting research questions of the categories (C) ‘differentiation between learning offerings’, (D) ‘differentiation between groups of students’ according to gender, age, language, learning style, field of study, etc., and (F) studying ‘effectivity’ including the learning outcomes, because we consider these questions to be most important for assisting teachers to become sensible to aspects of diversity and to improve learning situations for all students.

Furthermore, in advancements of our prototype we aim for integration with other LMS or personal learning environments. This could potentially lead to a broader use of Learning Analytics in everyday teaching and contribute to an incremental improvement of TEL [35]. Our future work will also include the integration of diverse data sources, finding clear data visualizations that maintain student and teacher data privacy, designing highly customizable monitoring interfaces that provide truly useful information to aid and individualize instruction, as well as Recommender Systems for teachers and learners.

Acknowledgment

This project was partly funded by the Excellence Initiative of the Federal and State Governments.

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