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論文の内容の要旨

The purpose of this study is to propose a framework for applying Learning Analytics (LA) to clustering learning process data of different granularity of active learning in ICT-enhanced education. It promotes instructors' "analytical activities" as a basis for Instructional Design (ID), a scientific approach to improving educational methods in which learners independently perform active learning tasks.

The spread of the COVID-19 in 2020 has forced a significant shift in traditional face-to-face education. To avoid the so-called "Three Cs," i.e., Closed spaces with poor ventilation, Crowded places with many people nearby, and Close-contact settings such as close-range conversations, not only primary and secondary education but also higher education have been forced to suspend face-to-face classes temporarily, and the effects are continuing in 2021. To improve this situation, online classes, which replace face-toface classes with video conferencing systems or MOOCs, and hyflex classes, which allow learners to choose face-to-face or online classes flexibly, are being promoted.

However, in these classes, it is more difficult for instructors to monitor and assess the progress of learners in remote settings than in the traditional way. Therefore, it is not easy to improve the educational content by grasping the status of learners through frequent formative evaluations, even though the summative evaluation through midterm and final examinations can be conducted.

Although the traditional face-to-face class style, based on teaching by the instructor and applying by the learners, is efficient in terms of knowledge transfer, many problems have been pointed out to guide them to a deeper understanding and establish skills such as "learning how to learn." For this reason, the introduction of active learning, which makes the learning process more active, is being recommended in the current educational scene. Since active learning consists of independent learning activities, it is difficult to assess the active learning results only by conventional examinations, and it is necessary to pay attention to the learning process. In addition, it is not easy for instructors to correctly grasp the status of each learner and improve the educational method because each learner has a different way of proceeding and trial and error with the target task.

ID is attracting attention as a practical approach for designing educational methods adapted to these new situations. Among the various methods of ID, the ADDIE model, which stands for Analysis, Design, Development, Implementation, and Evaluation, has been put into practice as a method of continuously constructing educational plans and materials as an educational process. Although many practices have been carried out, there is no definitive method for analyzing the issues faced in specific educational processes, and it is often pointed out that appropriate analysis has not been conducted.

This study proposes a framework for analyzing educational process issues by using the LA approach for time-series data. Various data related to learners' learning processes areaccumulated in online classes and active learning using ICT. There are various levels oftime-series data that vary depending on the platform used for learning. For example, long-term data concerning the curriculum that students acquire from the entrance to graduation; mid-term data relating to the learning process of individual courses, such as attendance, exercises, and examinations; and short-term data including learning activities in each of the lectures.

In this study, the access logs of the lecture archive system at JAIST were first analyzed to focus on the learning process at the subject level. This system provides a form of the online learning environment. The target logs were 42,470 cases for four years from 2010. The number of lectures recorded during this period was 5,389, and the number of unique learners was 912. The access logs were anonymized, and clustering methods were applied to the time-series access logs and the learner's attributes, such as working students and international students. Based on these data, we visualized the time of day and period of use of the lecture archive system and the usage tendency of users, analyzed the usage style of the lecture archive system by students, and examined the issues for the next system update.

Then, analyses of the learning activities per lecture were conducted, especially the active learning process. Two experiments were carried out: a small-scale preliminary experiment with eight students and a regular class-scale experiment with 32 students. In considering the improvement of the learning process at this level, it is essential that the learning activities of individual learners occur more frequently and require more data. Therefore, to emphasize the improvement points, the instructors should pay attention to when implementing ID, the proposed method aims to promote the effective analysis process in ID by extracting characteristics through LA's data-driven analysis. Clustering groups of learners and presenting them to instructors might reduce the cost of their analysis phase. To achieve this, the PC screen changes were adopted to collect the learning process since it is independent of the application used for such learning. Since the learning process is a kind of human behavioral data, the dynamic time warping
(DTW) method, often used in speech analysis, was applied to conduct flexible analysis.
In this study, the usefulness of this method was confirmed to compress the amount of information required for analysis to make ID more effective.

In conclusion, the clustering methods were applied to two time-series data with different granularity to highlight and visualize the characteristics of the system and learners. The

framework to apply such the LA approaches to ID was also discussed to improve the educational process. In the analysis of lecture archives for large-span analysis, the results reconfirmed the significance of the system for providing video materials as supplementary materials in a sustainable e-Learning environment. In addition, the system was also used as a part of language support in learning that was not the original purpose of its development. By applying this point to the ADDIE model, it is expected that the lecture archive system will be updated more effectively. In the analysis of learning activities in a single lecture with small granularity, clustering by DTW provided valuable results for understanding the situation in active learning situations. Especially, time-series clustering is expected to help compress the viewpoint of analysis in ID by integrating the learning behavior of multiple learners.

Keywords: Learning Process, Instructional Design, Learning Analytics, Time-Series Clustering, Dynamic Time Warping

論文審査の結果の要旨

本論文は，アクティブラーニングに代表される学習者に一定の自由度がある学習課題を行う ICT 活用教育において，学習プロセスを収集・分析する Learning Analytics(LA)の一手法として，異なる粒度の学習プロセスデータに対して時系列を考慮したクラスタリング手法を適用することにより，Instructional Design(ID)におけるプロセス改善のための分析活動を支援するアプローチを提案したものである．

まず，科目レベルの学習プロセスの分析として，本学講義アーカイブシステムに対する学生のアクセスログ 4 年分 35,472 件を対象として，学習スタイルの抽出およびシステム更新に向けた課題の検討を行った．講義アーカイブシステムは補完的学習環境と位置付けられており，その視聴は任意であるため，学生のアクセス数には大きな偏りが見られる．また，アーカイブへアクセスされた時間そのものよりも対象講義が開講された時期に対する相対的なアクセス時期の重要度が高いことが予想される．これらのことから，アクセスの対象や時期，回数等を特徴量としたクラスタリング手法を適用した．その結果，特にアクセス数の多い学習者に対する興味深いクラスタとして，従来意識されていた試験対策や対面講義の振り返りのニーズだけでなく，専門性の高い講義を中心とした開講期間外の視聴などといったより具体的なシステムに対するニーズを明らかにした．

次に，講義レベルの学習プロセスの分析として，講義時間内に行われるアクティブラーニングの過程を時系列クラスタリングすることにより，学習の活性度に基づいて学生をグルーピングする手法を提案した．一般にアクティブラーニングにおいては，達成すべき目標は教員から提示される一方で，学生が能動的に活動することによってその目標に到達することが求められる．そのため，成果物やテストだけでなく，学習プロセスに基づいた学習活動に対する分析や評価を行う枠組みが不可欠である．そこで，PC を利用したアクティブラーニングの過程を，学習活動を妨げず，アプリケーションに依存しない形で収集するためのシステムを開発した．ここでは，学生の学習過程が PC 画面上のテキストやオブジェクトの変化に反映されるとの仮定の下で，Windows 環境を対象として画面の変化率をリアルタイムに取得するサーバ・クライアントアプリケーションを開発した．また，MindMap の作成・編集を題材とする 2 つのケーススタディを行った．8 名の小規模なケーススタディでは，学習過程と画面変化の対応関係に

ついて分析するとともに，系列間の位相差を吸収可能な時系列クラスタリングの一手法である動的時間伸縮法 Dynamic Time Warping(DTW)によるクラスタリングを試行し，適切な位相差の制限を導入することで，より効果的なグルーピングを行える可能性が示唆された．さらに，32 名からなるケーススタディを実施し，位相差制限付きの DTW を適用することで，複雑で大量な時系列データから，アクティブラーニングにおいて教員の状況把握を容易にする，複数の活性パターンからなるグループが抽出できることを示した．

以上，本論文は，ICT 機器から得られる時系列データを粒度に応じたクラスタリング手法によって圧縮し，ID におけるプロセス改善のための効果的な視点を提供するものであり，データに基づく学習状態の把握を目指す LA の観点から学術的に貢献するところが大きい．また，パンデミック下のオンライン教育において，可視化しづらい学習状態の把握を支援する上でも基礎となる研究であるといえる．これらのことから，博士（情報科学）の学位論文として価値あるものと認めた．