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Guest Editorial of the FGCS Special Issue on Advances in Intelligent Systems for Online Education

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1. Introduction

The education sector is increasingly relying on online learning. Educational and training institutions are being motivated to endorse online learning strategies thanks to its technical, economic, and operational feasibility. This has become even more important after the lockdown caused by the breakout of COVID-19, when even universities revised their educational strategy, moving to online teaching. Learners and teachers are benefiting from the flexibility, accessibility, and costs of learning and teaching online. Nonetheless, moving education online is bringing unprecedented challenges. For instance, learners may feel isolation online, massive content alternatives often overload learners and teachers who look for educational resources, and institutions are being challenged to ensure academic integrity in online exams. The increasing amount of learning-related data and high performance computing are enabling intelligent systems that can successfully support stakeholders. Bringing this intelligence to online education leads to a wide range of advantages, e.g., avoiding manual error-prone tasks or providing learners with personalized guidance [1].

As artificial intelligence research and development is getting more mature, and the corresponding outputs are being deployed at scale in real-world contexts, the crucial role of using automated systems, as an additional support for stakeholders during decision making processes, becomes more evident nowadays. Current research has greatly expanded our understanding on such artificial intelligence, but there are less investigations on how it applies to online education. Data, methods, tools, and applications in this area are still limited, though they promise to proliferate in the next years. Further, more research and questions remain to be answered to bridge technological, social, pedagogical, and ethical aspects within intelligent systems.

This special issue brings together high-quality original research results reporting advances in the state of the art of online education systems empowered by artificial intelligence, covering different levels of the experimental pipeline, including but

not limiting to data collection, computational models, and applicative systems. The rest of this article is structured as follows: Section 2 briefly presents the articles included in this special issue, and Section 3 provides concluding remarks.

2. Content of This Special Issue

The submissions received in the context of this special issue are peer-reviewed on the basis of relevance for the special issue, novelty, originality, significance, technical quality and correctness, quality and clarity of presentation, quality of references and reproducibility. In the end, this special issue contains 12 articles that advance the state-of-the-art, considering different tasks, ranging from community analysis, student risk and success prediction to course recommendation, cognitive state analysis and classification, and teaching content analysis and classification. These articles target a wide range of educational scenarios, including massive open online courses (MOOCs) and higher university. The richness of the research in this special issue shows how learning analytics and educational technologies research have many different perspectives that join in one goal: understanding and improving student learning.

Community Analysis and Detection. The authors in this special issue address the analysis and detection of communities in educational settings from several perspectives.

The article “*Maximal Cliques Based Method For Detecting And Evaluating Learning Communities in Social Networks*”, by Adraoui et al. [2], examines the efficacy of using a Maximal Cliques based method for detecting learning communities, including a dynamic evaluation (social interactions of learners) and a static evaluation (e.g., using demographic information). The idea behind the authors’ approach involves the evaluation of learners by communities, instead of using their individual production. The detection of communities proved to be relevant in order to support all the stakeholders (e.g., teachers and administrators) in understanding learners’ needs and to finally improve the educational process. The reliability and efficiency of the approach are shown using three real-world scenarios.

Ruipérez-Valiente et al., in their article “*Data-driven Detection and Characterization of Communities of Accounts Collab-*

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75 orating in MOOCs” [3], propose a clustering-based approach
for the detection and characterization of different collaboration
types in MOOCs based on student interactions with the learn-
ing platform, without having prior knowledge about the exist-
ence of such collaborations. The authors also investigate the¹³⁵
80 behavioral characteristics of the detected communities of ac-
counts (e.g., fruitful, free-riding, and illicit collaboration). Ex-
periments on two MOOCs show that the proposed approach is
a viable way for automatically identifying community of ac-
counts and that, while collaborations in MOOCs are generally¹⁴⁰
85 positive for the learning process, not all the identified students’
collaborations can be considered as good or beneficial (e.g., col-
laborating in dishonest ways to facilitate course completion).

In their article “*Learning Behaviours Data in Programming
Education: Community Analysis and Outcome Prediction with
Cleaned Data*”, Tan Mai et al. [4] focus on identifying com-
90 munities of learners based on their behaviour in the event logs,
instead of analysing the behaviour of each individual student. A
further analysis contrast the behaviour of the communities and
the final results of students. The experiments are conducted on¹⁵⁰
95 two university programming courses with around 400 students
show that similar behaviour groups have similar performance
measure by the final grade. While high performing communi-
ties are characterised by more practical related activities, low
performing ones mostly passively engage with the course les-
100 son materials.

Student Success and Dropout Prediction. This special issue
sheds light on advances in the formalization, design, and devel-
opment of models for student success and dropout prediction.

In their article “*Student Success Prediction using Student¹⁶⁰
Exam Behaviour*”, Kuzilek et al. [5] study the impact of us-
ing temporal information from exam-taking behaviour on stud-
ent’s success prediction. They propose a new method for en-
coding students’ exam states and use these encoded states as
input of different typical predictive models. The experiments¹⁶⁵
110 show that their proposed approach not only leads to a signif-
icant improvement in terms of performance prediction, but also
allows to identify critical exam-taking patterns.

Prencakj et al., in their article “*Hidden Space Deep Sequential
Risk Prediction on Student Trajectories*” [6], present an end-
115 to-end deep-learning approach based on raw time series and
embedded information (e.g., navigational, forum-based, video-
based and homework-based e-tivities) to address the student
dropout prediction task. The proposed neural architecture ex-
ploits autoencoders to mitigate feature sparsity and stacked em-
120 bedded gated recurrent units to extract latent information and
temporal dependencies even in presence of long temporal gaps.
Experiments show that the proposed approach has superior per-
formances in capturing long-term behavioral dependencies and
outperforms a range of state-of-the-art shallow and deep learn-
125 ing baselines on two standard benchmarking datasets of on-
line courses (XuetangX and KDDCup15) and a novel released
dataset on online university degrees (Unitelma).

The article “*Deep Cognitive Diagnosis Model for Predicting
Students’ Performance*”, by Gao et al. [7], proposes a new gen-
130 erative model of the relations between problems and skills, with

the aim of improving students’ performance prediction and ed-
ucational recommendations. The authors represent skills and
problems as vectors whose dimensions correspond to difficulty
and keywords, and rely on students’ mastery of skills and skill
interaction to model the problems’ proficiency. They then com-
pare their proposed model with two classical cognitive diag-
nosis models, two latent factor models and two deep learning
based models on two datasets, showing that the proposed model
has a better predictive performance and interpretability.

Course Recommendation. The design and evaluation of intel-
ligent systems able to recommend courses of interest to students
are the focus of two articles in this special issue.

The article “*ACMF: An Attention Collaborative Extended
Matrix Factorization Based Model for MOOC Course Service
via a Heterogeneous View*”, by Sheng et al. [8], focuses on the
problem of personalized course recommendation in a MOOC
environment. The authors propose a new model, based on re-
cent methodologies from the domains of graph learning and
recommender systems, that captures structures and semantics.
The experiments compare the proposed model against a number
of node-embedding baselines and recommendation methods on
two datasets. The results show a good robustness against data
sparsity and imbalance.

The article “*Enabling Cross-continent Provider Fairness in
Educational Recommender Systems*” [9] by Gomez et al., deals
with the concept of provider fairness for demographic groups
of teachers that share the same continent of provenience. The
authors consider the notion of fairness based on equity, which
compare the share of recommendations of a group with its rep-
resentation in the data. They assess the presence of disparities
on data coming from a MOOC platform by applying state-of-
the-art collaborative filtering approaches (ranging from point-
wise to pair-wise as well as from memory-based to model-based
algorithms). The authors find out that there are disparities in
the visibility and exposure at expenses of smaller demographic
groups. These disparities are mitigated with a novel multi-class
approach that regulates the visibility and exposure given to each
group, without affecting recommendation effectiveness for the
learners, and thus allowing cross-continent provider fairness.

Cognitive State Analysis and Classification. Two articles of
this special issue focus on supporting a better understanding of
students’ cognitive states from diverse viewpoints.

Abate et al., in their article “*Attention Monitoring for Syn-
chronous Distance Learning*” [10], introduce a system for pro-
viding indicators on the didactic efficacy of the lecture to the
teacher, avoiding the need of activating learner cameras while
using a video conference system for synchronous distance lec-
tures. A software module runs in background and locally on the
learners’ computers for tracing their blinks, gaze and expres-
sions (no sensitive information is shared through the network),
while another software module automatically analyzes and ag-
gregates information in a user interface provided to the teacher,
including a heat-map that highlights the parts of the slide the
learners are focusing on the most and the distribution of the
classified expressions. Experiments with volunteers, ranging
from university students to employees engaged in training ac-

tivities, result in positive feedback in terms of gaze tracking and evaluation questionnaires, from both learner and teacher sides.

The article “*Classifying Students based on Cognitive State in Flipped Learning Pedagogy*”, by Shaw and Patra [11], investigates students’ learning while preparing for a lesson in a flipped classroom scenario by analysing their cognitive state based on their brain signals. Focusing on the EEG signal, the authors designed a method, based on a siamese neural network, that can classify students into three categories according to their attention. Experiments show that this approach outperforms other state-of-the-art classification methods. Once these sensors are more spread, this approach can help teachers identify students who are not paying enough attention and not learning despite putting effort into studying.

Teaching Content Analysis and Classification. Finally, the papers of this special issue investigate the automated analysis and classification of teaching material and strategies.

In their article “*Is it a Good Move? Mining Effective Tutoring Strategies from Human-Human Tutorial Dialogues*”, Lin et al. [12] investigate automated approaches for detecting both effective and ineffective tutoring strategies, by mining a large-scale dialogue corpus of online human-human tutoring. First, the authors adopt a widely-used educational dialogue act scheme to describe the action behind the utterance (e.g., asking/answering a question, providing hints). Then, they apply a sequence analysis on the inferred actions to identify prominent patterns closely related to students’ problem-solving performance. Lastly, they use these labelled tutorial actions as input to a well-established machine learning approach to predict students’ problem-solving strategies. Experiments on a large dataset of tutoring sessions contribute to a better understanding of tutors’ as well as students’ behavior in human-human online tutoring and show that the proposed approach can be practically used to locate (un)successful dialogues in an automated way.

Gasparetti, in his article “*Discovering Prerequisite Relations from Educational Documents through Word Embeddings*” [13], presents a novel method to discover prerequisites in documents, taking advantage of latent representations for their identification in a binary classification setting. The proposed methodology employs various machine learning algorithms and is tested on four different datasets which vary in terms of covered subjects and amount of instances. The results indicate that, although the underlying architecture is simple, the proposed approach achieves an accuracy close to complex deep learning architectures based on recurrent neural networks and transformers.

3. Conclusions

Intelligent systems empowered by data mining and machine learning and tailored to online education are fostering increasingly intense research to ensure that these systems can support stakeholders in an effective, efficient, adaptive and timely way. The articles included in this special issue cover a range of interesting topics and highlight important next steps in this active and rapidly evolving field of research and development. We

hope that the readers will find this selection of articles informative and helpful in keeping themselves up-to-date on the current challenges and directions, and that the content of these articles can contribute to timely drive their future research progresses.

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