Editorial
Technologies for Data-Driven Interventions in Smart Learning Environments

I. Introduction

SMART Learning environments (SLEs) are defined [1] as learning ecologies where students engage in learning activities, or where teachers facilitate such activities with the support of tools and technology. SLEs can encompass physical or virtual spaces in which a system senses the learning context and process by collecting data, analyzes the data, and consequently reacts with customized interventions that aim at improving learning [1]. In this way, SLEs may collect data about learners and educators' actions and interactions related to their participation in learning activities as well as about different aspects of the formal or informal context in which they can be carried out. Sources from these data may include learning management systems, handheld devices, computers, cameras, microphones, wearables, and environmental sensors. These data can then be transformed and analyzed using different computational and visualization techniques to obtain actionable information that can trigger a wide range of automatic, human-mediated, or hybrid interventions, which involve learners and teachers in the decision making behind the interventions.

Data-driven interventions in SLEs can be mediated by technologies that are not only oriented to learners but also to teachers with the aim of helping learners succeed in their learning and educational goals. Examples of such technologies oriented to learners include dashboards supporting the self-regulation of their own learning processes [2], [3], systems adapting learning contents and learning activities [4], [5], feedback systems [6], and recommender systems [7], [8] of learning activities that are available in the context of the students and match their interests. Examples of technologies oriented to teacher interventions include tools and systems that support real-time classroom orchestration [9], redesign of learning paths [10], the improvement of contents, gamification, and formation of groups of students that are expected to engage in fruitful and productive collaboration [11].

Even though there is already a significant body of research about learning analytics and educational data mining techniques that can be used to make data-driven interventions [12], the specific theme of how to use technologies to trigger data-driven interventions to support learning and teaching within the context of SLEs is still underexplored. This Special Section focuses on new perspectives and advances in applications of data technologies leading to data-driven interventions enhancing teaching and learning in SLEs.

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II. Papers in This Special Issue

This Special Section contains six papers reporting contributions that include rigorous inquiries and investigations about how technologies can make interventions of different nature to improve the efficiency and effectiveness of SLEs. The papers cover different aspects of the state of the art of SLEs, and the presentation and evaluation of different types of interventions, including the provision of hints and feedback, the use of different dashboards, recommender systems (for learners and teachers), and adaptive learning for personalization.

In [A1], Cosentino and Giannakos analyze 33 relevant empirical articles to understand how multisensory environment interactions and analytics capabilities can be combined to support the use and design of SLEs. Their findings show that multisensory and analytics capabilities in SLEs can help create new methods for engaging learners by increasing implicit awareness and enabling new data-driven interventions.

In [A2], Marwan and Price present the evolution of the iSnap system, which provides interventions in the form of different types of real-time hints when students struggle in peer programming tasks. The evaluation of the interventions with hints proves an improvement in class and homework assignments but not in students learning.

In [A3], Ilkou et al. present and evaluate a new way of visualization in a learning environment with collaborative searching activities, which is different for the traditional list view for searching. This type of visualization could be seen as an intervention for teachers and students. The evaluation of the approach provides good results in different scenarios by increasing the potential for closed-end scenarios and environments with intensive collaboration with a high number of collaborators.

In [A4], Wan et al. use feature engineering and nearest neighbor smoothing models to predict the performance of students in a small private online courses. Learning analytics are used to update students' dashboards, trigger weekly notifications, and support educators in proposing personalized exercises to their students. The implementation of these interventions reveals improvements in students' engagement and learning.

In [A5], Pereira et al. present a study that informs the design of SLEs where instructors are supported with AI systems in their decision making when defining learning tasks. The case addressed is focused on the selection of problems for programming online judges. Learning analytics considered include fine-grained data-driven analysis of the students' effort on solving problems and automatic detection of topics based on problem descriptions.

In [A6], Vykopal et al. describe and evaluate an SLE for the adaptive training of computer networks skills. The system proposes personalized learning paths based on a tutor model and learners' data. A study in the topic of cybersecurity illustrates the SLE capability of assigning tasks to students with an adapted level of difficulty that enable a successful completion of the training with good levels of reported satisfaction.

III. Conclusion

The innovations featured in this Special Section offer an overview of the opportunities that learning analytics provided to design data-driven interventions in SLEs. The proposed technologies support both learners and teachers tasks and offer solutions relying on automated functionalities. Some innovations stress the role of the human in the decision-making process about the interventions, based on data-driven recommendations. As learning analytics increasingly enable the understanding of learning and the context in which learning occurs, we may continue seeing new and extended opportunities for SLEs improving teaching and learning. It is hoped that the evolution of SLEs considers ethical dimensions, such as fairness, accountability, transparency, and human well-being [13] toward a new generation of trustworthy SLEs. The papers in this Special Section contribute to building a relevant base to inform further research and technology development in this rapidly unfolding field.

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Appendix
Related Articles

[A1] G. Cosentino and M. Giannakos, "Multisensory interaction and analytics to enhance smart learning environments: A systematic literature review," *IEEE Trans. Learn. Technol.*, early access, Feb. 08, 2023, doi: 10.1109/TLT.2023.3243210.

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[A3] E. Ilkou, T. Tolmachova, M. Fisichella, D. Taibi, "CollabGraph: A graph-based collaborative search summary visualisation," *IEEE Trans. Learn. Technol.*, early access, Feb. 06, 2023, doi: 10.1109/TLT.2023.3242174.

[A4] H. Wan, Z. Zhong, L. Tang, and X. Gao, "Pedagogical interventions in SPOCs: Learning behavior dashboards and knowledge tracing support exercise recommendation," *IEEE Trans. Learn. Technol.*, early access, Feb. 06, 2023, doi: 10.1109/TLT.2023.3242712.

[A5] F. D. Pereira et al., "Towards human-AI collaboration: A recommender system to support CS1 instructors to select problems for assignments and exams," *IEEE Trans. Learn. Technol.*, early access, Nov. 23, 2022, doi: 10.1109/TLT.2022.3224121.

[A6] J. Vykopal, P. Seda, V. Švábenský, and P. Celeda, "Smart environment for adaptive learning of cybersecurity skills," *IEEE Trans. Learn. Technol.,* early access, Oct. 21, 2022, doi: 10.1109/TLT.2022.3216345.

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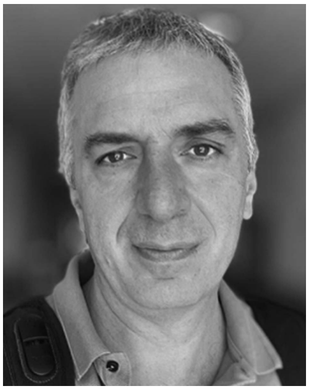

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