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Learning and Evidence Analytics Framework (LEAF): Research and Practice in International Collaboration

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Abstract Learning analytics (LA) is maturing as a research discipline in its own terms, focusing on multiple perspectives of data-informed understanding and supporting teaching and learning activities in different educational contexts. With the development of learning technology platforms, it is now possible to gather users' interaction traces in a standardized format as teaching and learning logs during such educational activities. At the Learning and Educational Technology Research Unit at Kyoto University, we developed a learning and evidence analytics framework (LEAF), an integrated technology framework that incorporates methods and tools in learning platforms that are implemented at an institutional level. We conducted research to investigate learning episodes and their effects to systematically inform practice. In this study, we present LEAF and the overall approach of the research and outreach that was achieved toward supporting evidence-based practices in education with the LA framework within Japan and internationally, with collaborators from Taiwan and India. LEAF enables a sustainable way to continue collecting learning logs, create data-driven services to support and improve teaching and learning practices while collaborating with researchers to share data and report internationally co-authored papers.

Keywords learning analytics, evidence-based education, LEAF, educational BIG data, collaborative research

1. Introduction

Learning analytics (LA) is a research discipline that incorporates data-informed perspectives and methods used to understand, support, and potentially improve learning activities of teaching. In the current technology-enhanced teaching-learning scenario, data can be logged when learners and teachers interact with one another, consume content, or produce artefacts during learning activities. These interactions are often ubiquitous, dissolving boundaries and supporting "anytime anywhere" learning. Extant literature compiles perspectives on LA in the higher education sector and distance education mode (reviews in [1], [2]). From an educational infrastructure development perspective, one of the expert panels[3] conceptualized a next generation digital learning environment (NGDLE). The panel highlighted the following main functional domains: interoperability; personalization; analytics, advising, and learning assessment; collaboration; and accessibility and universal design. A "Lego" approach was recommended, in which different applications were the building blocks that had specific functionalities and could be integrated using standard protocols to build a bigger NGDLE. This study demonstrates the operationalization of such an NGDLE, which we call the learning and evidence analytics framework (LEAF) system. LEAF focuses on a systematic collection and analysis of learning logs generated within an environment to build services that enhance teaching and learning activities. It also provides an opportunity for sustained educational big data research. The implementation of such a system requires capacity for continuous system development to realize the functions, resources for large scale deployment, and practical adoption with institutional support.

In this study, we present the components of LEAF, how the technology system enables international research collaboration for its adoption beyond Japanese institutions, and how it results in high quality collaborative research output.

2. LEAF to Link Research and Practice

LEAF is the overall technical framework that seamlessly integrates research and production systems to enable educational data science research as well as AI-driven services for the end users. LEAF aims to fulfil the following design goals: First, data-driven

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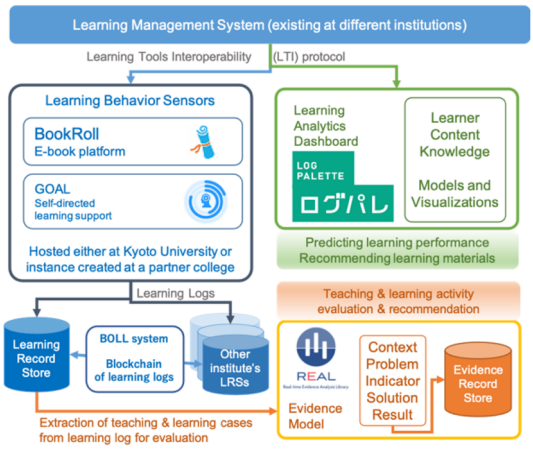

Figure 1. Overall system architecture of LEAF

research and practice is possible only when the system is easily integrated into an existing educational workflow to start collecting data continuously from the daily learning activities of teaching. Second, it should not excessively burden any of the stakeholders involved and aim for a larger adoption scope. Hence, the basic features should be kept user friendly, from elementary school to university and beyond. Last, the environment should be accessible through different devices and across different activity contexts, such as within class or out of class, in groups, or as individuals.

Fig. 1 presents the overall system architecture, with the LEAF components that are discussed in this study, which are described in the following sub-sections.

2.1 Overall System Architecture of LEAF

A learning management system (LMS) is an online system that provides an environment to structure courses and maintain user roles to grant access to different course materials and activities. LMSs such as Moodle or Sakai are already common at various educational institutes in Japan and abroad. Similarly, platforms such as Open edX or Google classroom serve as LMSs for Massive Online Open Courses (MOOCs). Within such an e-learning environment, learning often occurs seamlessly in both formal or informal situations[4]. LEAF integrates tools that can be considered as learning behvavior sensors to log learning interactions during e-learning episodes. It includes learning behavior sensors such as BookRoll[5], a digital learning material reader, and GOAL[6], a self-directed learning support system. These systems use standardized learnig tools interoperability (LTI)[7] for a seamless authentication transition from an existing LMS in an institution using an anonymized unique ID. The interactions are logged using xAPI[8], which is an open-source statement API for outputting anonymized event logs to a centralized independent learning record store (LRS)[9]. The data-driven services are built based on these learning logs. All system users have the option to opt-out of data logging by not providing consent to the tool during initial authentication or by subsequently modifying it. When the system stops to log their interactions, data-driven services also become unavailable to those users. For this study, we demonstrate the capabilities of BookRoll and its associated LA dashboard[10], which were adopted for collaborative research by Taiwanese and Indian researchers.

2.2 BookRoll: Learning Material Reader

BookRoll serves as a learning material distribution platform and captures the reading interaction logs that are used for students' LA and content. Teachers can upload learning materials to BookRoll in PDF format, while students can access them from a wide range of devices through a standard web browser. Fig. 2 presents the BookRoll system's reading interface. Other features of BookRoll include a smart dictionary[11] that allows readers to look up the meaning of any highlighted word and can be used for vocabulary learning activities. A hand-written memo function allows users to directly make strokes using a digital pen or a touch-enabled mobile device. Additionally, a recommendation panel slides in from the right, in which teachers can create a reflective quiz for formative evaluation. It can also be used for sharing links to external recommended contents or resources generated from the recommendation engine[12]. Such BookRoll functions are used flexibly by teachers to orchestrate classes in face-to-face mode[13] or online, either in flipped mode[14] or during remote teaching due to the pandemic[15], [16].

BookRoll also logs reading interactions such as navigating the reading content (going to the next or previous page, or jumping to different pages), annotating parts of the learning materials that are hard to under-

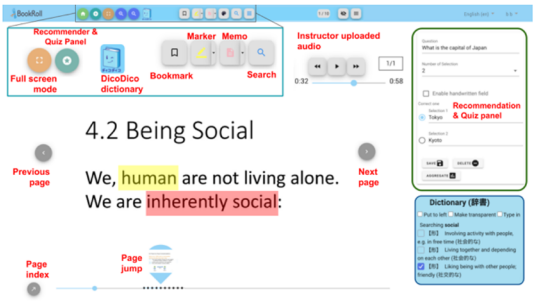

Figure 2. BookRoll user interface and functions

stand or important with memo comments, bookmarks, and markers through xAPI statements in the LRS.

2.3 Learning Record Store (LRS)

Data from the various learning behavior sensors are collected in a central LRS in real-time. This allows LA tools to access all event data from across the platform. Due to the open nature of the standard, the xAPI format was adopted as the mode of transporting and storing learning behavior data from other systems to the LRS. Each record essentially stores who (user id) did what (operation name and details) when (timestamp). Currently, each institutional member has a unique user id that is often distributed and managed locally by the institution. No connection of id and log data across an institution is in place. LEAF explores a decentralized infrastructure using blockchain to connect logs across institutions (e.g., across junior high schools, high schools, and universities) and provides access to learners' lifelong learning footprints. This approach also enables teachers to access their students' prior learning behaviors and share access to their teaching contents even after a student graduates from their class[17].

The collection of data in an LRS also reduces information silos, where data are only stored locally in the databases of different learning tools and has the potential to increase data availability for analysis. Here, the extract-transform-load (ETL) process is crucial for incrementally extracting logs from the LRS as it arrives, pre-processing them according to the requirement of another system that utilizes the data, and loading the transformed data in the system's database. In LEAF, the ETL process for BookRoll logs is automatically executed every minute. Next, we describe the learning dashboard, which visualizes the BookRoll logs, and share some of the data-driven services that are built on it.

2.4 BookRoll Learning Dashboard and Reading Log-driven Services

Learning analytics visualizations & evidence widgets (LAViEW[10]) is the LA engine in LEAF that analyzes the log data in the LRS and extracts features for further data-driven services and visualization in the dashboard. All these processes work in near real-time. The updated version of the learning dashboard is named Log Pallet. As with BookRoll, Log Pallet can be added as an external tool to an LMS by LTI. LTI automatically handles the role of the user as set in the course in LMS and shows corresponding visualized data panels for that role as a teacher and student. For instance, aggregated information on learning logs for a particular content can be viewed in the dashboard (see Fig. 3). In the teacher's view, it shows the number of annotations (markers and memo) on each page, along with a list of texts highlighted using a marker and the text of a memo (Fig. 3-left). An overlay shows the actual marked portion, and when clicked, it shows the identity of the user who marked it (Fig. 3-right). In the student tab (Fig. 4-left), a teacher can access an individual student's activity and send feedback messages to selected students. Some pre-defined templates assist teachers to easily edit messages (Fig. 4-right). The activity tab presents overall activity details, and students can compare their engagements with the class average (Fig. 5-left). For conducting flipped learning activities, a teacher can access the status of reading in the activity tab and the engagement behavior (Fig. 5-right) before a class, subsequently deciding the activity to be organized in the next class.

The learning dashboard also provides a gateway to various data-driven services that use the learning logs, such as an automatic group formation module[18]. A teacher can select a learner's attributes as logged in the LRS (see Fig. 6-left), and the system builds the learner model. This model is the input to generate groups of students using various algorithms that the system applies[19], [20]. The group work module further assists students to conduct a peer evaluation after their group activity[21] (Fig. 6-right). All the data regarding the formation of groups and teachers and peers' evaluation scores and comments are also exported and recorded in the LRS. The prior group work data can be reused for

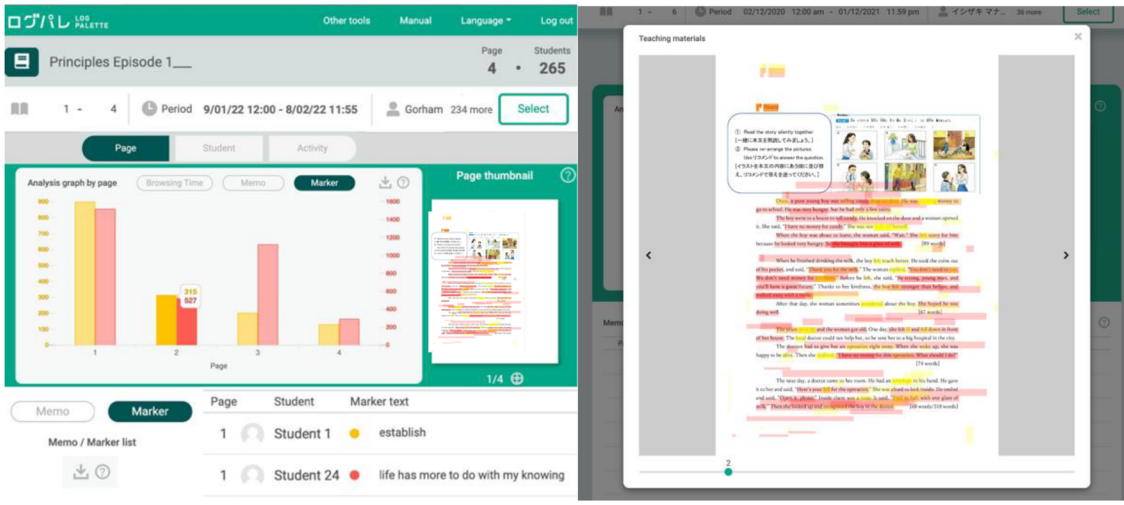

Figure 3. Annotations (markers and memos) statistics on each page (left) and overlay view (right)

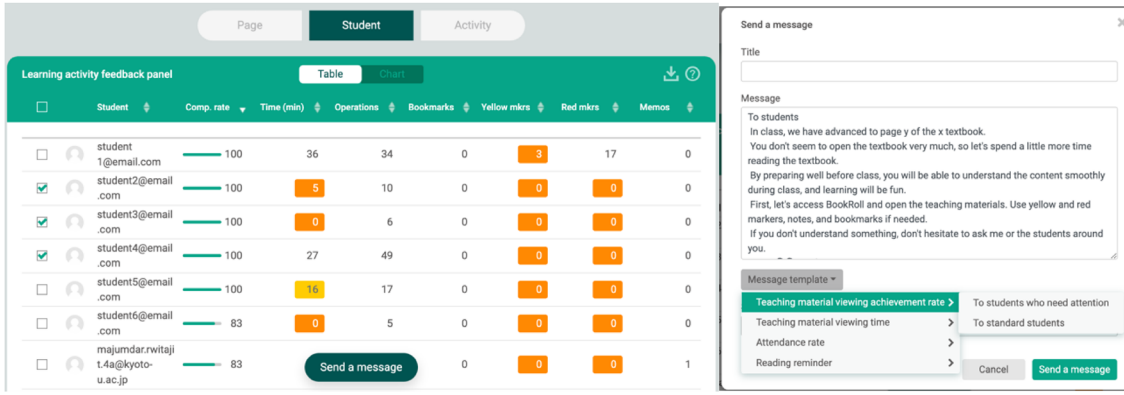

Figure 4. Statistics of individual students' reading behaviors (left) and message feedback templates (right)

Figure 5. Overview of reading activities in the content (left) and distribution of activity (right)

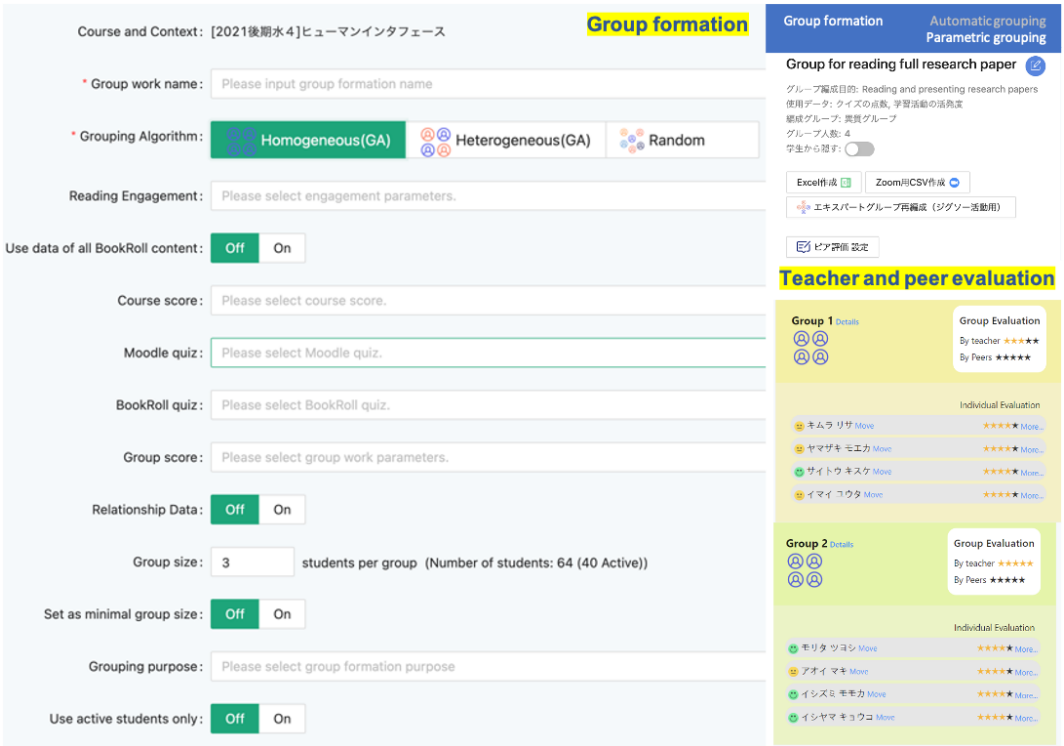

Figure 6. Parameter setting interface for the automatic group formation module
Note: Displaying formed groups (left) for teacher and peers to evaluate group work activity (right)

subsequent group formation or evaluation phases.

Other examples of data-driven services in the LEAF system include creating learners' knowledge maps[22] and using them for explainable recommendations[23]. Another example is the automatic extraction of effective teaching interventions based on learners' performance and engagement analysis using a real-time evidence analysis library (REAL) and storing them in a portal to create evidence-based teaching and learning practice across academic years and in different institutions[24]. Readers who are interested are directed to the following publications[25].

3. Implementation of LEAF in Japan

LEAF was initially centrally implemented in the server placed within Kyoto University. Each institution using the services was set as a separate tenant and had a unique URL to access the services. For instance, Kyoto University's LMS, Panda (based on Sakai), provided access to BookRoll for all its courses. During the COVID-19 emergency remote teaching, 243 courses distributed materials in BookRoll and more than 6,300 students actively used it, creating over 1.5 million logs. One of our studies conducted during that period investigated how different subject courses used different combinations of reading and listening materials and their effects on students' online engagement[15].

Meanwhile, the system was also scaled up to expand the services to different public schools across Japan using a cloud-based multi-tenant infrastructure. Fig. 7 shows students using BookRoll in their regular English class at a Japanese high school. Services such as explainable recommendation in LEAF are already being used in schools in the context of English extensive reading materials[26] and suggested math quizzes

Figure 7. Students in a Japanese school using BookRoll

for learning[27].

To co-design, develop, and adopt LA-enhanced teaching and learning practices, the project involves multiple stakeholders in addition to the core research team. Cooperation is required from teachers in schools and prefectural school boards to realize the benefits of a data-informed education system and agree to implement the technology and start collecting learning logs. Private technology firms play a role in maintaining the system and its daily operation while also expanding the services and liaison with different prefectures to scale the implementation. Private companies include publishers of text books and other reading resources, who agree to provide the digital versions, which are then uploaded to BookRoll and made available to teachers and their students. A formal research council on evidence-driven education (EDE) was formed in 2021 to provide a forum for the different stakeholders to discuss and collaborate regarding using LEAF[28]. Recently, a Science Council of Japan's subcommittee proposed an educational data utilization approach[29]. The implementation of this approach is possible with cooperation from EDE members. In future, policy making bodies such as MEXT can adopt the proposed data-driven educational system based on the effectiveness studied in the current pilot context and mobilize resources to further implement it at scale.

4. International Collaborations

Along with the implementation of LEAF for stakeholders within Japan, there was a sustained effort for an effective international collaboration. Among the collaborations, ties with research institutes from Taiwan and India are prominent, where the LEAF system was adopted at scale. The co-authors of this article from Taiwan (Prof. Yang) and India (Dr. Warriem) were instrumental in supporting that effort.

4.1 Taiwan

The dissemination of LEAF in Taiwan was through BookRoll Partnership in Taiwan (BRPT)[30]. It was initiated in July 2019 based on an International Cooperation Add-on Project between National Central University (NCU), Taiwan, and Kyoto University, Japan.

The objectives of BRPT are to conduct research-oriented collaboration between universities from Taiwan and Japan, to improve learning and teaching in practice and make an impact on policy. For conducting a research-oriented collaboration, BRPT aimed to find the right people and schools and then initiate the right topics. To establish a common platform for BRPT partners, a BookRoll system was installed in Taiwan, while researchers developed many analysis tools based on BookRoll log data.

BRPT has been held in the formats of an annual meeting (July 8, 2020), BookRoll partnership workshops (2019: 2 in Taiwan, 1 in Japan; 2020: 1 online; 2021: 2 online), and conference activities (2019: IC3 and ICCE; 2020: TWELF; 2021: ICALT). The first Workshop on BookRoll Partnerships was conducted on July 12, 2019. In addition to scholars from Kyoto University, faculty members from universities across Taiwan were invited to attend, for a total of 51 participants. The second workshop was held on August 15, 2019, with 48 people participating in the demonstration (group photo presented in Fig. 8). In September 2019, the NCU team visited Kyoto University and exchanged and discussed the BookRoll system's actual operation and course cases and explored learning analysis issues as well as activity design and analysis methods for students' e-book reading behavior. Through this field trip to Kyoto University, the NCU team learned that different courses were integrated with the BookRoll system to varying degrees. To use mathematics as an example, BookRoll is used in Taiwan for college calculus; students consider BookRoll as an individual reading system and pay more attention to text reading,

Figure 8. Second BRPT workshop in Taiwan

Table 1. Distribution of BookRoll usage in Taiwan

Term	University	Teacher	Course	Student
Fall, 2019	19	36	58	3,726
Spring, 2020	16	31	52	3,289
Fall, 2020	19	33	67	4,453
Spring, 2021	12	29	48	2,879
Fall, 2021	16	34	54	3,120

note-taking, exercises, and assignments; in contrast, in Japan, BookRoll is for high school students who are involved more in group discussion and collaborative learning. Therefore, to improve the quality of teaching, our team believes that it is essential to continuously track the teaching situation and exchange opinions with the teachers; thus, we plan follow-up activities. In addition to evaluating students' reading behaviors and calculus concepts, the NCU team will use Kyoto University's group formation module (Fig. 6) to design learning activities such as an in-class discussion for solving calculus problems and an after-class team project to encourage students' collaboration in their calculus course.

BRPT is the largest multinational digital learning initiative in the Taiwan and Japan communities, with more than 15 universities, 30 teachers, 50 courses, and 3,000 students who are constantly using LEAF. Table 1 provides the distribution of adoption and use across the years. The BRPT partnership made a great impact on Taiwan's partner university and teachers to nurture a community of likeminded researchers to improve learning and teaching in practice. They constructed smart learning environments, developed well-designed teaching and learning strategies, conducted an assessment of learning outcomes through LA, and impacted policy making. For instance, with the LEAF system successfully implemented in the Education Cloud, the official platform of the Ministry of Education Taiwan, many teachers have successfully applied for research grants based on a proposal to use the BookRoll system. They obtained quality research findings in their own classes and reported them in peer-reviewed publications.

At this level, BRPT not only provides a research platform for education experts from various universities in Taiwan, but it also creates a meaningful bilateral cooperation with the Japanese team. The Taiwanese team developed further data-driven services in LEAF and co-authored seven collaborative published journal papers; the papers were based on the BRPT using BookRoll to record students' reading logs, apply AI and machine learning algorithms to implement the four steps of precision education—diagnosis, prediction, treatment, and prevention—and improve the effectiveness of teacher teaching and student learning[31]–[37].

4.2 India

Efforts to promote BookRoll in India started in mid-2018, when we triggered a Faculty Development Initiative at the National Programme on Technology Enhanced Learning (NPTEL, https://nptel.ac.in/). BookRoll features—memos and highlights, along with the capabilities to provide a dashboard with meaningful insights—provided an ideal opportunity to examine the idea of identifying and nurturing reflective practitioners[38] among teachers. The visibility of NPTEL within the higher education space in India allowed us to connect with teachers across the country and demonstrate the capabilities of the tool.

We started with a series of workshops and demonstrations[39] during the 2018–2019 period, and could encourage 75 teachers to create courses that used BookRoll activities. Fig. 9 shows college teachers and researchers participating in the T4E 2019's Technology Enhanced and Evidence-based Education and Learning (TEEL) workshop. Among these teachers, 22 were consistently active, and through them we could reach out to 835 students who used BookRoll activities for their learning. More details on this effort are explained in one of our publications[40].

A major outcome of this effort was that we could identify instructors who wanted to engage in a research-practice partnership. In the initial phase of

Figure 9. T4E 2019 Evidence-based education workshop

the study, the instructor developed a blended learning pedagogy that used an active learning strategy along with BookRoll to improve learners' engagement in an undergraduate Physics class[41], [42]. A key finding of this study was the need for external motivation by instructors to initiate learners to use the technology for active learning. In the subsequent semester, based on the above finding, a semester-long implementation of BookRoll-based reflection activities was conducted[43]. The study was conducted in a semester that had been impacted by COVID-19. The study found that there was significant improvement in the quality of students' engagement and learning (both high and low performers) during the emergency remote teaching phase compared to the earlier blended learning phase. Another key insight was the impact that the learning dashboard made on how the teacher designed the pedagogical activity. Availability of data and relevant insights through the dashboard allowed the teacher to first reflect on their own actions and then introduce any pedagogical variations. During the pandemic, this was further extended to reflection-in-action, where the instructor dynamically adapted the pedagogy based on learner engagement and feedback, as seen through the dashboard.

The entire experience has provided a framework to approach the larger problem of developing reflective practitioners through research-practice partnerships. From an individual teacher's perspective, we have found that a pedagogic model that permits practice (for learner), followed by reflection (for both learner and teacher), is effective in increasing the quality of learning and engagement in an online setting. To scale this effort up, we also triggered a process to connect BookRoll as an LTI tool with SWAYAM (https://swayam.gov.in), the National MOOCs portal of the Government of India. SWAYAM hosts more than 700 courses in a semester, and the goal was to reach out to a few committed instructors (interested in reflective practice) and thereby reach out to more learners. While a typical Indian higher-ed classroom permits 50–100 learners, the scale is expected to increase at least tenfold when we use courses in the MOOC platform. Especially in such a MOOC setting, instructors' perseverance with the technology and the adoption of an appropriate pedagogy are essential, as there is a significant learner diversity that often poses a serious challenge[44]. Smarkola's work provide us with insight about how technology adoption attitude varies among teachers[45]. Experienced teachers look up to the larger goals of the use of technology in the classroom; in this case, students must perform active learning while engaging within the LEAF platform and persevere with both the technology and pedagogy. In this phase, a teacher training course co-instructed by one of the authors, titled, *Designing Learner-Centric MOOCs*[46], has been offered on SWAYAM since February, 2022. It introduces the LEAF platform to more than 1,600 registered participants and elaborates possibilities for active learning following the learner-centric MOOCs (LCM) model[44]. The teaching assistants for the course provide their support as mentors to show how to gain finer insights and improve on the practice while using LEAF.

5. Communities of Practice

For a sustained research effort, building communities of practice is essential. Along with international collaborations to adopt LEAF, further research outreach was achieved through organizing special issues in prestigious journals and conducting workshops and symposiums in international forums.

Through BRPT, a special issue, "Precision education—a new challenge for AI in education," was published in 2021 in Educational Technology & Society; it is the first SSCI journal paper collection to delineate the application of AI in precision education. Research leaders from Taiwan and Japan actively promoted human-centered AI in education, which emphasizes that AI operations must take the human situation as the main consideration, provide an interpretable calculation and judgment process, constantly adjust AI algorithms with reference to humans and social phenomena, and subsequently improve the well-being of human society under human conditions. Another SSCI special issue,

"Human-centered AI in education: augment human intelligence with machine intelligence," is under preparation and will also be published by Educational Technology & Society in 2023. It is a pioneer journal special issue that discusses human-centered AI in education. In the Indian context, collaboration led to the designing of specific student-centric flipped learning activities and introduced LEAF to a wider range of in-service teachers during their online faculty development programs, who then used the data collected in their own class to conduct research.

With the data collected within the context of LEAF, another community building effort involved the data challenges organized yearly in the leading LA and Knowledge conferences (LAK 19, 20, 21, 22) and International Conference of Computers in Education (ICCE 2018, 2019, 2020, 2021). It provides an anonymized and synthetic dataset related to learners' reading behaviors based on which participants can build models and present their evaluation results. A domestic data challenge for participants from Japan was also conducted, where participants aimed to build learner models based on synthetic data created to match the features of reading logs collected in the K12 context[47].

6. Conclusion

The study aimed to highlight an ongoing, systematic transition to utilize educational big data to support evidence-based education at scale. It involves multiple stakeholders from research, practice, industry, and policy to facilitate the transition. Additionally, an international collaborative research team adds different perspectives for analyzing and utilizing the learning logs. Both domestic and international outreach efforts were crucial for fostering the research and its adoption in different socio-cultural contexts. Such collaborations also provide opportunities for the unique positioning of the research and sharing of the findings in international co-authored forums and journals. Furthermore, all the collaborating teams learn about different cultural perspectives for adopting a socio-technical system in their context and conducting joint research. Overall, education systems and teaching learning practices may be different across different prefectures in Japan and across countries. Thus, proposing a simple e-book platform that could be used by any teacher to easily upload their course reading materials or activity sheets proved to have a low first-use barrier. Additionally, it has the potential to drive research on LA by being a probe, capturing its users' interaction data for understanding the teaching learning processes as well as designing technology features to support them. To effectively engage various stakeholders to build an evidence-based practice in addition to a robust multi-language supporting technology platform, data-driven research requires sharing policies for using the same tools at different educational institutions, learning logs for research analysis, and evidence for practitioners to uptake practices in their context.

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