Using Data Mining and Machine Learning Approaches to Observe Technology-Enhanced Learning

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***Abstract*— Understanding technology-enhanced learning (TEL) in schools continues to be difficult. A key reason is the complexity of digital technology use in the classroom to support learning. One of the reasons for this is the difficulty observing classrooms for extended periods of time to capture learning and the relevance to teacher's practice. This paper demonstrates how new technologies, data mining and machine learning approaches can be employed to explore the natural TEL classroom over time and meaningfully visualize results for teachers. To do this, a low-disturbance classroom observation kit is used to collect data in a secondary Science classroom for two months. One learning topic is identified, multimodal data are analysed and presented to the teacher for reflection. Three audio patterns relating to classroom activities and two teacher behaviours are identified, which bear relation to pedagogy, digital technology use and teaching strategies. Implications future research are discussed.**

Keywords—technology-enhanced learning, secondary school, multimodal data, data mining, machine learning

I. Introduction

Schools have long collected data on students, from test scores to lunches purchased. However, while an increasing amount of educational data is available, researchers and educators continue to struggle with the complexities of educational systems, particularly understanding technology-enhanced learning (TEL). Use of data is a cultural change and must address "the social complexities of application, sensemaking, privacy, and ethics alongside the development of a shared organizational culture" [1, p. 1391]. In this discussion, we specifically focus on using data to understand TEL. We argue that approaches to better understand these contexts can be embedded in research design, using new technologies in data collection and methods of analysis that can address large volumes of 'noisy', and potentially 'big', classroom data. This means designing research that can address the ever-changing physical classroom space and digital technology use, and in close collaboration with the teacher. These strategies can help create legitimate ties between data, specific learning tasks and teachers' practice. Given the importance of all young people being able to work with technology in sophisticated ways [2], it is necessary to better understand how TEL practices can be effectively integrated into the classroom.

In this paper we present the second phase of our research looking at improving how TEL is observed in classrooms, and therefore how it can be understood. The first part of this research agenda focused on automated collection of students' digital classroom behaviours, specifically app use in K-6 classrooms see [3]. In this part, we employ a low-disturbance classroom observation system. This system is able to observe the physical classroom over extended time periods and collect continuous, highly granular and relatable audio and video data.

To do this, we will first briefly discuss the complexities of TEL and limitations of classroom observations to understand technology use and effects. This is followed by a discussion of our data collection and analysis approach. The learning context being analysed was a Year 9 (age 14-15) Science unit, in a Bring Your Own Device (BYOD) teaching and learning space. Working in close collaboration with the teacher we particularly focus on the aspect of the teachers' reflection on the classroom through the use of data. A subset of the audio and video observation data were analysed (5.33 hours of instruction) to test analysis methods. Results showed three audio patterns and two patterns of teacher movement relating to different classroom activities and/or tasks, and some questions around teacher talk. These were explored with the teacher. Implications for TEL, directions of future research and the next steps in the data collection method are discussed.

II. Observing Technology-Enhanced Learning

TEL can be defined as the use of information and communication technologies (ICTs) to support teaching and

978-1-5386-6522-0/18/$31.00 ©2018 IEEE 4-7 December 2018, Wollongong, NSW, Australia
2018 IEEE International Conference on Teaching, Assessment, and Learning for Engineering (TALE)

learning activities [4]. The complexity of teaching and learning has been a key issue in the study of TEL and has resulted in difficulty observing and understanding the role and effect of digital technology use in the classroom. As outlined above, it has been identified that digital technology use does have a small positive effect on learning e.g. [5], [6]. However, that effect has proven to be inconsistent in some cases and generally not well understood [7]. One of the key reasons for this problem is the significant effect of context on the success and quality of digital technology use in a classroom, which includes important factors such as pedagogy, teacher practices, school and classroom culture [4], [6], [8]. This results in a highly complex system of teaching and learning, which has proven difficult to observe, and therefore understand and communicate to teachers to improve practice.

Moreover, existing methods of observing and collecting data classroom data have struggled to capture the complexity of the TEL learning context [9]. This brings into question how well classroom observation methods are suited to studying TEL. Standard approaches to classroom observation would typically include having video cameras, audio capture, a researcher in the room with an observation check-list to monitor the physical environment and interactions, such as the BROMP method [10]. The Baker Rodrigo Ocumpaugh Monitoring Protocol (BROMP) use field observations to determine the meaning of patterns in educational data mining results, specifically instances of various affective states. Methods such as this that include field observations require considerable protocol development and researcher training, as well as having a researcher in the classroom.

Digital technologies are known to be most effective when used to enable “students to construct deep and connected knowledge, which can be applied to real situations” [11, p. 257], such as problem or project-based learning and within authentic tasks. These types of learning designs often span over multiple days or even weeks. They include a range of tasks and activities, some of which may include digital technologies. Observing classrooms for long periods of time is often resource intensive, e.g. having a researcher present in the classroom, so only small instances of learning and teaching or specific tasks are observed [12], and/or disruptive, e.g. having recording equipment in the classroom for long periods of time [13]. The amount of video and audio data generated when observing hours of instruction and the diversity of activities, quickly becomes prohibitively large for a human to analyse. However, large volumes of data are not a problem for machines [9]. These are just a few aspects of classroom observation that have proven limiting in studying TEL in the classroom to understand teaching and learning.

III. New methods for TEL observation

In a TEL environment, it is necessary to capture how students and teachers work in both the physical classroom space (having a face-to-face discussion), in the online and/or digital space (word processing using Google Docs or Office365) and/or in a blended space where the two approaches are combined. An example of this is students searching online while writing in a Word document. In the classroom, they may speak to another student and amend their writing. While the talk is visible, the online/digital behaviours are not and can only be observed in a final product. Therefore, even in this small event the full learning process is lost, leaving an incomplete understanding of students’ learning process, physical and/or digital interactions and the role of technology.

New methods of collecting multimodal data, such as audio, video, gaze can be used to capture both physical and digital learning actions and inform students and teachers participating in TEL [14], [15]. Data mining and machine learning approaches are also able to handle the complexity of learning and teaching occurring in a TEL environment [16]. By collecting data that can be analysed using data mining and machine learning approaches, more analysis can take place and at a higher level of precision and without bias [17]. There has been work in this area, capturing students’ face-to-face and digital work in a learning space. In particular, principles of multimodal learning and how to combine heterogenous data have been identified. An important aspect of using multimodal data is employing multiple perspectives are needed to interpret data and rich contextual data is critical for sense making [14]. This suggests working with participants, such as students and teachers, and interdisciplinary researchers. Yet, given the limitations of traditional classroom observation methods, to be able to answer questions about complex TEL environments new technologies and approaches need to be more fully explored and developed.

IV. Approach and methods

In this paper, we present the second part of our developing approach to observe the physical TEL classroom to better understand teaching and learning processes. The current study addressed the question: What are the observable repeating student and teacher behaviours in a TEL classroom?

Methods collecting and analysing students’ digital practices have been reported in Yang, Ma and Howard [3] and Howard et al. [19]. To observe the physical classroom, we use a low-disturbance observation kit that collects audio and video data, which has the capacity to observe over long periods of time. The kit includes capturing video and audio data for four 80-minute classes each week, for four weeks. The system comprises four hand-sized wireless cameras, an internet-connected base station, a 4G router with broadband USB and a digital audio recording system. The system is online and video is accessible through an app and a webpage. It is important to note that the cameras are small and lightweight, therefore affording easy install using regular wall adhesives, e.g. 3M wall-mount adhesive tabs. No drilling was required. The base station and wireless router were placed in a small box under the teacher’s desk. The additional audio recorder was simply placed on the teacher’s desk. Early work piloting this system was reported in Howard et al. [20].

A. Context

For the current analysis, a Year 9 (age 14-15) Science classroom, in an urban Australian secondary school, was observed for two months. This study was an extension of an Australian Research Council Discovery Project (2013-2016). It received ethical clearance from the University of Sydney

(HREC approval #2013/754) and approval to conduct research in schools from the NSW Department of Education (SERAP #2013189). Consent to participate in the research was gained from the students, their parents and the teacher.

The observed class was a Bring Your Own Device (BYOD) class, so each student had a laptop. All class resources, work and notetaking were done in Microsoft OneNote. They would take notes using the laptop and complete classroom tasks, such as filling in a diagram, which the teacher would check through OneNote. All four cameras were in fixed positions in the classroom with one at the rear and capturing the whole classroom, one mounted on the ceiling and focused on the teacher and the interactive white board, one on the left and one on the right of the classroom. Audio was captured through the two cameras on the side, plus a digital recorder with external mic to capture the teacher. Twenty-five students and one teacher were usually in the classroom. Class durations were 80 minutes. The kit was set to only record when the specific Year 9 class was in session, four times a week.

While two months of class time were observed, a four-lesson sequence of teaching and learning was identified to test methods of analysis. Observing the natural classroom, given new technologies commonly available, is not difficult. What is difficult is deciding how to analyse the data and usefully communicate findings to the teacher. This is also called identifying 'actionable knowledge' or 'insights' from data e.g. [21]. Working closely with the teacher, a difficult teaching topic from the observed two months was identified. The topic was 'pulleys' from a Physics unit. The teacher had not taught this topic previously. The four lessons analysed for this paper were primarily teacher lecture, with students working in a collaborative OneNote document and Google Docs, in preparation for the practical component of the topic. In the practical component students experimented with pulleys and collected data. To be able to perform these tasks, they needed to have foundation knowledge of the physics of pulleys. It was selected for analysis to provide the teacher with potentially useful ways to reflect on how to change delivery of the topic for the following year.

B. Analysis

The long-term aim of this project is automation of audio and video analysis, so large amounts of teaching and learning time can be analysed. For audio analysis, we used the Decibel Analysis of Research in Teaching (DART) machine learning algorithm [22]. The algorithm DART is based on audio segmentation of recorded sequences of different decibel levels and number of speakers, combined at any one time. The creators of DART have provided good documentation, so it was not difficult to apply the algorithm. However, it should be noted that it is necessary to first manually code segments of audio, to understand and validate the DART output, which can be quite time consuming. Audio data was the processed to improve quality, but this did not result in significantly better performance of the algorithm. Ultimately, data used in analysis was unprocessed, which reduced overall analysis time.

Results from the DART analysis were discussed among the researchers and refined twice. To improve accuracy, small instances of audio were merged with larger durations, e.g. < 30 seconds and researcher definition of 'medium babble' was refined, to reach over 78.2% accuracy. This was validated based on ground truth derived from listening to the audio recording. The related classroom activities were then identified through the audio. To further validate the results they were triangulated with video data, using the timestamp. For video mining, optical flow was used to aggregate the teacher's movements around the classroom. This method was selected for its high rate of accuracy. The method approximates motion in a field by mapping visible points from one frame to another [23]. Outputs for both audio and video were presented to the teacher after the second DART review. The teacher immediately saw how results had the potential to be meaningful, as a way to understand extended periods of teaching time and her practice. Final results were. reviewed with the teacher to discuss how they were meaningful and how visualizations may inform the specific observed pulley lesson.

V. RESULTS

Frequencies of single speaker, multiple speaker and no voice from the four classes are presented in Table 1.

TABLE I. DISTRIBUTION OF SPEAKERS

Class	Single speaker	Multiple speaker	No voice
1	72.0%	19.8%	8.2%
2	74.4%	25.6%	0.0%
3	93.8%	6.2%	0.0%
4	90.2%	9.8%	0.0%
M	82.6%	15.4%	2.1%

The first 28 minutes of the first and second classes were all single speaker and then alternating single to multiple for the remainder. The third and fourth classes were quite different. They were predominantly single speaker with 3-5 multiple speaker incidents dispersed in each over the 80-minute class.

Three patterns were identified (see Figure 1).

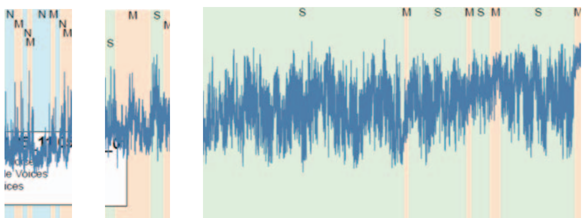

Fig. 1. Three major patterns in the classroom audio

The first pattern, N-M-N-M, identifies 'no speaker, multiple speakers, no speaker'. N-M-N-M patterns which corresponded with silent work (no speaker) but students often talked and discussed their work over their laptops (multiple speakers). This pattern was observed at the beginning of the first and second lessons. S-M-S-M patterns were characterized by short single speaker periods and longer multiple speaker. This pattern was particularly visible in the second halves of the first and second lessons, this corresponded to a student talking or the teacher giving some short instruction. During these periods, students were intermittently talking and working on their laptops. The babble was high most of the time and corresponded with in-class group work. For the final pattern, Long S-M-S-M pattern, the single speaker segments were much longer than the multiple speaker. This corresponded to lecture, taking notes on the laptop and discussion activities, in all four classes. In the first and second lessons, this was the first 28 minutes. There were larger portions of this activity in the third and fourth classes, that also corresponded with individual seat work and some babble in both. In the analysis, the higher decibel corresponded with the teacher lecturing and the lower with individual work. Ultimately, the combined patterns reveal two larger macro-patterns.

Video analysis from the right-side camera and the ceiling mounted camera showed the teacher's typical movements in the classroom (see Figure 2). Overall, these did not significantly vary over the four lessons. In the instances where the teacher is lecturing and/or using the interactive white board, their movements are confined to the front of the classroom. During group and individual work, the teacher travels more widely. However, it can be seen that interactions with students on the perimeter of the seating block are more likely. The teacher did not frequently venture in between the desk rows. This reveals two patterns of movement correlated to the furniture and digital technology positioning.

Fig. 2. Teacher's typical classroom movement

Visualizations were presented to the teacher for review. In regard to the audio results, their first response was immediately "Ooooh, I talk too much in the classroom." They noted the large amount of time in 'lecturing' in all four of the lessons. They felt this was in contradiction to employing a student-centred pedagogy.

> *…they teach you how to teach and stuff like the model's now, they're saying, "Well you need to make it more student-centred… Less teacher-centred." And we always talk about how best to deliver content that doesn't involve you talking yourself… And so, um, yeah, when I see that, I just think, "Ooh, too much – too much talking for me".*

They found audio outputs to be a very useful reflection on teaching, to see the ratio of single-multiple speaker in a waveform. They elaborated that they had wanted to work on talking less in the classroom, so this analysis was particularly meaningful. In looking at the specific patterns, they noted the 'no speaker' time and wondered what was happening there. They felt this was unusual for the class, where they typically liked to "have lots of noise". They also noted that this did not mean "the wrong kind of noise", such as off-task chatter. They felt the patterns might relate to the teaching sequence of a particular unit. For the pulley topic, "you would expect there to be lots of instruction at the beginning… as they learn the skill and they learn the content, you would expect to see more of their chatter and less of yours." Ultimately, the audio visualizations introduced a large number of questions about teaching and promoted immediate reflection on what else was happening in the classroom.

Looking at the optical flow results from video analysis, they immediately divided the movement path into 'monitoring' (learning support) and 'instruction' (content-delivery).

> *If you're thinking about your teaching overall, this would be useful for helping you to identify how much student time is being designated in the classroom versus teacher instruction at the front… But then also, how active you are as a teacher in terms of monitoring the students' learning while they are working.*

These two behaviours were felt to be typical. Review of the video and audio revealed that the teacher's monitoring roughly aligned with multiple speakers or 'no speaker' in the audio, suggesting group or individual work. Instruction was more likely to align with a single speaker. The teacher felt balance between monitoring and instructing would vary depending on the type of task or activity happening in the class, and that their position in the classroom would relate to the task. The teacher agreed their position in the classroom would be affected by using digital technologies. "If you are using an electronic device and you're monitoring them using OneNote, for example, you would spend all your time at the front and very rarely would you be moving around the classroom." This was not qualified as positive or negative.

They felt the video outputs would be helpful examining your strategies, such as identifying how you are using questioning and engagement techniques, e.g. how you get the students' attention and "saying 'Okay' 50,000 times". The teacher did not feel watching video in real-time (a full lesson), would be useful for really seeing the different patterns in one's practice. They found the combined video and audio analysis meaningful in showing interaction with students in relation to learning and indicators of a student-centred classroom, which would not have been evident otherwise. Visualizations of their movement and classroom audio resulted in several significant changes in the teacher's practice. The first was leaving more 'quiet space' in classroom discussion to encourage student speed. The teacher also reduced the amount of time they speak at the beginning of a lesson, to allow for more student interaction and discussion. The final change was varying her movements in the classroom to cover more 'floor space'. They felt this would support more individual questioning and risk-taking, when students did not need to speak in front of the whole class.

In future analysis, they wanted to see the audio and video visualizations directly connected, so the patterns from each data type could be more easily understood as a whole. They felt this might be done with timestamping. They also thought 'heat mapping' would be useful to see the duration of time in various classroom locations, instructing and interacting with students.

VI. Discussion and Conclusions

This paper has presented the second phase of our research looking how TEL is observed in the physical classrooms and how it is understood. The analysis has revealed audio and video patterns from a small excerpt of a larger classroom observation, to address the question "What are the observable repeating behaviours in a TEL classroom?" The main finding was the presence of three audio patterns related to different activities happening in the classroom, and two teacher behaviours also related to these activities. Audio patterns in the first and second lessons suggested less 'lecturing' and more group work. The patterns in third and fourth lessons suggested more lecture and a higher instance of individual work. Video analysis and teacher reflection demonstrate how these class activities related to the teachers' movement. Some implications for the TEL classroom were also observed, particularly how use of digital technologies would affect behaviours and implications for a more student-centred approach, which is typically aligned with TEL designs e.g. [11].

Results are significant for two reasons. First, while the current analysis has only looked at four lessons, the same methods can be applied to identify patterns across much longer periods of TEL classroom observations. In collaboration with a teacher, this makes it possible to identify where TEL classroom activities intersect with content, pedagogy, assessment or other key factors of the learning context. Teacher expertise is needed to unpack underlying principles of pedagogies, relation to content and teaching strategies [1]. Second, this analysis demonstrates how audio and video collected in the natural TEL classroom is meaningful to teachers. The teacher's reflections were enhanced by having both visualizations, and the teacher felt it was easier to reflect having the visual tools. While not in relation to collaborative learning, the teacher's response to the outputs supports prior research showing aggregated data was more manageable, helped teachers focus on specific issues and teachers were more confident of their assessments [24]. Most importantly, the data was directly linked to the teaching and learning context, so the teacher could draw directly on their experience to understand the data. Ultimately, this has the potential for a very powerful reflection tool.

While data was meaningful to the teacher and revealed useful patterns, the approach has a number of significant limitations. For the audio, direct auto-transcription was not yet possible for the data. Therefore, to identify the content manual transcription is required. The particular classroom observed had two issues limiting this approach. The first was the high level of background noise and cross-talking in the classroom, which resulted in difficulty isolating a voice to transcribe, which is typical of a secondary school classroom. The second was the Australian accent. We found the most reliable auto-transcription programs were primarily designed for United States (American) and United Kingdom (British) accents. To address this issue, we are working on Australian voice models with the particular teacher. In regard to the DART algorithm, the comparison between the volume of the students' talk and the babble had a great influence on the judgement of DART. While all of the mismatches could be explained by previously noted inaccuracies in Owens et al. (2017), the checking had to be done manually. For larger datasets this could become quite onerous. It is very possible to improve the accuracy with some manual assistance. Some environmental changes to improve the recording or data preparation methods many need to be employed. Finally, we have designed a new audio and video set up to improve the resolution and control over when video is recorded and audio is captured.

Future work on the physical and digital data collection approach will include extraction of OneNote log files to align students online work in future classroom observations, using some of our existing methods working with computer log files, see [3]. This would also provide a basis to begin aligning data with learning outcomes. Another strategy in this area will be keyword analysis of the audio recording. This is currently being tested as an interim approach to auto-transcription. Frequency of keywords will be overlayed on the DART analysis. As the teacher had suggested, one might expect teachers to have more knowledge (and thus technical language) at the beginning of a topic, which would shift to students in subsequent lessons. Keyword analysis can begin to unpack some of this. The same keywords can also be used to understand students' learning in their digital work and aligned it to the physical space. Keywords can be searched in OneNote files and final assessments and mapped to where they appear over the course of lessons. For the video, heat mapping will be done on teacher movements to see where they spend their time, within different monitoring and instructing activities.

Drawing both video and audio data from the natural TEL classroom setting, it has allowed some of the complexity to be revealed. In future work, data will be tested in Howard et al.'s [25], [26] system dynamics model to study technology use in learning, which will be able to begin unpacking some of the complexity of learning across digital and physical spaces. Further, system models have proven useful in helping teachers and school leadership understand classroom dynamics [27]. Other models used to engage teachers with classroom data will be identified in collaboration, to insure models are meaningful and relevant to their practice. One approach already identified by the participating teacher is heat mapping her classroom location, which will allow her to see how much time and how frequently she is in certain areas.

Even in this early analysis, implications of technology use affecting teacher behaviours in the classroom and students continual use of their laptops in both individual and group work were noted. Activity patterns, their relation to pedagogy, content and teaching strategies all begin to reveal what is happening in the teaching and learning process. New technologies can easily collect rich data. The current analysis has started to show how this data, as actionable knowledge, is meaningful when directly connected to the classroom and can be used to inform teaching and learning. Continuing to develop this line of inquiry will continue to reveal connections between the learning context and digital technologies, how they can be usefully integrated and how they best support technology-enhanced learning.

Acknowledgment

The research was supported by Faculty of Social Science Seed Grant at the University of Wollongong.

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