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A Gaze-based Learning Analytics Model: In-Video Visual Feedback to Improve Learner's Attention in MOOCs

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ABSTRACT

In the context of MOOCs, "With-me-ness" refers to the extent to which the learner succeeds in following the teacher, specifically in terms of looking at the area in the video that the teacher is explaining. In our previous works, we employed eye-tracking methods to quantify learners' With-me-ness and showed that it is positively correlated with their learning gains. In this contribution, we describe a tool that is designed to improve With-me-ness by providing a visual-aid superimposed on the video. The position of the visual-aid is suggested by the teachers' dialogue and deixis, and it is displayed when the learner's With-me-ness is under the average value, which is computed from the other students' gaze behavior. We report on a user-study that examines the effectiveness of the proposed tool. The results show that it significantly improves the learning gain and it significantly increases the extent to which the students follow the teacher. Finally, we demonstrate how With-me-ness can create a complete theoretical framework for conducting gaze-based learning analytics in the context of MOOCs.

Categories and Subject Descriptors

K.3.1 [**Computers and Education**]: Computer Uses in Education—*Collaborative learning*

Keywords

Eye-tracking, video based learning, MOOCs, Student attention

1. INTRODUCTION

The new wave of online learning – Massive Open Online Courses – has brought with it new challenges as well as new opportunities for learning analytics on a population of learners with high diversity of profiles. We specifically look at the teacher-student interaction in MOOCs, and frame it from a dyadic interaction point of view: "How can we measure and improve students' attention in MOOC lectures?" The solution we propose in this contribution works independent of the learning topics or the students' backgrounds. In addition, it can stay at the periphery, keeping the students focused on the learning content.

In our previous works, we have shown that, with eye-tracking methods one can get insight into the learner's performance irrespective of their background or the learning content [13]. Grounded in those results, this contribution presents a tool that, through visual feedback, drives the student's attention to the part of the displayed content that is being explained by the teacher.

In two previous studies, we captured students' attention as a response to what the teacher was saying. We addressed this situation from the teacher's perspective: *"How much the student is with me?"* We called this gaze-measure **With-me-ness** which identifies the extent to which the student was "following" the lecturer, i.e. paying attention to the parts of the display that correspond to the instant behaviour of the teacher. We selected two aspects of teacher's behaviour that could influence the students' attention: the teacher's dialogue and the deictic references.

In this paper, we build on our previous results and present a gaze-aware feedback tool to notify the learners about their levels of With-me-ness, while they watch a MOOC lecture. In addition, we construct a discussion that is structured within the Learning Analytics (LA) models with three phases [3, 9] [2]: 1) collecting data from the learners, 2) analysing different variables and their relation with learning processes and outcomes, and 3) providing the feedback to the learners and further study the change in their behaviour, the learning processes and outcomes. We show how the proposed tool contributes to the third phase and completes the different LA loops. Given the results of our previous studies coupled with the results of the study presented in this paper, **we will argue that the notion of With-me-ness can create a complete theoretical framework for conducting gaze-based learning analytics in the context of MOOCs.**

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2. IN-VIDEO VISUAL FEEDBACK

2.1 Background

In our previous studies we analyzed the learner's gaze behavior while watching MOOC videos and developed the notions of perceptual and conceptual With-me-ness as following:

Perceptual With-me-ness: Is the extent to which the learner succeeds in following the teacher's explicit deictic gestures. It is defined as combination of three components: 1) entry time is the temporal lag between the times a referring pointer appeared on the screen and stops at the referred site (x,y); and the time student first looked at (x,y); 2) first fixation duration is how long the student gaze stopped at the referred site for the first time; 3) revisits are the number of times the student's gaze came back to the referred site.

Conceptual With-me-ness: Is the extent to which the learner succeeds in following the content that is being explained through other channels such as dialogue. The teacher may also verbally refer to the different objects on the display. We measured how often a student looked at the object (or the set of objects) verbally referred to by the teacher during the whole course of time (the complete video duration). In order to have a consistent measure of conceptual "With-me-ness" we normalised the time a student looked at the overlapping content (the verbal reference and the slide content) by slide duration.

User studies have shown that both the levels of With-me-ness are significantly correlated (positive) with the learning gain.

2.2 Visual feedback tool

The visual feedback that we developed consists of a set of red rectangular wire-frames highlighting the area of the screen which the teacher was talking about (Figure 1). This is made visible to the learner only when her With-me-ness levels went below the baseline.

The baseline was calculated as the average of the "With-me-ness" levels of the participants from our previous experiment (with the same video content). This baseline was calculated for each second of the video lecture. To calculate the baseline we took the participants from the previous experiment whose leaning gains were between 33 and 66 percentiles of the overall learning gains of the previous experiment. The reason for selecting this range of scores was that we wanted to give the feedback based on the typical behaviour of the students. In the remaining part of this paper this group is called the "baseline group". The learning gains of the two groups are comparable as they had the same pretest and posttest. We considered only a subset of this group to define our baseline, however, to compare the learning gains we will use the complete set (with 50 students).

2.3 The present Study

We conducted an eye-tracking study where 27 participants attended a MOOC lecture and received the visual feedback as described in the previous subsection. Students received the feedback whenever their With-me-ness was less than the baseline at any given point of time in the video. The hypothesis is that the gaze-aware feedback increases students' With-me-ness; and thus their learning gains. Precisely, through this study we address the following research questions:

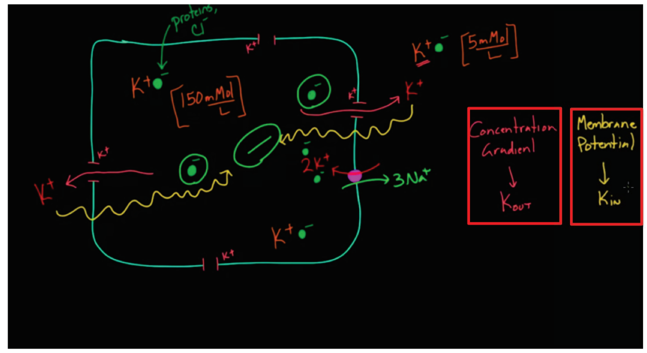

Figure 1: Example of the feedback used in the experiment. The circumscribing red rectangle were shown if the With-me-ness of the participant went below the baseline With-me-ness at any given instant during the video.

1. How does the gaze-aware feedback affect the gaze patterns (With-me-ness) while watching the video?
2. How does the gaze-aware feedback affect learning gains?

2.4 Experiment

2.4.1 *Participants and procedure*

There were 27 bachelor students from École Polytechnique Fédérale de Lausanne, Switzerland participating in the present study. There were 6 females among the participants. The participants were compensated with an equivalent of $30 for their participation in the study.

Upon their arrival in the laboratory, the participants signed a consent form. Then the participants took a pretest about the video content. Then the participants watched two videos about "Resting membrane potential". Finally, they took a posttest. The videos were taken from "Khan Academy". The total length of the videos was 17 minutes and 5 seconds. It is worth mentioning that the teacher was not physically present in the video. The participants were told that the feedback would appear only when they were not paying attention to what the teacher was saying or writing.

2.4.2 *Dependent variables*

Learning Gain: The learning gain was calculated as the difference between the individual pretest and posttest scores. The minimum for each test was 0, and the maximum for the pretest was 9 and for the posttest was 10.

With-me-ness: We used the same method as described Section 2.1, to calculate students' With-me-ness levels, in this experiment, in real time.

2.5 Results and interpretation

Feedback and Learning Gain: We observed a significant improvement in learning gain for the experimental group over that for the baseline group (t ($df = 49.88$) $= -2.50$, $p = .02$, figure 2). The two populations (in the baseline and the experimental) were largely similar (the participant recruitment was done using the same university channel, and there was no drastic changes in student populations) in the two conditions.

Immediate effect of feedback on gaze: We observed a significant improvement in With-me-ness levels for participants (within the experimental group) before (mean = 0.31, sd = 0.08) and after (mean = 0.57, sd = 0.16) displaying the feedback (F [1, 26] = 310, p < .001, figure 3). The duration of each instance of the displayed feedback was minimum 2 seconds. The With-me-ness levels were significantly higher after showing the feedback than before showing the feedback. It can be explained by the salient nature of the feedback: since the red rectangles appeared as a salient visual feature for the participants, their attention was drawn towards the feedback.

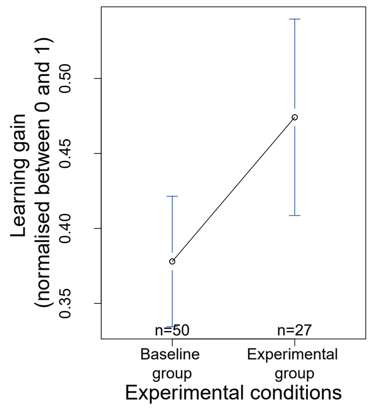

Figure 2: Learning gain for the experimental and baseline conditions.

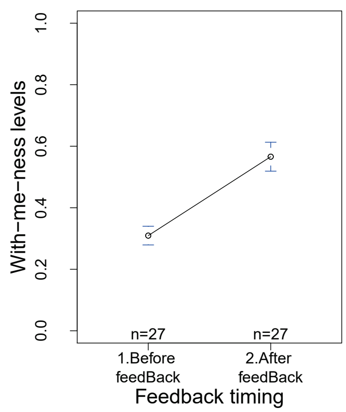

Figure 3: Immediate effect of feedback on With-me-ness.

Overall effect of feedback on gaze: In order to find the overall effect of the feedback on the participants' gaze, we divided the whole video in one minute episodes. Results from a linear mixed effect model showed that on average, participants' With-me-ness increased by 1% every minute. This improvement was significant over time (F [1, 26] = 32.60, p < .0001). Figure 4 shows the temporal evolution for the difference between the observed mean With-me-ness and the baseline With-me-ness for the participants; and the average number of times the feedback was shown to the participants. We can see in Figure 4 that, towards the end of the video, the difference increased and the number of feedback displayed decreased. This showes that the participants became more aware of the fact that they should follow the teacher in an efficient manner.

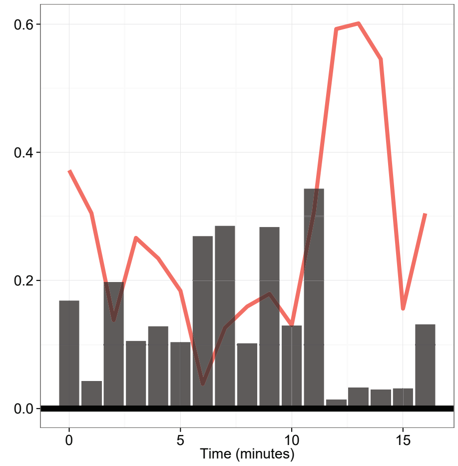

Figure 4: Overall effect of feedback on the gaze. The whole video was divided into one minute episodes. The red curve shows the difference between the observed and baseline With-me-ness (smoothed using a two minute rolling window). The bars denote the number of required feedback per participant per minute.

The significant long term effect on the With-me-ness indicates that the feedback had an effect on participants' attention in the terms of "how well they follow the teacher in both the deictic and dialogue spaces". One plausible interpretation of increase in With-me-ness over time could be that the participants internalized the fact that following the teacher during the MOOC video is important to understand the content and thus they started following the teacher more closely than before. This effect is also evident from Figure 4, where we can see that the difference between the baseline With-me-ness and the observed With-me-ness was higher during the second half of the video.

3. RELATED WORK

In this section, we present the previous studies demonstrating the relation between 1) gaze and dialogues, 2) gaze-awareness, and 3) learning analytics models proposed in the literature.

3.1 Gaze in communication and referencing

Gaze and speech are coupled. Mayer et. al.,[11] showed that the time duration between looking at an object and naming it is between 430 and 510 milliseconds. [7] showed that there exists an eye-voice span of about 900 milliseconds. The eye-voice span denotes the time between looking at a picture and start to provide a short explanation to it. Allopenna et. al.,[1] showed that the mean delay between hearing a verbal reference and looking at the object of reference (the listeners' voice-eye span) was between 500 and 1000 ms.

Richardson et. al.,[4] proposed the eye-eye span as the difference between the time when the speakers started looking at the referent and the time when listeners looked at the referred object. This time lag was termed as the cross-recurrence between the participants. The results show that the cross recurrence was correlated with the correctness of the answers given by the listeners in a comprehension quiz. The average cross-recurrence was found to be between 1200 and 1400 milliseconds.

Jermann and Nüssli[10] extended the concept of cross-recurrence in a pair programming task, by enabling the remote collaborators to share their selections on the screen. Results showed that the cross-recurrence levels were higher when there was a selection present on the screen than the times when there was no selections on the screen. Moreover, the cross-recurrence was higher, in the case, when a selection was followed by a verbal explanation.

Gergle et. al.,[6] conducted a dual eye-tracking study where the participants completed a collaborative reference elicitation task. The participants were given four replicas for the same sculpture. The key task for the participants was to find the correct replica. The authors found that the gaze overlap between the partners was lowest when the references were local as compared to when the references had location modifiers.

The notion of With-me-ness builds upon the combined notion of gaze-speech and gaze-deixis coupling. The two levels of With-me-ness, perceptual and conceptual capture the gaze-speech and gaze-deixis couplings respectively, for a teacher-student dyad.

3.2 Gaze-awareness

Gaze-awareness had been used to build intelligent tutoring systems [5, 15, 8], online collaboration support [12, 14]. D'Mello et. al., [5] used students' real time gaze information to inform the tutor about the boredom and engagement levels for selecting the dialogue moves for the virtual tutor accordingly. The authors found that the gaze-aware tutor was more effective in terms of both maintaining a higher engagement level and achieving a higher learning gain. Wang wt. al, [15] used students' gaze information to infer the tutor's strategy in terms of the instruction and feedback to be given, and the emotions of the tutor. The authors also used gaze as the interaction modality for students to interact with the system. In a preliminary usability test the authors found that such a feedback improved students' involvement with the learning processes. Gaze-awareness was also shown to be effective in improving the quality of online collaboration [12, 14].

The gaze-aware feedback tool that we propose, gives real-time feedback to the students based on their gaze. The key difference from the reviewed similar work is that we give the feedback directly to the students rather than providing it to a tutor. The system computes students' With-me-ness levels and gives them a visual feedback on the video lecture, if their With-me-ness levels fall below a certain threshold.

3.3 Learning analytics models

Clow [3], proposed a learning analytics cycle as a four-step loop: 1) identifying the learner population, 2) generating and capturing the data from the learners, 3) analysing the data to get insights about the learning processes, and 4) providing interventions to the learners based on the insights acquired.

Jermann [9], proposed learning analytics as a cybernetic control with four phases: 1) learner data collection, 2) selecting one or more indicators to represent the current state of learner, 3) diagnosis of the current state by comparing it to a desired state, and 4) proposition for a remedial action.

Chatti et. al., [2], proposed learning analytic process as a loop consisting of three phases: 1) learner data collection and pre-processing (finding patterns in the data), 2) data exploration based on the learning analytics objectives and taking appropriate actions, such as, prediction, assessment and recommendation, and 3) post-processing the newly acquired data.

4. GENERAL DISCUSSION

In this section, we revisit the learning analytics models summarized in Section 3.3 and use the results of the presented study, to argue that the notion of With-me-ness can create a complete theoretical framework for conducting gaze-based learning analytics in the context of MOOCs.

First, we consider the model proposed by Clow [3]. The example model for a gaze-based LA model is shown in Figure 5. The learner population is a subset of MOOC students (step 1). In our previous two experiments, we collected students' gaze data while they watched the MOOC videos (step 2). Further, we developed With-me-ness as a gaze-based indicator and we found that it is positively correlated to the learning gain (step 3). The experiment described in this paper uses With-me-ness as an indicator for building a gaze-aware feedback tool to notify students about their attention level (step 4). The results show that the feedback tool not only helped students to learn more but also improved their attention levels.

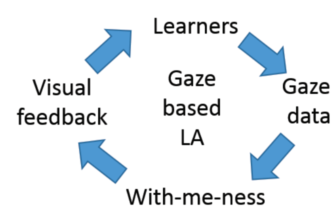

Figure 5: A gaze-based learning analytics model in compliance with the model proposed by Clow [3].

Second, we consider the model proposed by Jermann [9]. The gaze-based cybernetic control system is shown in Figure 6. We collect the gaze data of the students while they watch the videos (phase 1). We define With-me-ness as an indicator of the students' current state (phase 2). We create the desired learner state using the With-me-ness levels of the students from our previous studies (phase 3). Finally, the proposed gaze-aware feedback tool provides the feedback to the students about which part of the display that students should look at, if the measured With-me-ness is lower than desired With-me-ness at any instant (phase 4). The gaze-aware feedback tool acts as the key element in this gaze-based cybernetic control system.

Finally, we consider the LA model proposed by Chatti and colleagues [2]. The gaze-based LA model is shown in Figure 7. We collect the gaze data of the students and measure their With-me-ness (step 1). We found that students' With-me-ness is positively correlated with their learning gains (step 2). The gaze-aware feedback tool, we presented, monitors the With-me-ness levels of the students and give them the feedback about how much attention they are paying to the teacher (step 3).

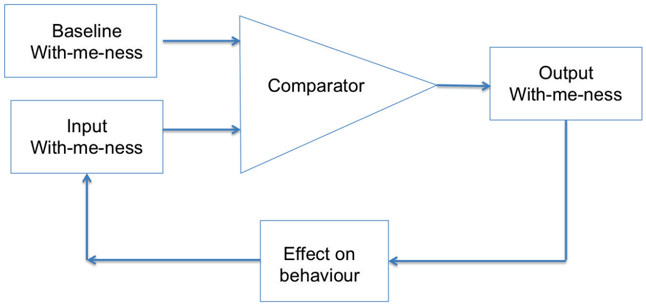

Figure 6: A gaze-based learning analytics cybernetic control model in compliance with the model proposed by Jermann [9].

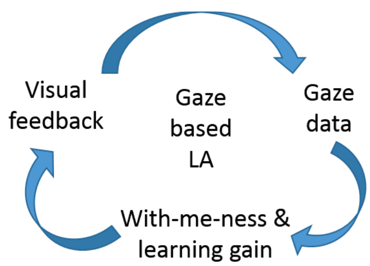

Figure 7: A gaze-based learning analytics model in compliance with the model proposed by Chatti and colleagues [2].

Succinctly, With-me-ness as a gaze-based variable can be used as a accurate learning analytic indicator for two purposes: 1) to quantify learners' attention, and 2) to design intervention tools to provide feedback to the learners to increase their attention levels as well as learning outcome. Moreover, the feedback tool completes the LA loops by intervening the learning process during the moments of lack of attention.

5. CONCLUSIONS

In a nutshell, the gaze-aware intervention in the learning process of the students had a positive effect on their attention. Provided that such a feedback is used during regular MOOC studies, this might have a long term impact on students' overall attention. Regarding our general research question about "how to improve the attention of the students during MOOC videos"; gaze-aware feedback emerged as a influencing tool for intervention.

Finally, we propose, as future work, to create the visual-feedback directly from the heat-map of students' gaze pattern, rather than eliciting it from the teachers' dialogue and deixis (as implemented in the presented system). This can construct a reliable method especially in the context of MOOCs as the number of students increases.

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