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Supporting learners' self-regulated learning in Massive Open Online Courses

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Massive Open Online Courses**

Abstract

In MOOCs, learners are typically presented with great autonomy over their learning process. Therefore, learners should engage in self-regulated learning (SRL) in order to successfully study in a MOOC. Learners however often struggle to self-regulate their learning. We implemented an SRL intervention in three MOOCs. The intervention consisted of three short videos containing SRL instruction and study suggestions to improve learners' SRL. We tested the effects of the SRL intervention on both learners' course completion as well as on learners' SRL. Learners' SRL was measured with trace data variables indicating SRL activity. The results showed that the intervention positively affected learners' course completion. Furthermore, the learners who complied with the intervention also engaged in more SRL activities compared to the learners in the control condition: learners who complied showed more metacognitive activities before learning (planning), help seeking, and persistence. Intervention compliance was however low. Further analyses exploring potential causes of the low intervention compliance were conducted. The great majority of learners who did not comply with the intervention dropped out of the MOOC before they encountered the implemented intervention. We conclude that the SRL intervention has been successful in supporting both learners' SRL as well as their course completion. Implications include the importance of supporting learners' SRL as well as the necessity to conduct further research on how to improve intervention compliance.

Keywords: intervention, MOOC, online learning, self-regulated learning, trace data

1. Introduction

In online education, learners typically have more autonomy over their learning process than in traditional, campus-based education. This is especially so in Massive Open Online Courses (MOOCs), a specific form of online education. In MOOCs, learners have the freedom to decide over the pace, place, and time of their learning. This autonomy provided to learners in MOOCs requires that learners engage in self-regulated learning (SRL; Littlejohn, Hood, Milligan, & Mustain, 2016; Wang, Shannon, & Ross, 2013; Zimmerman, 2000). Learners however often struggle to successfully regulate their learning process (e.g., Azevedo & Cromley, 2004; Bol & Garner, 2011; Dunlosky & Lipko, 2007; Peverly, Brobst, Graham, & Shaw, 2003). It is therefore important to support learners' SRL. In this study, we present an SRL intervention implemented in three MOOCs to improve learners' SRL as well as their course completion.

1.1 Self-regulated learning

In order to successfully deal with the autonomy offered in online education, learners have to engage in SRL. SRL entails that learners are actively involved in their learning, both metacognitively, as well as motivationally, and behaviorally (Zimmerman, 2002). SRL is split into three phases: the forethought, the performance, and the reflection phase. In the forethought phase, learners who self-regulate set goals and plan their learning. In the performance phase, learners work on the task, monitor their learning, seek help when needed and focus their attention. In the reflection phase, learners reflect on their progress and the cognitive strategies they used (Puustinen & Pulkkinen, 2001; Zimmerman, 2002).

The influence of SRL on course outcomes and academic achievement has been studied extensively. Meta-analyses have shown that the relationships between SRL and academic achievement and SRL and course outcomes are significant and positive across educational levels (Boer, Donker-Bergstra, Kostons, & Korpershoek, 2013; Broadbent & Poon, 2015; Dignath, Buettner, & Langfeldt, 2008; Dignath & Büttner, 2008; Sitzmann & Ely, 2011): when learners engage more in SRL, their achievement is enhanced. However, students differ in their abilities to accurately regulate their learning (e.g., Azevedo & Cromley, 2004; Bol & Garner, 2011; Dunlosky & Lipko, 2007; Peverly et

al., 2003). Therefore, scholars have invested much effort in exploring the effects of SRL interventions on SRL and achievement, reasoning that when interventions are successful in increasing students' SRL, their achievement will also increase. SRL interventions are, for instance, designed to inform learners about SRL strategies and the importance of SRL, or to prompt students to monitor and reflect on their learning, or to have learners track their learning in a diary (e.g., Berthold, Nückles, & Renkl, 2007; Dörrenbächer & Perels, 2016; Rosário et al., 2010). The effects of SRL interventions have been integrated in a number of meta-analyses. These meta-analyses consistently show that SRL interventions are effective both in improving learners' SRL knowledge and activities, as well as their course performance and overall academic achievement (Boer et al., 2013; de Bruijn-Smolters, Timmers, Gawke, Schoonman, & Born, 2016; Devolder, van Braak, & Tondeur, 2012; Dignath & Büttner, 2008).

1.2 SRL in Massive Open Online Courses

SRL becomes of greater importance for learner success when the learning process is less externally regulated (e.g., by the teacher). Learners must then manage their learning to a greater extent, making SRL more critical (Beishuizen & Steffens, 2011; Wang et al., 2013). Massive Open Online Courses (MOOCs) are a particular form of online education in which learners are provided with a great amount of autonomy (Hew & Cheung, 2014; Kizilcec & Halawa, 2015). MOOCs are courses offered by universities on designated MOOC platforms (e.g., edX and Coursera). These courses are free of charge and available to anyone with an Internet connection. There usually are no prior knowledge requirements. Due to their open character, MOOCs often attract hundreds to thousands of learners. In MOOCs, learners are free to study what, where and when they like. In terms of Anderson's framework of interaction equivalence (Miyazou & Anderson, 2013), most MOOCs are high on student-content interaction, but low on teacher-student and student-student interaction. Thus, learning occurs primarily through self-study. The autonomy offered to learners underpins the need for students to self-regulate their learning in order to be successful in a MOOC (Azevedo, 2005; Kizilcec, Pérez-Sanagustín, & Maldonado, 2017).

The necessity of SRL in MOOCs in combination with the increased number of MOOCs offered (Allen & Seaman, 2016) has made researching learners' SRL in this context topical and valuable. Initially, research on SRL in MOOCs and other forms of online education made use of questionnaires, showing positive correlations between self-reported SRL activity and course completion (Wang et al., 2013; Yukselturk & Bulut, 2007). Recently, however, trace data are increasingly used to study SRL. Trace data consist of information that is automatically stored as learners engage with the online course materials, for instance when they watch a video, submit their answer to a quiz question, or navigate to a page. This automatically stored log of all learner activities forms a trace of their learning behavior, hence the term *trace data*. Within the field of educational data mining, trace data have been used to identify variables related to student success (e.g., Lerche & Kiel, 2018; Theobald, Bellhäuser, & Imhof, 2018). Several researchers have attempted to use trace data as an indicator of learners' SRL. Kizilcec, Pérez-Sanagustín, and Maldonado (2017) for instance related learners' self-reported SRL to their trace data. The authors identified short sequences of activities (e.g., revisiting an assessment after completing a lecture) that occurred more commonly for learners that scored highly on their SRL scales (e.g., strategic planning, help seeking) compared to learners that scored low on that particular scale. Overall they found that learners who reported stronger SRL skills were more likely to revisit course materials they had already completed. Unfortunately, the authors did not explain these correlations; information on why specific SRL scales and activity sequences are associated is missing.

Maldonado-Mahauad, Pérez-Sanagustín, Kizilcec, Morales, and Munoz-Gama (2018) took a different approach and made use of trace data only. They first identified the most common patterns of activity between when a learner started a learning session and when the learner finished the learning session. These learning patterns were then labeled based on the activities that occurred. For instance, one of the patterns was labeled '*video lecture complete to assessment try*', as it involved the learner starting the session with watching a video and ending the session with working on an assessment. The authors then attempted to associate each of these six frequently occurring patterns to SRL strategies. '*Video lecture complete to assessment try*' was interpreted as self-evaluation, as the learner first studied material and then tested him/herself. While the labeling of the patterns is subjective, the results

of the study do show that learners engage with the course materials in different ways and that SRL interpretations of these patterns are possible.

In contrast to Maldonado-Mahauad et al. (2018), Min and Jingyan (2017) and Cicchinelli et al. (2018) took a top down approach to their analyses. In both studies, researchers defined a priori how instantiations of SRL would be visible in trace data. Min and Jingyan (2017) defined activities signaling each of the three phases of SRL, for instance, viewing the progress page was labeled as an instance of reflection, as course progress information helps learners review their performance. The majority of learners were classified as less-effective self-regulated learners as their trace data did not indicate activities in all three SRL phases. More effective self-regulated learners (i.e., those whose trace data showed activities in all three phases), showed greater persistence in the course and achieved higher course grades. Cicchinelli et al. (2018) related the frequency of learners' planning (e.g., viewing course organization information), monitoring (e.g., solving quizzes), and regulating (e.g., viewing content) activities to their course performance. The number of planning, monitoring, and regulating activities learners engaged in were all three strongly related to learners' course performance. In sum, these recent studies show that SRL can be identified in trace data. Furthermore, SRL detected in trace data seems to predict learners' success in these online environments.

1.3 Supporting SRL in MOOCs

The importance of SRL for successful MOOC learning has not only spurred research into measuring SRL with trace data; researchers have also started exploring the effectiveness of SRL interventions in this context. Kizilcec, Pérez-Sanagustín, and Maldonado (2016) asked 17 successful learners of a MOOC to write down study tips for those starting the MOOC. As an intervention, the tips were presented to half of the learners in a pre-course survey. These learners were asked to rate the usefulness of the tips. The learners in the control group were not presented the tips; they were presented the course topics and were asked to rate the usefulness of these topics for their career. To determine the effectiveness of the intervention, students' persistence (i.e., percentage of video lectures watched) and achievement (i.e., percentage of assignments completed with a passing grade) were measured. No differences were found between those learners who had and had not been presented the

study tips in the survey. The authors provided several explanations for the lack of significant differences, including that the intervention may have been too small and insufficiently integrated with the rest of the course.

Yeomans and Reich (2017) also implemented an intervention in a pre-course survey. They measured the effects of the intervention on course completion, in line with Kizilcec et al. (2016), as well as on course verification (i.e., buying the course certificate). The intervention of Yeomans and Reich (2017) was more strongly related to the course content and required more input from learners. In the voluntary pre-course survey, learners were randomly assigned to a control condition or a planning condition. In the planning condition, learners were asked to describe any specific plans they had for learning the course content and completing quizzes and assignments. The implemented planning prompts increased completion and verification rates. The results thereby showed that SRL interventions in MOOCs can be effective; achievement was improved by linking the intervention to the course content and prompting learners to engage in SRL.

Davis, Triglianios, Hauff, and Houben (2018) made an even stronger connection between the course content and the intervention, by integrating the intervention in the course environment instead of integrating the intervention in a pre-course survey. The intervention was presented to all learners. The effects of the intervention were studied by comparing the learners who complied with the intervention with the learners who did not interact with the intervention (self-selected control group). The intervention consisted of asking learners to express their motivation to follow the course. This motivation expression was presented back to learners while learners studied the course content. The intervention furthermore entailed asking learners to indicate how many videos they would watch, how many quizzes they would make, and how much time they intended to spend in the course in the upcoming week. Progression towards these self-set goals was visually depicted in the course environment. Those who complied with the intervention (i.e., submitted at least one weekly motivation expression and one weekly plan) engaged in the course to a much greater extent (e.g., time spend, videos watched, quizzes made), than those who did not comply. However, causality could not be established as all learners were presented with the intervention. Those learners who complied with the intervention may have differed from the learners in the self-selected control group before the

intervention; for example, those who were more active in the course may have self-selected to also engage with the intervention.

From these studies measuring and improving learners' SRL in MOOCs, we identify several implications. First, research on SRL interventions in MOOCs is sparse and more research is needed to learn how SRL can be supported in these learning environments. Second, having learners comply with the intervention is challenging, which is a common problem in SRL support research (Clarebout & Elen, 2006; Clarebout, Horz, Schnotz, & Elen, 2010). Therefore, an intervention that is embedded in the course, that stimulates learners to think about and improve their SRL, is likely to be most effective. Third, while researchers are trying to identify instances of SRL in trace data, effects of SRL interventions have been measured in terms of simple interaction frequencies, course completion, and verification. We consider it worthwhile to combine these strands of research into SRL in the context of MOOCs. We thus propose measurement of the effects of an SRL intervention on SRL indicators obtained from trace data, in addition to measuring the effects of an SRL intervention on SRL with a questionnaire. Not only would such a study lead to greater insight into the effects of SRL interventions, but it would also shed light onto *why* SRL interventions improve course completion. Therefore, we propose a study in which the effects of an SRL intervention are measured on course completion *and* on SRL activity, with the latter measured with both a questionnaire as well as with trace data.

1.4 Current study

In the current paper, we present the results and implications of an SRL intervention study. Learners in three MOOCs were randomly divided over a control and an intervention condition. The intervention focused on all three phases of Zimmerman's model of SRL, to improve the effectiveness of the intervention and to help learners understand the relations between the different phases (Schmitz & Wiese, 2006). We measured the effects of the intervention both on learners' SRL as well as on their course completion. Following suggestions for SRL research, we pay special attention to the coupling between SRL theory, the intervention and the SRL measures (Kizilcec et al., 2017; Pérez-Álvarez, Maldonado-Mahauad, & Pérez-Sanagustín, 2018).

The following research questions were formulated:

1. Does an SRL intervention in a MOOC affect learners' SRL as (a) measured with a self-report SRL questionnaire, and (b) measured with SRL indicators in trace data?
2. Does an SRL intervention in a MOOC affect learners' course completion?

2. Method

2.1 Participants

Data were gathered in three MOOCs. The MOOCs were titled Child Development, Clinical Epidemiology, and Human Rights. In each MOOC, participants were randomly divided over two versions of the course: an experimental version and a control version. In total, 2,426 learners enrolled in one of the three MOOCs. However, there is a large difference in the number of learners who enroll in a MOOC and the number of learners who actually log in to the course at least once and engage in any activity (Davis et al., 2018; DeBoer, Ho, Stump, & Breslow, 2014; Jordan, 2014). In our sample, 955 out of the 2,426 enrolled learners (39%) never engaged in any behavior within the MOOCs. These learners were excluded from further analyses. A distribution of the learners included in the analyses over conditions and MOOCs is presented in Table 1. As Coursera stopped the collection of demographic information with a voluntary survey in March 2015 and no longer allows collection of such data, demographic information is available for only 80 learners who enrolled in one of the MOOCs (44 of which were active learners). We therefore do not report learners' demographics.

Table 1.

Distribution of learners over conditions and over MOOCs.

		Child Development	Clinical Epidemiology	Human Rights
Enrollments (<i>n</i> = 2,426)	Control	721	148	337
	Intervention	723	160	337
Active learners (<i>n</i> = 1,471)	Control	438	98	175
	Intervention	469	114	177

2.2 Context

The experiment was conducted in three MOOCs offered by a Dutch university on Coursera. Although each MOOC covered a different domain (social sciences, law, medicine), the instructional design of the MOOCs was similar. In each MOOC, content was split into different course modules, each of which had a specific topic. All MOOCs had five modules containing the main content, and one final module containing a final exam. The MOOC on Clinical Epidemiology also had a separate introductory module at the start of the MOOC (total of seven modules). For the other two MOOCs, the first content module started with a course introduction (total of six modules). The content modules in all MOOCs contained a mixture of videos and readings. Course materials were alternated with quiz questions in all three MOOCs, and all content modules ended with a quiz on the content of the whole module. A distinction was made between graded quizzes and practice quizzes. Graded quizzes counted towards the course grade and were mandatory for students who wanted to obtain the course certificate. Practice quizzes were highly similar to graded quizzes, as they had a threshold to pass and a deadline, but they were voluntary and did not count towards a learner's course grade. The MOOCs on Clinical Epidemiology and Human Rights both had only one practice quiz, all other quizzes included in the MOOCs were graded. The MOOC on Child Development only included practice quizzes: both the short quizzes in between videos as well as the larger quizzes at the end of modules were not graded. All MOOCs also contained several peer-graded assignments which counted towards the course grade. In the MOOC on Child Development these peer-graded assignments were the only graded components. Both graded quizzes as well as peer-graded assignments were assigned a weight by the course designer. The total weight of graded items always sums to 100%. Learners' course completion was calculated by summing the weight of the graded items (i.e., quizzes and assignments) they had passed.

The MOOCs had a fixed start date before which learners had to register. When registering for the MOOC, learners could access all materials of the first module. When the MOOC started, all other materials (module 2-6 or 2-7) became available for learners. Learners could then view all videos, access all readings, and work on quizzes and peer-assessed assignments. The suggested pace of the MOOCs was one module per week. This pace was enforced on learners as the quizzes and assignments all had deadlines. The deadline for the quizzes in module 1 was one week after the start of the MOOC;

the deadline for quizzes and assignments in module 2 was two weeks after the start of the MOOC, and so on. Quizzes and assignments could however still be completed after their deadline had passed; their final (and real) deadline was the course end which was six or seven weeks after the course start. The deadlines thus solely functioned to help learners regulate their learning. Videos and readings were accessible all throughout the duration of the course. After the final deadline - six weeks after the start of the MOOCs with six modules and seven weeks after the start of the MOOC with seven modules - the courses closed.

All throughout the course, learners could access information about the course goals and structure through the Course Info page. Information on graded assignments (due date, weight, passing status yes/no, and grade) was always available through the Grades page.

2.3 Intervention

learners were randomly divided over the control and experimental versions of the courses upon enrollment. The educational materials in both versions of the courses were identical. The intervention materials added to the experimental version of the course were the only difference between the two versions.

To support learners in all three phases of Zimmerman's model of SRL, the intervention consisted of three parts: part one on the forethought phase, part two on the performance phase, and part three on the appraisal phase (Becker, 2013; Dörrenbächer & Perels, 2016; Zimmerman, 2002). By supporting learners' SRL in all three phases, learners not only learned about SRL and SRL activities, but also about the interconnections between phases (Schmitz & Wiese, 2006). The phases were presented to learners as the '*preparation phase*', the '*action phase*', and the '*reflection phase*' to ease understanding. Each part of the intervention consisted of (i) a short video (3-4 minutes) with information on the three-phase model of SRL and several suggestions on how to improve SRL in the phase the video focused on. The presenter in the videos was a peer model who introduced himself at the start as a student who had previously taken the course. A peer model was chosen to increase the similarity between learners and the presenter, and to improve learners' belief in the usefulness and attainability of the suggestions (Bandura, 1994; Rosário et al., 2010; Wischgoll, 2016). As there were

likely large differences with respect to learners' ability to regulate their learning, three or four different suggestions were given in each video. Thereby we attempted to appeal to the large diversity of learners (Masui & De Corte, 2005). After the video, (ii) learners were asked to rate the usefulness of each of the suggestions given on a 5-point Likert scale with the endpoints labeled 'not useful' (= 1) and 'very useful' (= 5). These questions served a dual purpose. First, they required students to evaluate the advice and thus to reflect on it. Second, the questions served to determine if the intervention resonated with learners' needs. After the closed-questions, learners were (iii) presented an open-ended question asking them to indicate how they could improve their learning in the SRL phase. This open question was a prompt for learners to apply the advice to their own learning process.

In the first video, three suggestions were given on how to improve one's learning in the preparation phase (SRL activity indicated in *italics*): (a) check the course content on the Course Info page to help you with goal setting (*goal setting*), (b) set time for learning (*planning/time management*), and (c) make your planning specific and concrete (*planning*). The advice for the action phase was structured into two steps. Step one focused on monitoring and provided learners with two suggestions to monitor their learning: (a) note-taking or (b) taking quizzes (*monitoring*). Step two focused on actions to take when a gap in knowledge is detected: (a) increase focus by taking a short break or by taking notes (*persistence*) or (b) seek help on for instance the course forum (*help seeking*). The third video focused on the reflection phase. Three suggestions were given: (a) think about what you learned (*reflection*), think about how you learned (*strategy regulation*), and think about what you will do the next time you learn (*planning*).

To help learners understand the relation between the three videos, the SRL model was presented at the start and at the end of each video. The presenter explained the relationship between the three phases and indicated the phase the current video focused on. The presenter furthermore referred to the other videos (e.g., "*in the next video I will be giving you some tips and tricks on the reflection phase, the last phase you encounter during learning*"). The SRL model and the SRL suggestions were depicted when they were mentioned, thereby presenting the information in two modalities to help learners comprehend the material (Low & Sweller, 2014). As with all videos in

Coursera, transcripts of the videos were provided to learners. Screenshots of the SRL videos are presented in Figures 1 and 2.

All intervention materials were embedded into the course structure to make sure learners automatically came across the videos and questions, as learners are unlikely to actively look for help (Clarebout & Elen, 2006; Clarebout et al., 2010; Davis, Chen, Van der Zee, Hauff, & Houben, 2016). The video and questions on the preparation phase were added to the first content module (module 1 for the MOOCs on Human Rights and Child Development, and module 2 for the MOOC on Clinical Epidemiology). The intervention on the action phase was added to the second content module, and the intervention on the reflection phase was added to the third content module. The intervention materials were included after the final content materials of the module, but before the final quiz of the module.

The scripts of the intervention videos and the questions presented to learners are available as online supplementary material.

2.4 Measures

2.4.1 SRL questionnaire. Learners' SRL was measured with the Self-regulated Online Learning Questionnaire – Revised (SOL-Q-R; Anonymous, 2018) at the start and at the end of each course. Learners were invited to fill out the questionnaire as a voluntary activity within the learning environment. The questionnaire consisted of 42 items divided over 7 scales: metacognitive activities before learning (7 items, $\alpha = .87$), metacognitive activities during learning (7 items, $\alpha = .80$), metacognitive activities after learning (6 items, $\alpha = .85$), time management (5 items, $\alpha = .69$), environmental structuring (4 items, $\alpha = .81$), persistence (7 items, $\alpha = .86$), and help seeking (6 items, $\alpha = .92$). A total of 193 learners filled out the SOL-Q-R, 96 learners in the control condition and 97 learners in the intervention condition.

2.4.2 Course intention. Learners were asked to indicate their course intention in the pre-course questionnaire, which furthermore contained the SOL-Q-R. Course intention was measured with a single item: "In this course I intend to ...". The answering options ranged from 'browse' (= 1) to 'participate in 100% of the learning activities and strive for a certificate' (= 8; Henderikx, Kreijns, & Kalz, 2017).

2.4.3 Course evaluation. The post-course questionnaire contained several questions measuring learners' course experience in addition to the SOL-Q-R. Learners were asked to grade the course on a scale of 1-10, to rate the course workload and course difficulty on a scale on a 5-point scale ranging from 'too light' (= 1) to 'too heavy' (= 5), and to indicate if the number of hours spent on the course was according to their expectations. Learners in the intervention condition were then asked for their opinion, both positive and negative, of the SRL videos. The final open-ended questions in the course evaluation, posed to both groups, were what they liked most about the course and what they liked least about the course. Since only 21 learners filled out the course evaluation, these data were not used for further analyses.

2.4.4 SRL indicators in trace data. All learners' activities in Coursera were stored on the platform's server. Activities stored include, but are not limited to, video interaction events (play, pause, stop, seek), quiz interaction events (open quiz, submit answers), marking readings as completed, submitting assignments and assessing peers, visiting and posting on the forum, and navigating between pages. Video interactions were stored every five seconds. This type of trace data is known as *heartbeat data*. Furthermore, progress records showed learners' scores on quizzes and assignments, and the course materials they had completed. By keeping track of all these activities with a timestamp, the trace data formed a trace of a learner's path through the course.

By extracting variables from the trace data related to SRL, the influence of the intervention on learners' SRL was assessed. Below, the list of variables extracted in the current study is presented. In total, 12 variables were extracted from the trace data. For each variable, the aspect of SRL measured is indicated, as well as how the intervention may have influenced the variable measured.

2.4.4.1 Accessing overall course information. The Course Info page provided learners with general information on the course: the topics of the modules, a list of materials per module, and a list of graded elements per module. The Course Info page furthermore provided learners with an indication of the time required per module, the level of the course and more information on the requirements to pass the course. This information is valuable for learners as it helps them with goal setting and planning. Cicchinelli et al. (2018) found the frequency of accessing course information (both general info and detailed week by week info) to be significantly correlated to quiz scores ($r =$

.69) and final exam scores ($r = .60$). In the video with suggestions for the preparation phase, learners were specifically instructed to visit the Course Info page to help them set goals. The *number of visits to the Course Info page* was therefore included as a variable indicating goal setting and planning, which are metacognitive activities before learning.

2.4.4.2 Accessing weekly course information. The weekly course information provided learners with a more detailed overview of the materials per week. In addition to a listing of the materials, quizzes, and assignments (which was also presented on the Course Home and the Course Info pages), an indication of the time necessary to complete each element was given. Accessing this information is related to achievement, as explained above (Cicchinelli et al., 2018). Information on the time needed to complete materials is necessary to make a specific, realistic and time-bound planning. Creating such a planning is known to be related to course completion and course verification (Yeomans & Reich, 2017). The *number of times a learner accessed a weekly overview page* was thus included to indicate goal setting and planning, both metacognitive activities before learning.

2.4.4.3 Pausing videos. By pausing the video, learners could control the pace in which information was presented to them (i.e., self-pacing principle; Van Merriënboer & Kester, 2014), and they could segment the video into meaningful units (i.e., segmenting principle; Mayer & Chandler, 2001; Mayer & Moreno, 2003; Van Merriënboer & Kester, 2014). As learners' working memory is limited, and overloading working memory hampers learning, segmenting and self-pacing may serve an important function in reducing learners' cognitive load. In addition, self-pacing and segmenting facilitate elaboration and deep processing. Learners are for example likely to take notes when they pause a video for a short amount of time. For this reason, pausing is considered a monitoring activity and beneficial for learning. In the action phase video, pausing videos and monitoring one's comprehension by taking notes were therefore recommended. The *number of times a learner paused a video* was included to indicate monitoring which is a metacognitive activity during learning. To control for differences between learners in the amount of time spent watching videos, the number of pauses was calculated as the average number of pauses per minute.

2.4.4.4 Handling failed quizzes. For each quiz, a predefined percentage of questions had to be answered correctly to pass the quiz. However, failing a quiz did not mean that the learner could not

continue in the MOOC. Practice quizzes were voluntary and thus did not influence the learner's score. Graded quizzes influenced learners' performance, but learners could pass the course if enough other quizzes and assignments were passed. Nevertheless, failing a quiz did indicate that the learner did not sufficiently comprehend the material, as was explained in the action phase video. If learners restudied the material tested in the quiz, they acknowledged the gap in their knowledge. Learners were then likely to focus on those parts of the learning material that they had not understood correctly (Dirkx, Thoma, Kester, & Kirschner, 2015). The *percentage of instances learners, after a failed quiz (either practice or graded), moved back to materials previously in the module, instead of continuing the course*, was therefore considered an outcome of monitoring, a metacognitive activity during learning.

2.4.4.5 Accessing the course forum. The course forum provided learners an easy option to find help when they had trouble understanding the course materials or understanding the right quiz answers. Browsing and/or posting on the forum was therefore suggested as a help seeking strategy in the action phase video, especially considering that accessing the course forum is related to course completion (Kizilcec, Piech, & Schneider, 2013). The *number of times a learner accessed the forum* was analyzed to indicate help seeking, a variable that was independent of whether they browsed or posted as both activities are suitable for help seeking.

2.4.4.6 Accessing grade information. The course grade page provided learners with an overview of the graded quizzes and assignments in the course, the learner's grades and the learner's overall course progress. Metacognitive reflection involves reflecting on one's progress, and deciding on what still needs to be done in order to achieve one's goal (Winne & Hadwin, 1998; Zimmerman, 2002). Information on the goals to be attained and the current progress, as presented on the course grade page, could therefore be considered critical for reflection (Min & Jingyan, 2017). In the reflection phase video, learners were stimulated to think about what they learned and how they would continue the next time they worked on the course. Therefore the *number of views of the course grade information* was analyzed as indicating metacognitive activity after learning.

2.4.4.7 Completing course materials on time. The three MOOCs were designed for a pace of one module per week. Learners were thereby stimulated to engage in regular study behavior. Regular studying (i.e., staying on track) was found to be positively associated with course grade in previous

online education studies (Cicchinelli et al., 2018; Goda et al., 2015; You, 2016). In order to engage in regular studying, learners must be able to adequately manage their time. The intervention was aimed at helping students plan, monitor, and reflect on their learning, thereby also supporting their time management. The *ratio of materials (i.e., videos and readings) completed on time (in or before the week they were due)* was included in the analyses as an indicator of learners' time management. To control for differences between learners in course completion, the ratio of materials completed on time was calculated by dividing the number of materials that were completed on time, by the total number of materials completed.

2.4.4.8 Passing quizzes and assignments on time. In each module, the videos and readings were combined with quizzes and assignments. In order to engage in regular studying, both types of learning activities should be completed on time. The videos and readings however differed from the readings and assignments in two ways. First, quizzes and assignments had deadlines, while materials did not. Second, one could decide to attend the course without passing the quizzes and assignments. Furthermore, assignments and quizzes also differed from each other. Practice and graded quizzes were scored automatically and had to be passed. Assignments, in contrast, were peer-assessed and had to be handed in on time. Handing in assignments late is related to lower course achievement (You, 2016). Due to the differences between quizzes and assignments, we calculated variables for these two course components separately. The *ratio of practice and graded quizzes passed on time (in or before the week they were due)* and the *ratio of assignments handed in on time (in or before the week they were due)* were included in the analyses as additional indicators of learners' time management. To control for differences between learners in course completion, the ratio of quizzes passed on time was calculated by dividing the number of quizzes that were passed on time, by the total number of quizzes passed. For the same reason, the ratio of assignments handed in on time was calculated by dividing the number of assignments handed in on time, by the total number of assignments handed in.

2.4.4.9 Persistence. For successful learning, learners should focus their attention, and persist when they are struggling (Zimmerman, 2002). In the action phase video, learners were presented with strategies on how to keep focused (e.g., find help, take notes). If the intervention helped learners to regulate their effort, learners would be expected to complete a higher percentage of the videos and

practice and graded quizzes they started. We did not expect them to *pass* the quizzes they started, but they should *finish* them. Therefore, the *ratio of video persistence* and the *ratio of quiz persistence* were included in the analyses to measure learners' persistence. To control for differences between learners in course completion, the ratio of video persistence was calculated by dividing the number of unique videos completed, by the number of unique videos started. For the same reason, the ratio of quiz persistence was calculated by dividing the number of unique quizzes finished, by the number of unique quizzes started.

If the intervention supported learners' persistence, then we would also expect learners to persist further in the course and thus to complete a greater number of videos and readings. The *ratio of videos and readings completed* is therefore incorporated in the analyses as course persistence, an additional measure of learners' persistence. To control for differences in the number of materials between the three MOOCs, the ratio of course persistence was calculated by dividing the number of unique videos and readings completed by the number of videos and readings in the MOOC.

2.4.5 Course completion. Problems with SRL are known to result in learners not attaining their intended goals (Kizilcec & Halawa, 2015; Zheng, Rosson, Shih, & Carroll, 2015). If the intervention successfully supported learners' SRL, more learners should have been able to attain their goal. Overall course completion should then be higher for learners in the intervention condition compared to overall course completion for learners in the control condition. Course completion was defined identically to the definition of course success in the MOOCs. Each graded course item (i.e., graded quizzes and peer-assignments) had a weight assigned by the course designers. The sum of the weight of all graded items in a MOOC is always 100%. Course completion was calculated by adding the weight of all passed assignments and graded quizzes. For instance, if a learner passed 3 quizzes, all with 8% weight, 2 peer-assessed assignments both with 10% weight, and the final exam with 30% weight, then the learner completed 74% of the course ($3 \times 8 + 2 \times 10 + 30$).

2.5 Analyses

In the performed analyses, we did not differentiate between learners in different MOOCs, as we were not interested in differences between courses. In all analyses, we only included data from

learners who engaged in *some* activity in the course. Therefore in the first step, all learners who did not engage in any activity in the course were filtered from the data. These learners did not start watching a video, did not start a quiz, did not open a reading, nor did they look at the course information. In the second step, learners in the intervention and control conditions were compared on their SRL as reported with the SOL-Q-R at the start of the courses. No differences between the control and intervention group were found on any of the seven scales included in the questionnaire. In the third step, the trace data variables described in the previous section were calculated. The script used to calculate the variables from the Coursera trace data is available as supplementary material (online only). While the script contains all information necessary to replicate calculation of the trace data variables, we would like to mention several details of the calculations here, as they are important for a correct interpretation of the results presented.

When counting the number of visits to the course forum, only visits to the content pages of the forum were included. We excluded visits to the ‘introduce yourself’ page of the forum and to pages discussing ‘technical difficulties’. As introducing yourself and posing technical problems with the MOOC itself do not constitute seeking help with comprehending the content of the MOOC. Videos were counted as completed by the learner if the learner watched at least 80% of the video. Learners’ video watching behavior was calculated with the *heartbeat data*. A so-called *heartbeat* was stored for every five seconds a learner watches or pauses a specific video. The heartbeat data thereby allows for accurate calculation of amount of time spent watching videos and the number of videos completed (defined as $\geq 80\%$ in the current study). Intervention videos were not included in the number of videos started or completed, nor were they included in the total number of videos in the MOOC, nor in the amount of time spent watching videos, as the inclusion of the intervention videos would lead to differences in the total amount of videos available between the intervention and the control condition, and potentially also to differences in the total amount of videos started, videos completed, and time spent watching videos.

In the fourth step, the extent to which learners in the intervention condition *complied* to the intervention (i.e., if they watched the intervention videos) was calculated. The amount of time spent watching the intervention videos was calculated by using the heartbeat data, as explained above.

Intervention compliance was very low. Therefore, we considered all learners who watched at least one of the intervention videos for more than 50% ‘intervention compliers’ ($n = 76$). We thus did not differentiate between watching one, two, or three intervention videos. As all intervention videos contained information about the three phase model of SRL (preparation, action, reflection) at the start and the end of the video, all learners watching 50% of one of the videos would have, at least, been introduced to this model. Furthermore, after watching one of the videos for $\geq 50\%$ the learner would also have, at least, been given several study suggestions for the SRL phase the video focused on. In Table 2, an overview is given of the statistics concerning intervention compliance. The low intervention compliance is further analyzed with explorative analyses in the Results section.

Table 2.

Frequency distribution of the number of intervention videos watched by learners in the intervention condition.

Number of intervention videos watched for 50% or more	0	1	2	3
<i>n</i>	684	41	20	15

Subsequently, *t*-tests were conducted for two types of comparisons to test whether the SRL intervention affected learners’ SRL as measured with SRL indicators in the trace data. In the fifth step, the trace data variables were compared between the intervention and control group. This first group of comparisons is called *intention to treat (ITT)* analyses, as they also include learners in the intervention condition that did not adhere to the intervention (Lamb, Smilack, Ho, & Reich, 2015). Bootstrapping was used to conduct the independent samples *t*-tests, as the data were highly zero-inflated and thereby strongly deviated from a normal distribution (Field, 2018). In the sixth step, *treatment on treated (TOT)* analyses were conducted (Lamb et al., 2015). For this second group of comparisons only learners who complied with the intervention were included from the intervention condition. The trace data variables were compared between these compliers and all learners in the control condition. It was not tested whether the SRL intervention affected learners’ SRL as measured with the SOL-Q-R since only 21 learners filled out the post-course questionnaire.

To answer the second research question, the seventh step entailed analysis of learners' course completion. Course completion was compared both between the control and the intervention group (ITT analysis) as well as between the control group and those who complied with the intervention (TOT analysis). In both cases, independent samples t-tests with bootstrapping were conducted.

3. Results

3.1 RQ 1: Does the SRL intervention affect learners' SRL?

We attempted to measure the effect of the SRL intervention both on learners' self-reported SRL as measured with a questionnaire, as well as on SRL indicators in the trace data. As the post-course SRL questionnaire was filled out by only 21 learners, we did not have sufficient data to compare pre- and post-course scores, and we do not further report on these results.

To determine whether the SRL intervention affected learners' SRL as measured with SRL indicators in the trace data, the trace data variables described in the Method section were calculated. Whether learners moved back to material previous in the MOOC after failing a quiz, was described as an indicator of monitoring behavior. However, failing quizzes occurred very infrequently. In the control group, 32 learners had failed a quiz and in the intervention group 25 learners had failed a quiz. Therefore, the variable 'handling failed quizzes' could be calculated only for a small group of learners. This sample size was too small to conduct bootstrapping analyses. The variable 'handling failed quizzes' was therefore not incorporated in the analyses conducted.

Figures 3A-3K present graphical overviews of the SRL indicators in the trace data for the control group, the intervention group, and the compliant group (a subset of the intervention group). Since the groups are highly dissimilar in size, the x-axis does not represent the number of learners, but the distribution quantile. The graphs show that large numbers of learners engage in the MOOC only minimally. The graphs also indicate that those who comply with the intervention self-regulate their learning to a greater extent than the intervention and control groups. The descriptives of the SRL indicators for the three groups can be found in the Appendix.

ITT analyses were performed comparing the SRL indicators between learners in the intervention and control conditions as described in the Analyses. The results of the ITT analyses are

presented in columns 2-7 in Table 3. Columns 8-13 of Table 3 contain the results of the TOT analyses that were performed to compare the SRL indicators between learners in the control group and the intervention compliers. No significant differences were found for the SRL indicators in the trace data between the learners in the intervention and the control conditions (ITT analyses). However, significant differences in the SRL indicators in the trace data were found when comparing the learners in the control condition to only those learners in the intervention condition that complied with the intervention (TOT analysis). Learners who complied with the intervention visited the course info page (metacognition before learning), the weekly course info pages (metacognition before learning), and the forum (help seeking) more often than learners in the control condition. Learners who complied with the intervention also completed a greater proportion of the videos and quizzes they started (persistence). Furthermore, compliers completed a greater proportion of the videos in their course (persistence). These results all point to higher frequencies of SRL activities for learners who complied with the intervention.

Table 3.

Results of the ITT and TOT analyses of the SRL indicators in the trace data and learners' course completion data.

	Comparison control - intervention (ITT)						Comparison control – comply (TOT)					
	Mean diff.	df	t	p	Hedges' g	95% CI	Mean diff.	df	t	p	Hedges' g	95% CI
Course info (c)	0.07	1469	0.97	.36	0.05	[-0.08;0.22]	-1.30*	78	-3.60	.01	-0.80	[-2.03;-0.66]
Weekly course info (c)	-1.19	1435	-1.04	.30	-0.05	[-3.45;0.98]	-37.61**	77	-6.01	<.01	-1.51	[-50.32;26.99]
Pauses/min video (r)	-0.02	720	-0.21	.86	-0.02	[-0.19;0.16]	0.01	426	0.05	.96	0.01	[-0.26;0.22]
Forum (c)	-0.14	1310	-1.49	.14	-0.07	[-0.31;0.03]	-2.21*	76	-4.05	.01	-1.14	[-3.40;-1.22]
Grade info (c)	-0.36	1131	-2.04	.07	-0.10	[-0.71;-0.03]	-4.29	76	-3.21	.05	-1.04	[-7.29;-2.01]
Materials on time (r)	-0.02	1211	-1.52	.14	-0.09	[-0.05;0.01]	0.04	681	1.33	.14	0.16	[-0.02;0.10]
Quizzes on time (r)	-0.02	262	-0.41	.69	-0.07	[-0.13;0.08]	-0.05	111	-0.83	.42	-0.14	[-0.18;0.07]
Assign. on time (r)	-0.07	187	-1.09	.27	-0.16	[-0.20;0.06]	-0.13	104	-1.78	.08	-0.30	[-0.29;0.02]
Video persistence (r)	-0.02	720	-0.70	.50	-0.07	[-0.09;0.04]	-0.20**	146	-4.67	<.01	-0.47	[-0.28;-0.12]
Quiz persistence (r)	-0.00	1075	-0.20	.86	0.00	[-0.05;0.04]	-0.40**	89	-7.78	<.01	-1.09	[-0.50;-0.30]
Course persistence (r)	0.00	1469	0.32	.77	0.05	[-0.02;0.02]	-0.38**	80	-9.26	<.01	-1.80	[-0.46;-0.30]
Course completion	-0.02*	1416	-2.13	.04	-0.15	[-0.041;-0.002]	-0.37**	77	-7.40	<.01	-1.18	[-0.47;-0.27]

Note. Variables marked with 'c' concern counts of activities; variables marked with 'r' concern ratios. Bootstrapping analyses conducted with 1000 samples.

* $p < .05$, ** $p < .01$

3.2 RQ 2: Does the SRL intervention affect learners' course completion?

Course completion was calculated by summing the weight of all graded quizzes and assignments passed by the learner, as described in the Method section. Thus, learners could pass between 0 and 100% of graded course items. Learners' course completion in the control and intervention conditions, as well as the course completion of the intervention compliers, is visualized in Figure 3L. To determine whether the SRL intervention affected learners' course completion, course completion was compared both between the control and the intervention group (ITT analysis), as well as between the control group and those who complied with the intervention (TOT analysis). The results of these analyses are presented in Table 3. Both analyses indicate that the intervention significantly improved learners' course completion.

3.3 Low intervention compliance

Intervention compliance was low: only 10% of the learners in the intervention condition who engaged in any behavior in the course watched one or more of the intervention videos for at least 50%. To better understand the low intervention compliance, we performed five additional, exploratory analyses. Only learners in the intervention condition who engaged in some behavior in the course are included in the exploratory analyses, and we compare the learners who complied with the intervention (*compliers*) with the learners who did not comply with the intervention (*non-compliers*).

First, learners' self-reported SRL at the start of the course was compared between the compliers and non-compliers to determine if differences in SRL already existed before the start of the course. The SRL scores did not differ significantly between the compliers and the non-compliers on any of the seven scales included in the SOL-Q-R. It is thus unlikely that non-compliance with the intervention was the result of pre-existing differences in SRL.

Second, learners' course intentions were compared between the compliers and non-compliers to determine if differences in intentions existed at the start of the course. Course intention was greater for learners who complied with the intervention than for learners who did not comply with the intervention ($M_{\text{comply}} = 7.35$; $M_{\text{non-comply}} = 6.50$; $t(df) = -3.37(116)$, $p < .01$). Learners course intentions might therefore explain why some learners in the intervention condition complied with the

intervention while others did not. To test whether course intentions influenced our results, we conducted the TOT analyses for the SRL indicators and course completion for a second time, only this time with groups matched on course intention. For compliers, the minimum reported course intention was 4 (*participate in 40% of the course*). For the matched group analyses, all intervention compliers who filled out the questionnaire ($n = 37$) were compared with those in the control group who reported course intention ≥ 4 ($n = 133$). The differences between the control group and intervention compliers remained significant for the following SRL indicators: visiting the course info (metacognition before learning; $t(df) = -2.95(40)$, $p = .01$), visiting the weekly course info (metacognition before learning; $t(df) = -3.73(42)$, $p < .01$) and visiting the course forum (help seeking; $t(df) = -2.63(39)$, $p = .049$). Furthermore, significant differences remained in quiz persistence ($t(df) = -3.93(70)$, $p < .01$) and course persistence ($t(df) = -5.39(168)$, $p < .01$). The only SRL indicator that no longer differed significantly between the control group and the compliers was video persistence (i.e., ratio of videos started that are completed; $t(df) = -1.81(92)$, $p = .07$). Course completion also remained significantly greater for those who complied with the intervention than for the learners in the control group, after matching the groups on course intention. We therefore conclude that, while the intervention compliers had greater course intentions than the learners in the control group and those who did not comply with the intervention, the differences in course intentions do not explain the differences in SRL indicators and course completion found with TOT analyses.

The third and fourth exploratory analyses both attempted to determine if the advice that was given in the intervention videos had been helpful for the learners. The number of learners who started watching the intervention videos was determined. If a large number of learners started the intervention videos, but stopped before watching 50%, this could signal that learners stopped watching the videos because the videos in some way did not match their needs. We also calculated the average usefulness of the study suggestions in the videos as rated by the learners. The results of both analyses indicated that the intervention videos were useful for the learners. The great majority of learners who started watching an intervention video also continued watching the intervention video for 50% or more. The average usefulness rating of the videos was 4.09 for the preparation phase, 4.11 for the action phase, and 4.08 for the reflection phase on a scale of 1 to 5. Tables 4 and 5 present an overview of these

results. Thus, a lack of usefulness of the intervention videos was not a likely explanation for non-compliance either.

Table 4.

Number of learners who started and completed watching the intervention videos.

		<i>n</i>
Preparation phase	Started watching (5 sec)	86
	Completed video ($\geq 50\%$)	67
Action phase	Started watching (5 sec)	47
	Completed video ($\geq 50\%$)	31
Reflection phase	Started watching (5 sec)	38
	Completed video ($\geq 50\%$)	28

Table 5.

Average usefulness rating of the study suggestions presented in the intervention videos.

	Study suggestion	Average (SD) usefulness rating (1 = not useful, 5 = very useful)
Preparation phase ($n = 35$)	Check the course content	4.29 (0.93)
	Set time for learning	3.94 (1.08)
	Be concrete in your planning	4.03 (0.99)
Action phase ($n = 20$)	Monitor your comprehension at regular times	4.15 (0.59)
	Monitor your comprehension with an activity	4.10 (0.72)
	Try to get your focus back	4.20 (0.70)
	Look for help	4.00 (1.08)
Reflection phase ($n = 16$)	Think about what you learned	4.06 (1.00)
	Think about how you learned	4.00 (1.10)
	Decide how you will continue	4.19 (1.05)

A final potential explanation for the low intervention compliance is that learners never came into contact with the intervention because they dropped out of the course too early. We therefore checked if the furthest video in the course watched for minimally 80% by the non-complying learners was before or after the intervention videos. The results of this analysis are presented in Table 6. The results indicate that only 29 of the 648 learners who did not comply with the intervention completed a video further in the MOOC than the first intervention video (preparation phase). A massive amount of learners who did not comply with the intervention did not complete a single video ($n = 494$) or dropped out before the first intervention video ($n = 161$). We therefore conclude that the main reason

for non-compliance is that learners did not come into contact with the intervention because they had already dropped out of the course.

Table 6.

Location in the MOOC of the furthest video completed by learners who did not comply with the intervention.

Location furthest video	<i>n</i>
No video completed	494
Furthest video < preparation video	161
Furthest video > preparation video but < action video	11
Furthest video > action video but < reflection video	4
Furthest video > reflection video	14

4. Discussion

Learners in open online education need to self-regulate their learning in order to be successful (Beishuizen & Steffens, 2011; Wang et al., 2013). However, learners often struggle to engage in successful SRL (e.g., Azevedo & Cromley, 2004; Bol & Garner, 2011; Dunlosky & Lipko, 2007; Peverly et al., 2003). To support learners' SRL in open online education, we implemented an SRL intervention in three MOOCs and tested the effects of the intervention on both learners' SRL (RQ 1) as well as on course completion (RQ 2). To answer research question 1, the effects of the SRL intervention on learners' SRL could only be investigated for the SRL indicators extracted from the trace data, since the response rate for the SRL questionnaire at the end of the MOOCs was too low to be included in the analyses. When testing the effects of the SRL intervention on learners' SRL, no differences were found between the control and the intervention group (ITT analyses), leading to the conclusion that the intervention did not result in more SRL. However, only a small portion of the learners' in the intervention condition complied with the intervention to at least some extent (i.e., watched one of the intervention videos $\geq 50\%$). When comparing the SRL of learners in the control group with learners who complied with the intervention (TOT analyses), significant differences were found for a number of SRL indicators: intervention compliers engaged in more SRL. Specifically, they engaged in more metacognitive activities before learning (visiting the course info and weekly course

info), they engaged in more help seeking behavior (visiting the forum), and they showed greater persistence (completed a greater proportion of videos and quizzes started, and completed a greater proportion of videos in the course) compared to learners in the control condition. To answer research question 2, we tested the effects of the SRL intervention on learners' course completion. Learners in the intervention condition completed a significantly greater proportion of the graded items of the MOOC than learners in the control condition (ITT analysis). The difference between the control and the intervention condition was enlarged when comparing the control condition with the learners who complied with the intervention (TOT analysis).

4.1 Theoretical implications

From the results, we conclude that even a small intervention, as implemented in the current MOOCs, positively affects learners course completion. The value of the intervention is even greater if the increased SRL of learners who complied with the intervention is due to the implemented SRL intervention. However, since learners in the intervention group self-selected to comply with the SRL intervention, we cannot establish if the SRL intervention caused the differences in SRL between the control group and the compliers. We conducted a number of analyses to determine whether the differences found with the TOT analyses could be explained by other factors (e.g., suitability of the intervention). Among other explorative analyses, we tested two learner characteristics that potentially could have influenced the decision of learners to comply with the intervention: SRL and course intentions. These learner characteristics however did not influence the results. There may be other learner characteristics, not tested in the current study, that may influence learners' decision to comply with the intervention and their SRL activity. These factors may, for instance, include learners' self-efficacy or learners prior experiences with online education as both are known to be related to course completion (Greene, Oswald, & Pomerantz, 2015; Wang et al., 2013). But since these factors were not measured in the current study, further research is necessary.

The finding that differences between the control group and the compliers cannot be explained by differences in learners' self-reported SRL or course intention, points us in the direction that the differences between the compliers and the control group in SRL were due to the intervention. Due to

the low intervention compliance we were forced to already count a mere 50% of a single intervention video watched as intervention compliance. This relatively small intervention improved learners' course completion and likely also improved learners' metacognitive activities before learning, their help seeking and their persistence. Our results are thereby unlike the results of previous studies in online and higher education in which a small SRL intervention was implemented (Greene, Hutchison, Costa, & Crompton, 2012; Hodges & Kim, 2010; Kizilcec et al., 2016; Sitzmann, Bell, Kraiger, & Kanar, 2009). In these studies, no differences between the intervention and the control groups were found on course completion, course achievement, and SRL. While several differences between the current study and the previous studies can be identified, a vital difference appears to be that these previous intervention studies only prompted students to engage in SRL activities: students were stimulated to engage in SRL activities, but were not explained how or why they should do so. In contrast, learners in the current study were mostly instructed about the three phase model of SRL and the importance of SRL for successful learning in open online education. Study suggestions were provided to support the SRL instruction and to give students practical advice. Instructing students on the importance of SRL and how to engage in successful SRL thus appears to be key when implementing an SRL intervention in open online education. The positive effects of SRL instruction in open online education are in line with results found with (larger) interventions containing SRL instruction in higher education. In these studies, SRL instruction was found to have positive effects on both learners' achievement as well as on their SRL activity (e.g., Azevedo & Cromley, 2004; Bannert, Hildebrand, & Mengelkamp, 2009; Bol, Campbell, Perez, & Yen, 2016; Lee, Shen, & Tsai, 2008; Rosário et al., 2015). By testing the effects of alternative (small) interventions in MOOCs in future studies, it can be established if the incorporation of SRL instruction indeed causes a small SRL intervention to be effective. Future intervention studies would furthermore increase insight in other factors important for the implementation of a successful SRL intervention.

4.2 Practical implications

The positive effect of the SRL intervention leads to the practical implication that the implementation of SRL instruction is beneficial for learners in open online education. Not only does

an SRL intervention improve learners' course completion, but it likely also supports learners' SRL activity during learning in the MOOC. However, an intervention cannot be effective if learners do not come into contact with the intervention. Therefore, the low intervention compliance remains problematic. In previous studies, it was suggested that intervention compliance could be improved by (more) strongly integrating an SRL intervention in the course (Clarebout & Elen, 2006; Clarebout et al., 2010; Kizilcec et al., 2016). We therefore paid extra attention to the way the intervention was implemented in the current study: the intervention was integrated in the course itself (not in a pre-course survey), in multiple weeks at the start of the course, and between the videos and the quiz. Our strong integration of the intervention in the MOOCs however still led to low intervention compliance: only 10% of learners in the intervention condition watched at least 50% of one of the intervention videos. Low intervention compliance thus appears to be a persistent problem in SRL intervention research in open online education.

We conducted further analyses to determine why intervention compliance was low. We found that the low adherence was not due to the intervention being irrelevant to learners; rather the opposite appears to be the case with usefulness ratings of the study suggestions ranging between 3.94 and 4.29 (scale of 1 to 5). A large number of learners had already dropped out of the course before they came into contact with the intervention video. Of the 1220 learners who were assigned to the intervention condition, 760 learners engaged in the course in some way. Of these 760 learners, only 266 completed one or more videos and 76 complied with the intervention. To increase intervention compliance, it thus appears most important to implement an intervention earlier in the learning process. It may therefore be interesting to consider the possibility of implementing an intervention when learners enroll for a MOOC. Learners may, for instance, be provided with more information about the course content and the time investment required when they express the intention to enroll for the MOOC. Prompting learners to reflect if this information is in line with their own goals before finalizing their enrollment might be helpful. Such an intervention might lead to lower enrollment numbers, but to a greater percentage of enrolled learners engaging in the course and completing the course. Another suggestion to increase intervention compliance would be to require learners to engage with the intervention (e.g., watch an intervention video) before they can engage with the course materials. This

is however not in line with the open-ended nature of MOOCs, and might result in resistance from learners.

4.3 Limitations and directions for future research

In this study, we calculated intervention compliance as the proportion of learners who engaged in the course in some manner and who watched at least one intervention video for 50% or more (10%). However, one could also calculate intervention compliance as the proportion of learners who were assigned to the intervention condition and who watched at least one intervention video for 50% or more (6.23%). Other alternatives would be to set a different bar for what behavior is considered 'compliant' or to only include learners who have been exposed to the intervention (Yeomans & Reich, 2017). These different calculations naturally lead to different results. Decisions concerning which learners to include and what activities to include, not only influence statistics concerning intervention compliance, but also the numbers of (SRL) activities engaged in and the results of analyses. We have been careful throughout the manuscript to report which (groups of) learners were considered and how variables were exactly calculated, not only to make replication of the study possible, but also to support accurate interpretation of the data. The different results of the ITT and TOT analyses for SRL activity provide a principal example of the influence group selection can have on results. In ITT analyses, the random allocation of learners to conditions is preserved. ITT analyses can therefore be used to establish causality of effects. In this study, the ITT analyses showed that the SRL intervention improved learners' course completion, but did not affect learners' SRL. At the same time, low intervention compliance makes it hard to find significant differences between conditions, as a large number of learners in the intervention condition were not compliant with the intervention. This problem is remedied with TOT analyses in which only learners who complied with the intervention are included in the analyses. In this study, significant differences were found both for learners' course completion as well as several aspects of SRL activity with TOT analyses. However, as learners decided themselves whether or not they complied with the intervention, causality cannot be established with TOT analyses. By combining ITT and TOT analyses, and exploring factors that might

have influenced intervention compliance, we have attempted to resolve the disadvantages of both analyses as well as possible.

By analyzing the effect of the SRL intervention on not only course completion, but also on SRL activity, we were able to determine which aspects of SRL activity were likely influenced by the intervention. The finding that SRL indicators differed between compliers and the control group, after controlling for course completion by calculating ratios, is unique in itself. Future research could investigate the correctness of these indicators: are they indeed a measure of the SRL activity for which we have considered them an indicator based on theory and empirical knowledge? Furthermore, since we cannot establish if the differences in course completion are caused by the better SRL of compliant learners, this may be an interesting suggestion for further research. It might for instance be worthwhile to determine which of the SRL indicators influences learners' course completion.

4.4 Conclusion

To conclude, the implemented SRL intervention has been successful in improving learners' course completion and has likely also been successful in improving learners' SRL activity. SRL activity was measured with variables calculated from learners' trace data and indicated differences between the control group and the intervention compliers in metacognitive activities before learning, help seeking, and persistence (both in terms of finishing materials that are started and finishing more materials in the course as a whole). The results thereby provide evidence for the benefit of implementing SRL support in MOOCs. More research into the effects of different SRL interventions, and how to best implement SRL support to improve intervention compliance, is necessary. The current study provides a valuable base to build on.

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Appendix A – Descriptives of SRL indicators

SRL activity	Trace data variable	<i>n</i>	Mean	Control			<i>n</i>	Intervention				<i>n</i>	Intervention comply			
				Min	Max	SD		Mean	Min	Max	SD		Mean	Min	Max	SD
Meta before learning	Course info (c)	711	0.51	0	14	1.39	760	0.44	0	19	1.53	76	1.82	0	19	3.12
	Weekly course info (c)	711	6.20	0	265	19.46	760	7.39	0	289	24.34	76	43.83	0	289	53.71
Meta during learning	Pauses/min (r)	355	0.32	0.00	12.00	1.14	367	0.34	0.00	16.00	1.26	73	0.31	0.00	7.09	0.92
	Failed quiz back (r)	32	0.08	0.00	1.00	0.21	25	0.017	0.00	0.21	0.06	13	0.00	0.00	0.00	0.00
Help seeking	Forum (c)	711	0.32	0	18	1.34	760	0.45	0	28	2.07	76	2.53	0	28	4.73
Meta after learning	Grade info (c)	711	0.34	0	34	2.16	760	0.70	0	71	4.32	76	4.63	0	71	11.61
Time management	Materials on time (r)	608	0.90	0.00	1.00	0.25	652	0.92	0.00	1.00	0.22	75	0.86	0.00	1.00	0.22
	Quizzes on time (r)	125	0.65	0.00	1.00	0.43	139	0.68	0.00	1.00	0.42	53	0.71	0.00	1.00	0.37
	Assign. on time (r)	83	0.59	0.00	1.00	0.45	106	0.66	0.00	1.00	0.43	45	0.72	0.00	1.00	0.37
Persistence	Persistence video (r)	355	0.58	0.00	1.00	0.45	367	0.61	0.00	1.00	0.44	73	0.78	0.09	1.00	0.30
	Persistence quiz (r)	519	0.20	0.00	1.00	0.36	558	0.20	0.00	1.00	0.37	74	0.60	0.00	1.00	0.42
	Persistence course (r)	711	0.08	0.00	1.00	0.19	760	0.07	0.00	1.00	0.20	76	0.46	0.00	1.00	0.35
Course completion		711	0.04	0.00	1.00	0.17	760	0.07	0.00	1.00	0.22	76	0.42	0.00	1.00	0.43

Note. Variables marked with ‘c’ concern counts of activities; variables marked with ‘r’ concern ratios.

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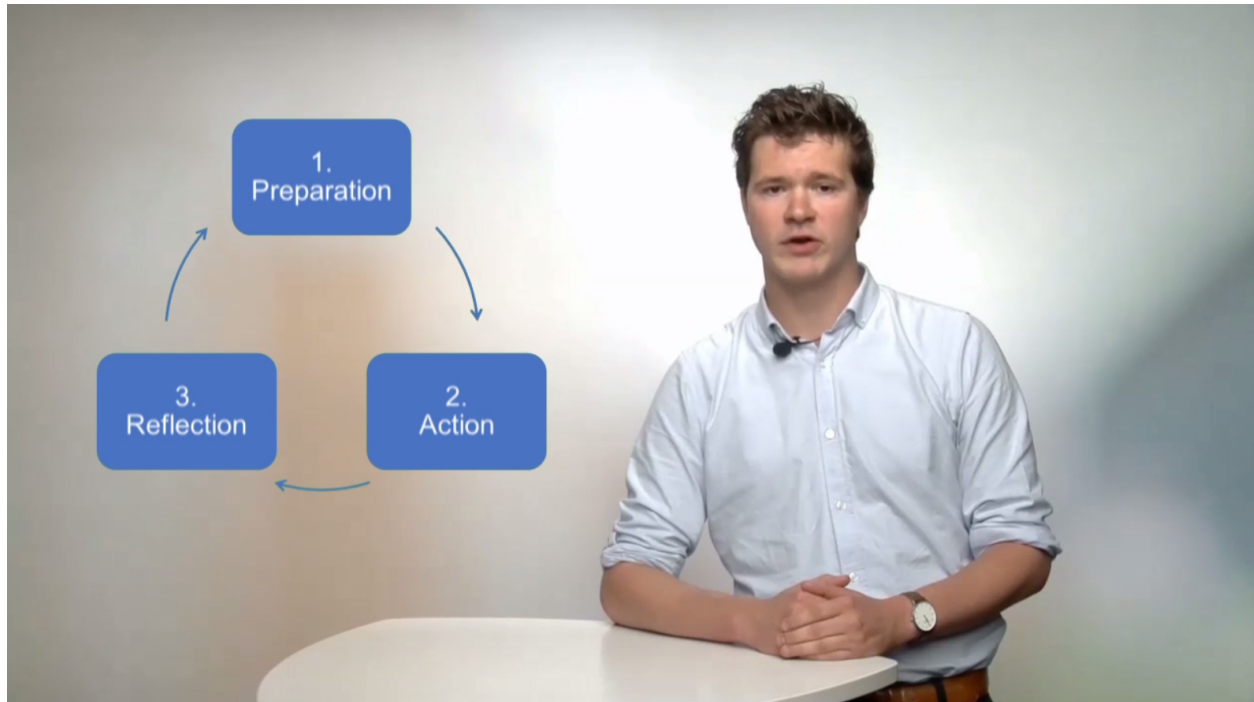
Figure 1. Screenshot of the SRL model presentation in the intervention video.

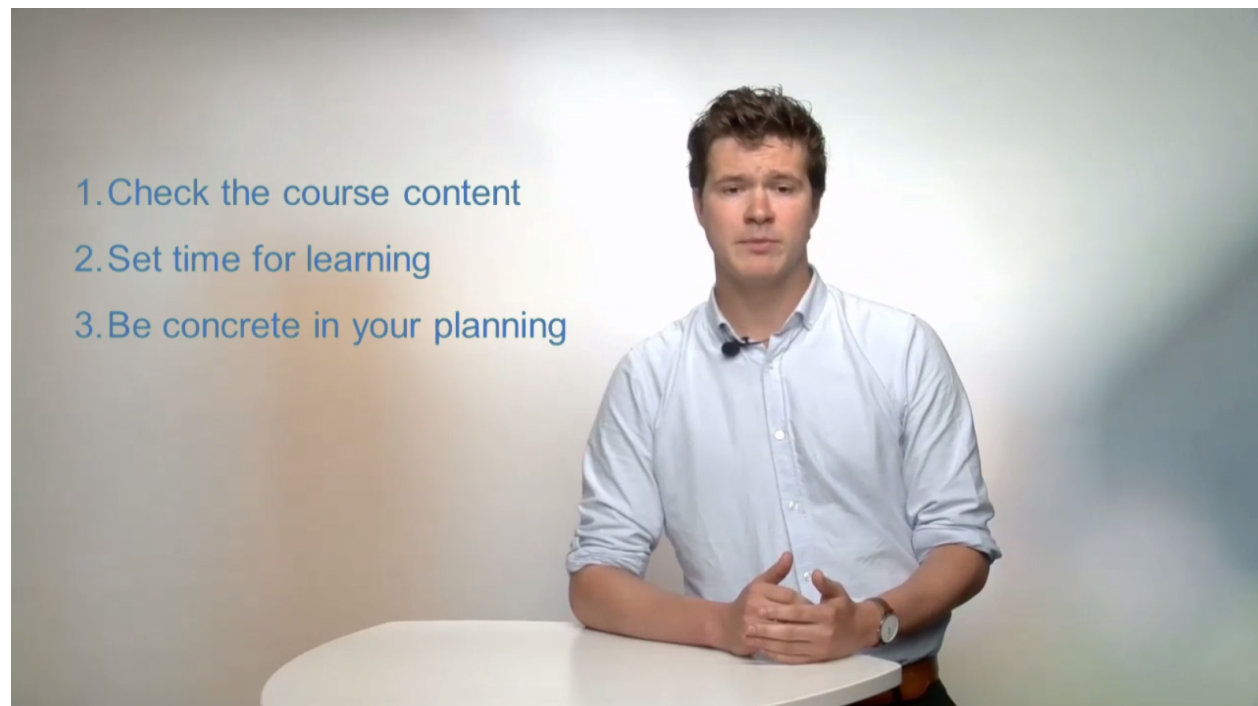
Figure 2. Screenshot of the study suggestions given in the intervention video.

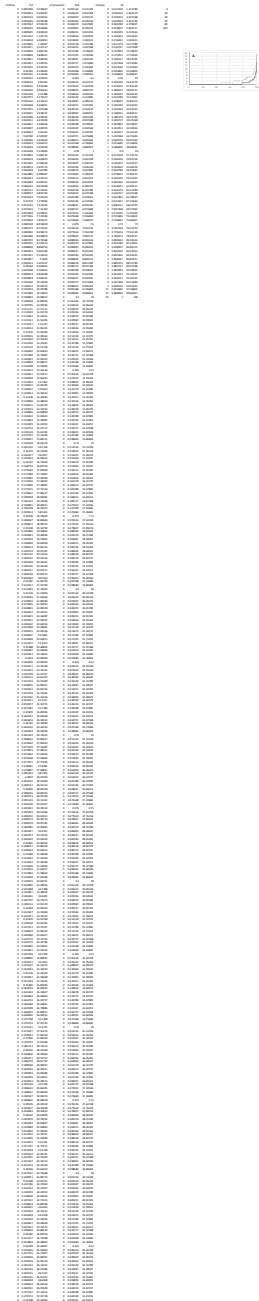
Figure 3A-L. SRL activity ordered by distribution quantile. The x-axis represents 0-100% of learners within the control/intervention/comply condition, ordered from the least activity to the most activity.

—— Control condition; - - - - Intervention condition; - - - Intervention compliers.

- A. Number of visits to the course info page (metacognition before learning).
- B. Number of visits to the weekly course info pages (metacognition before learning).
- C. Ratio of pauses per minute of video watched (metacognition during learning).
- D. Number of visits to the course forum (help seeking).
- E. Number of visits to the grade info page (metacognition after learning).
- F. Ratio of materials completed on time (time management).
- G. Ratio of quizzes passed on time (time management).
- H. Ratio of peer-assignments handed in on time (time management).
- I. Ratio of videos completed that were started (persistence).
- J. Ratio of quizzes finished that were started (persistence).
- K. Ratio of videos present in the course that were completed (persistence).
- L. Course completion.







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Journal Pre-proof

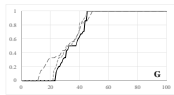
Journal Pre-proof

Journal Pre-proof

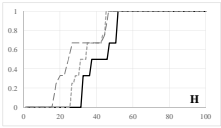
Journal Pre-proof

Journal Pre-proof

Control	125	Intervention	139	Comply	53
0	0.028	0.8	0	0.007198	0.718424
0	0.026	1.6	0	0.004888	1.886792
0	0.024	2.4	0	0.003580	1.773585
0	0.022	3.2	0	0.002777	2.877998
0	0.04	4	0	0.009971	3.097122
0	0.046	4.8	0	0.004165	4.310547
0	0.056	5.6	0	0.00306	5.039971
0	0.064	6.4	0	0.027951	5.753186
0	0.072	7.2	0	0.004744	6.47482
0	0.08	8	0	0.007042	7.20445
0	0.088	8.8	0	0.009137	7.931369
0	0.096	9.6	0	0.00813	8.633094
0	0.104	10.4	0	0.009129	9.325158
0	0.112	11.2	0	0.007012	10.01384
0	0.12	12	0	0.107914	10.79137
0	0.128	12.8	0	0.115079	11.51079
0	0.136	13.6	0	0.122302	12.23022
0	0.144	14.4	0	0.12969	12.9694
0	0.152	15.2	0	0.136971	13.69696
0	0.16	16	0	0.143889	14.38849
0	0.168	16.8	0	0.151079	15.10791
0	0.176	17.6	0	0.158271	15.82744
0	0.184	18.4	0	0.165466	16.54675
0	0.192	19.2	0	0.17262	17.26219
0	0.2	20	0	0.179851	17.98501
0	0.208	20.8	0	0.18705	18.70504
0	0.216	21.6	0	0.194244	19.42446
0	0.224	22.4	0	0.201439	20.14388
0	0.232	23.2	0	0.208613	20.86131
0.13	0.24	24	0	0.215871	21.58773
0.17	0.248	24.8	0.14	0.223022	22.30236
0.2	0.256	25.6	0.17	0.230121	23.01238
0.2	0.264	26.4	0.19	0.23741	23.74101
0.25	0.272	27.2	0.25	0.244619	24.46193
0.27	0.28	28	0.31	0.251799	25.17986
0.31	0.288	28.8	0.31	0.258991	25.89928
0.33	0.296	29.6	0.33	0.266187	26.61871
0.33	0.304	30.4	0.33	0.273381	27.33813
0.41	0.312	31.2	0.36	0.280576	28.05755
0.45	0.32	32	0.36	0.28777	28.77698
0.5	0.328	32.8	0.43	0.294966	29.4964
0.5	0.336	33.6	0.44	0.302156	30.21583
0.5	0.344	34.4	0.5	0.309351	30.93525
0.5	0.352	35.2	0.5	0.316547	31.65468
0.5	0.36	36	0.5	0.323742	32.3741
0.5	0.368	36.8	0.5	0.330935	33.09353
0.5	0.376	37.6	0.5	0.338129	33.81295
0.57	0.384	38.4	0.5	0.345324	34.53237
0.6	0.392	39.2	0.56	0.352518	35.25188
0.63	0.4	40	0.56	0.359712	35.97122
0.67	0.408	40.8	0.57	0.366906	36.69063
0.67	0.416	41.6	0.6	0.374101	37.41007
0.7	0.424	42.4	0.61	0.381295	38.1295
0.71	0.432	43.2	0.67	0.388489	38.84892
0.86	0.44	44	0.89	0.395684	39.56835
0.86	0.448	44.8	0.89	0.402878	40.28777
1	0.456	45.6	0.89	0.410072	41.00719
1	0.464	46.4	0.89	0.417266	41.72622
1	0.472	47.2	0.86	0.42446	42.44604
1	0.48	48	0.86	0.431655	43.16547
1	0.488	48.8	0.91	0.438849	43.88489
1	0.496	49.6	0.91	0.446043	44.60432
1	0.504	50.4	1	0.453237	45.32374
1	0.512	51.2	1	0.460431	46.04317
1	0.52	52	1	0.467626	46.76239
1	0.528	52.8	1	0.474821	47.48201
1	0.536	53.6	1	0.482015	48.20144
1	0.544	54.4	1	0.489209	48.92086
1	0.552	55.2	1	0.496403	49.64029
1	0.56	56	1	0.503597	50.35971
1	0.568	56.8	1	0.510791	51.07914
1	0.576	57.6	1	0.517986	51.79856
1	0.584	58.4	1	0.52518	52.51799
1	0.592	59.2	1	0.532374	53.23741
1	0.6	60	1	0.539568	53.95683
1	0.608	60.8	1	0.546762	54.67626
1	0.616	61.6	1	0.553957	55.39548
1	0.624	62.4	1	0.561151	56.11511
1	0.632	63.2	1	0.568345	56.83453
1	0.64	64	1	0.57554	57.55396
1	0.648	64.8	1	0.582734	58.27338
1	0.656	65.6	1	0.589928	58.99281
1	0.664	66.4	1	0.597122	59.71223
1	0.672	67.2	1	0.604316	60.43165
1	0.68	68	1	0.611511	61.15108
1	0.688	68.8	1	0.618705	61.8705
1	0.696	69.6	1	0.625899	62.58993
1	0.704	70.4	1	0.633094	63.30935
1	0.712	71.2	1	0.640288	64.02878
1	0.72	72	1	0.647482	64.7482
1	0.728	72.8	1	0.654676	65.46763
1	0.736	73.6	1	0.661871	66.18705
1	0.744	74.4	1	0.669065	66.90647
1	0.752	75.2	1	0.676259	67.6259
1	0.76	76	1	0.683454	68.34532
1	0.768	76.8	1	0.690647	69.06475
1	0.776	77.6	1	0.697841	69.78417
1	0.784	78.4	1	0.705036	70.5036
1	0.792	79.2	1	0.71223	71.22302
1	0.8	80	1	0.719424	71.94245
1	0.808	80.8	1	0.726619	72.66187
1	0.816	81.6	1	0.733813	73.38129
1	0.824	82.4	1	0.741007	74.10072
1	0.832	83.2	1	0.748201	74.82014
1	0.84	84	1	0.755396	75.53957
1	0.848	84.8	1	0.76259	76.25999
1	0.856	85.6	1	0.769784	76.97842
1	0.864	86.4	1	0.776978	77.69784
1	0.872	87.2	1	0.784173	78.41727
1	0.88	88	1	0.791367	79.13669
1	0.888	88.8	1	0.798561	79.85612
1	0.896	89.6	1	0.805755	80.57554
1	0.904	90.4	1	0.81295	81.29496
1	0.912	91.2	1	0.820144	82.01439
1	0.92	92	1	0.827338	82.73381
1	0.928	92.8	1	0.834532	83.45324
1	0.936	93.6	1	0.841726	84.17266
1	0.944	94.4	1	0.848921	84.89209
1	0.952	95.2	1	0.856115	85.61151
1	0.96	96	1	0.863309	86.33054
1	0.968	96.8	1	0.870504	87.05036
1	0.976	97.6	1	0.877698	87.76978
1	0.984	98.4	1	0.884892	88.48921
1	0.992	99.2	1	0.892086	89.20863
1	1	100	1	0.899281	89.92866
				0.906476	90.64748
				0.913669	91.36691
				0.920863	92.08613
				0.928058	92.80576
				0.935252	93.52538
				0.942446	94.24466
				0.949641	94.96403
				0.956835	95.68345
				0.964029	96.40288
				0.971223	97.1223
				0.978417	97.84173
				0.985611	98.56115
				0.992806	99.28058
				1	100



Control	83	Intervention	106	Comply	45
0	0.012048	1.204819	0	0.009434	0.943396
0	0.020496	2.409639	0	0.010868	1.086792
0	0.036145	3.614458	0	0.028302	2.830189
0	0.048193	4.819277	0	0.037736	3.773585
0	0.060241	6.024096	0	0.04717	4.716981
0	0.072289	7.228916	0	0.056604	5.660377
0	0.084337	8.433735	0	0.066038	6.603774
0	0.096386	9.638554	0	0.075472	7.54717
0	0.108434	10.8437	0	0.084906	8.490566
0	0.120482	12.04819	0	0.09434	9.433962
0	0.13253	13.25301	0	0.103774	10.37736
0	0.144578	14.45783	0	0.113208	11.32075
0	0.156627	15.66205	0	0.122642	12.26415
0	0.168675	16.86747	0	0.132075	13.20755
0	0.180723	18.07229	0	0.141509	14.15094
0	0.192771	19.27711	0	0.150943	15.09434
0	0.204819	20.48193	0	0.160377	16.03774
0	0.216867	21.68675	0	0.169811	16.98113
0	0.228916	22.89157	0	0.179245	17.92453
0	0.240964	24.09639	0	0.188679	18.86792
0	0.253012	25.3012	0	0.198113	19.81132
0	0.26506	26.50602	0	0.207547	20.75472
0	0.277108	27.71084	0	0.216981	21.69811
0	0.289157	28.91566	0	0.226415	22.64151
0	0.301205	30.12048	0	0.235849	23.58491
0	0.313253	31.3253	0	0.245283	24.5283
0.33	0.325301	32.53012	0	0.254717	25.4717
0.33	0.337349	33.73494	0.25	0.264151	26.41509
0.33	0.349398	34.93976	0.25	0.273585	27.35849
0.33	0.361446	36.14458	0.33	0.283019	28.30189
0.5	0.373494	37.3494	0.33	0.292453	29.24528
0.5	0.385542	38.55422	0.33	0.301887	30.18868
0.5	0.39759	39.75904	0.5	0.311321	31.13208
0.5	0.409639	40.96386	0.5	0.320755	32.07547
0.5	0.421687	42.16867	0.5	0.330189	33.01887
0.5	0.433735	43.37349	0.5	0.339623	33.96226
0.5	0.445783	44.57831	0.67	0.349057	34.90566
0.5	0.457831	45.78313	0.67	0.358491	35.84906
0.67	0.46988	46.98795	0.67	0.367925	36.79245
0.67	0.481928	48.19277	0.67	0.377358	37.73585
0.67	0.493976	49.39759	0.67	0.386792	38.67925
0.67	0.506024	50.60241	0.67	0.396226	39.62264
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1	0.53012	53.01205	0.67	0.415094	41.50943
1	0.542169	54.21687	0.67	0.424528	42.45283
1	0.554217	55.42169	0.75	0.433962	43.39623
1	0.566265	56.62651	0.75	0.443396	44.33962
1	0.578313	57.83133	1	0.45283	45.28302
1	0.590361	59.03614	1	0.462264	46.22642
1	0.60241	60.24096	1	0.471698	47.16981
1	0.614458	61.44578	1	0.481132	48.11321
1	0.626506	62.6506	1	0.490566	49.0566
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1	0.650602	65.06024	1	0.509434	50.9434
1	0.662651	66.26506	1	0.518869	51.88679
1	0.674699	67.46988	1	0.528302	52.83019
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			1	0.792453	79.24528
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			1	0.830189	83.01887
			1	0.839623	83.96226
			1	0.849057	84.90566
			1	0.858491	85.84906
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			1	0.877358	87.73585
			1	0.886792	88.67925
			1	0.896226	89.62264
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			1	0.915094	91.50943
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			1	0.933962	93.39623
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			1	0.95283	95.28302
			1	0.962264	96.22642
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			1	0.981132	98.11321
			1	0.990566	99.0566
			1	1	100



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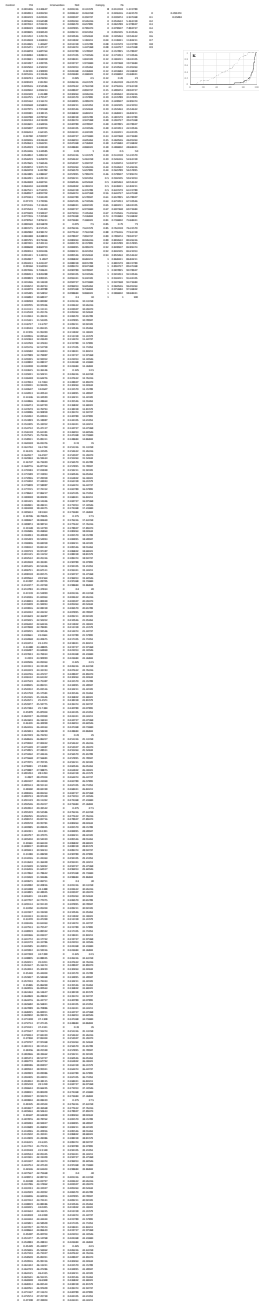


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Highlights

- Learners struggle to regulate their learning in massive open online courses (MOOCs)
- A self-regulated learning (SRL) intervention was implemented in three MOOCs
- Learners' SRL was measured with trace data variables
- Intervention compliance was low due to learners' early course dropout
- Learners' SRL and course completion were improved by the SRL intervention

Renée Jansen: conceptualization, methodology, investigation, formal analysis, writing - original draft, writing- review & editing

Anouschka van Leeuwen: conceptualization, methodology, writing- review & editing

Jeroen Janssen: conceptualization, methodology, writing- review & editing

Rianne Conijn: software, data curation, writing- review & editing

Liesbeth Kester: conceptualization, writing- review & editing, supervision