In Proceedings of the 1st Workshop on Massive Open Online Courses at the 16th Annual Conference on Artificial Intelligence in Education (2013). Memphis, TN. http://www.moocshop.org

Improving learning in MOOCs with Cognitive Science

Joseph Jay Williams[1]
[1] University of California at Berkeley
joseph_williams@berkeley.edu

Abstract. MOOCs and other platforms for online education are having a tremendous impact on the learning of tens of thousands of students. They offer a chance to build a set of educational resources from the ground up, at a time when scientists know far more about learning and teaching than at the advent of the current education system. This paper presents practical implications of research from cognitive science, showing empirically supported and actionable strategies any designer or instructor can use to improve students' learning. These all take the form of augmenting online videos and exercises with questions and prompts for students to consider explanations: *before, during,* and *after* learning. This class of instructional strategies provides students with direction while allowing them to take charge of their learning, is technically easy to implement, and is applicable to a wide variety of video and exercise content, that ranges across multiple topics.

Keywords: learning, learning, cognitive science, MOOCs, educational software, online learning, problem based learning, explanation, self-explanation, retrieval practice, interleaving, mixing, spacing

1 Introduction

High quality pedagogy is an essential goal for MOOCs. There are few barriers to students moving between courses, and the expectations are also that online learning platforms will take advantage of their greater freedom to innovate than many education reform movements in traditional schools.

One way to complement the practical experience of quality instructors is to synthesize and apply insights from scientific research. The nature of such work is produce insights that people's direct experience is unlikely to uncover. This paper considers how research from cognitive science can improve learning in MOOCs. The following consider educational implications of cognitive science more generally. [1] is an Institute of Education Sciences practice guide that is short, available online, constructed by an expert panel, and peer-reviewed. Books include [2], which is targeted at university instructors, [3] is for a general audience and K-12 teachers, and [4] focuses on multimedia learning for both K-16 education and corporate training.

This paper follows the approach taken in the reviews above in selecting practical principles from a broad review and synthesis of literature in cognitive science. This includes publications of basic research and controlled laboratory experiments, as well as studies with educational materials and K-12 and university students from K-12 and university students – which are directly relevant to lessons in current MOOCs.

The principles are selected to target key challenges in online learning, like ensuring learners remain engaged and active even without a physical community, promoting deep understanding rather than superficial memory, and supporting students in being strategic and independent learners, even without much direct feedback.

The principles specifically focus on how to appropriately prompt students to answer questions and provide explanations, *before*, *during*, and *after* watching instructional videos or engaging in exercises. It is a common intuition that students learn when they are *given* comprehensive knowledge: MOOCs deliver high-quality online videos with cogent explanations, and include practice exercises like that in Figure 1, accompanied by clear answers and solutions. However, there is substantial evidence that students can learn far more by trying to *answer* questions themselves (than by receiving the answers), or by being pushed to construct explanations (rather than provided with them), which will be discussed in the following sections.

2 Context of application: example video and exercise

Each principle for adding question prompts is targeted at the grain size of an online *module* – a short, self-contained batch of information like a video or exercise.

The principles are abstract in that they can improve learning from a range of online videos and exercises, but to provide concrete and actionable insight they are illustrated through application to specific examples of a video and exercise.

The example video is a three minute Udacity.com video from an introductory statistics course (http://tiny.cc/examplevideo): It explains what the normal distribution is, and how the area under its curve corresponds to the probability of observing certain sampled observations from a population.

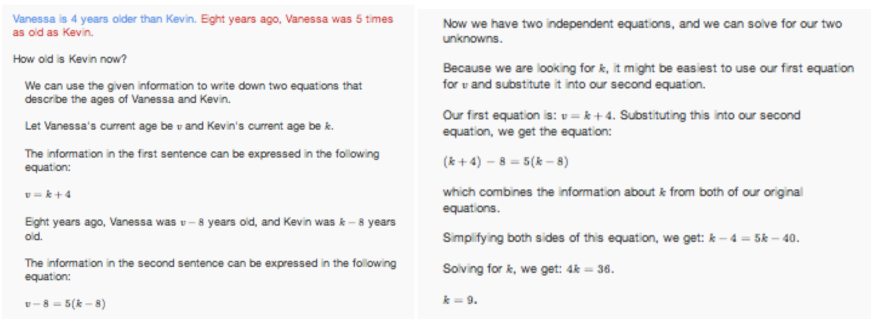

Fig. 1. Example math exercise from Khan Academy: http://tiny.cc/exampleexercise

The example exercise is shown in Figure 1, an algebra word problem from Khan Academy's collection of mathematics exercises at www.khanacademy.org/exercisedashboard. These share a common format. Only the problem statement is shown at first (blue & red text in Figure 1). Students can submit an answer for feedback or request a hint at any point. They only move onto the next problem when they are correct, but each hint request reveals the next step in a worked example solution – which ultimately gives the answer as its final step.

3 Adding questions before, during, and after videos & exercises

Questions or prompts to generate explanations can be added in at least three ways to online modules: *pre*-module (immediately preceding or in the very beginning of a video/exercise, preceding the presentation of content), *intra*-module (popping up in a video or emphasized as an activity by the instructor, embedded into the steps of an exercise), or *post*-module (following the student's engagement with a video/exercise).

3.1 Pre-Module: Framing Questions

Even before learners are presented with information in a video or exercise, prompting them to consider *framing questions* can make them more motivated to learn, as well as help them connect a module's content to their existing knowledge, and understand how they can apply it to future problems.

In contrast to delivering a traditional sequence of *subject-focused* videos & exercises (which touch on a succession of topics students may struggle to relate), *problem-based learning* [5] frames videos & exercises as the knowledge needed to solve particular problems and answer previously articulated questions. For example, a problem-based learning version of an introductory statistics course [6] would precede lessons with a keen emphasis on what problems the lesson would teach students how to solve, rather than a typical focus on the specific facts and concepts in each lesson.

Examples of pre-module framing questions are shown in Table 1.

Table 1. Examples of Framing Questions that could precede videos and exercises.

Udacity video on the normal distribution	Khan Academy algebra math exercise
Before a video, a page with a Framing Question can be presented: "*Explain what you already know about normal distributions*." *"What is a normal distribution useful for?"* Instructors can also introduce a fixed time delay (e.g. 10 seconds), a required text response, or a strong emphasis on a Framing Question at the start of a video.	If you are only told about the relationships between two people's ages, what kind of math is useful for figuring out actual ages? The guiding question to keep in mind for this exercise is: "How can you convert word problems into algebra expressions?"

The motivational benefit is in greater excitement to learn in order to solve a problem, rather than learn to memorize and be tested. The cognitive benefit arises in part by getting learners to activate their existing knowledge, so they connect new information to well-established ideas. Prompts to explain a fact can be largely unsuccessful, but still increase how much is learned once a lesson is presented [7]. [8]

In Proceedings of the 1st Workshop on Massive Open Online Courses at the 16th Annual Conference on Artificial Intelligence in Education (2013). Memphis, TN. http://www.moocshop.org

showed that students were mostly unsuccessful when asked to solve a problem related to calculating variability, but that having tried to solve this problem changed *what* they learned from a subsequent lesson. Compared to other students who received alternative instruction without this framing question or problem, these students were better able to apply what they learned in subsequent lessons to new situations.

Developing Framing Questions. To generate framing questions for a particular resource, an instructor can ask:

- "What questions should students be able to answer after watching this video, that they can't right now?"
- "What problems do I think they should be able to solve afterwards, that they would have struggled with before?"

3.2 Intra–Module: Reflection Questions

Typically, instruction is seen as *providing* learners with answers or *giving* them explanations. But extensive work in cognitive science, education, and intelligent tutoring has shown that giving learners the right prompts to self-generate explanations can be *more* effective than giving students explanations [9] [10]. This provides empirical insight into how and when "teaching is the best way to learn". Without changing the content of online videos and exercises, MOOCs can improve learning by appropriately embedding questions and prompts for learners to provide explanations.

Videos in MOOCs already have the functionality to pop-up short multiple choice exercises, which could be used to present questions that are more conceptual and that allow open-ended responses. Solutions to exercises can be split up into multiple lines, and have questions and prompts with text boxes to type answers embedded inline. Examples are shown in Table 2.

Table 2. Examples of how Reflection Questions could be embedded in videos and exercises.

Udacity video on normal distribution	Khan Academy algebra math exercise
Explain what the video has talked about so far. (@1:35)	The information in the first sentence can be expressed in the following equation: $v = k + 4$
What are you thinking about right now? Just say it out loud. (@ 2:15)	Do you see why this step makes sense or is justified? Simplifying both sides of this equation, we get: $k - 4 = 5k - 40$. What step do you think is coming next?

There is substantial evidence that learners' understanding is improved by prompts to explain out loud the meaning of what they are learning or say out loud what they are thinking [9] – although studies typically ensure learners are not confused by the sudden appearance of these prompts. Asking learners to explain *why* particular facts are true or answers are correct has been shown to help them understand key principles and generalizations [11]. [12] shows that anticipating next steps in a solution and making predictions about what will be discussed next leads to a better understanding of how and where to use what they are learning about, and provides implicit feedback as the video continues or solution is revealed.

Developing Reflection Questions. In addition to examining the methods of the studies cited above, the Institute of Education Sciences practice guide [1] provides a reference of effective question stems: E.g., why, why-not, how, what-if, how does X compare to Y, what is the evidence for X?

An instructor can use a list of these stems to generate and insert question or explanation prompts throughout an instructional video or an exercise's solution.

3.3 Post–Module Memory Practice Questions

Questions that target information from a past video or exercise are common in MOOCs, but often do not realize their potential for *Memory Practice*. One reason is that they are often designed to *assess* learning without attention towards *improving* it. [13] shows that simply asking students to recall what they read in a science passage (an open ended prompt that is not common in testing, but encourages Memory Practice) greatly improved memory a week later – outperforming students who read the passage *three more times*, or made elaborate concept maps. Post-module prompts for this paper's current examples might include "Write down the main points from that video." or "Explain the method you used to solve these exercises."

In fact, MOOCs often do include post-module questions designed to help students revisit content – such as review questions or practice exercises. However, these may not successfully produce Memory Practice if they occur so soon after a module that a learner can answer using rote memory. [14] provides an extensive review of how to ensure post-module questions are beneficial, so that Memory Practice helps learners generate the meaningful cues and connections to other concepts that are needed to remember over the long-term.

For example, simply *spacing* practice exercises improves long-term retention (although benefits are deceptively absent in the *short-term*), and learning is even further improved by *interleaving* or *mixing* problems and concepts that students frequently confuse [15]. For example, a typical practice sequence might be 12 problems of type A, then 12 of type B, and 12 of type C. But it can be better for deep, lasting learning to practice [6 A, 4 B, 2 C], [4 A, 6 B, 2 C], and [2 A, 4 B, 6 C]. Often, however, students and instructors may assume that the more challenging learning in the *mixed* condition means that it is a poorer strategy and abandon it – even though it produces larger and lasting benefits *without any increase* in the number of problems [15]. Ironically, the same studies that empirically show the advantages of Memory Practice also find that students expect typical study strategies to help more [13] [14].

Conclusion

This paper considered how to improve learning in MOOCs by adding question & explanation prompts before, during, and after online videos and exercises. This is not to say that MOOCs *never* incorporate questions into instruction as advised – this is unlikely given the diversity of online instruction. Scientific principles for learning can be used to design novel instruction *or* to support *benchmarking* – to identify which of the vast set of instructional strategies are supported by cognitive science. Moreover, consulting and working with cognitive scientists (to embed practical experiments and design measures of learning) allows MOOCs to maximize learning by tailoring general learning principles to specific courses and lessons. Collaborations like these between instructions and scientists can provide the best outcomes for students.

References

1. Pashler, H., Bain, P., Bottge, B., Graesser, A., Koedinger, K., McDaniel, M., Metcalfe, J.: Organizing Instruction and Study to Improve Student Learning (NCER 2007-2004). Washington, DC: Institute of Education Sciences, U.S. Department of Education (2007)
2. Ambrose, S. A., Bridges, M. W., DiPietro, M., Lovett, M. C., Norman, M. K.: How learning works: Seven research-based principles for smart teaching. Jossey-Bass (2010)
3. Willingham, D. T.: Why Don't Students Like School. Jossey-Bass (2010)
4. Clark, R. C., & Mayer, R. E.: E-learning and the science of instruction: Proven guidelines for consumers and designers of multimedia learning. Pfeiffer (2004)
5. Hmelo-Silver, C. E.: Problem-based learning: What and how do students learn? Educational Psychology Review, 16(3), 235-266 (2004)
6. Boyle, C. R.: A problem-based learning approach to teaching biostatistics. Journal of Statistics Education, 7(1) (1999)
7. Needham, D. R., Begg, I. M.: Problem-oriented training promotes spontaneous analogical transfer: Memory-oriented training promotes memory for training. Memory & Cognition 19, 543–557 (1991)
8. Schwartz, D.L., Martin, T.: Inventing to Prepare for Future Learning: The Hidden Efficiency of Encouraging Original Student Production in Statistics Instruction. Cognition and Instruction, 22(2), 129-184 (2004)
9. Fonseca, B. Chi, M.T.H.: The self-explanation effect: A constructive learning activity. In: Mayer, R. & Alexander, P. (Eds.), The Handbook of Research on Learning and Instruction (pp. 270-321). New York, USA: Routledge Press (2011)
10. Mazur, E.: Farewell, Lecture? Science (2009)
11. Williams, J. J., Walker, C. M., Lombrozo, T.: Explaining increases belief revision in the face of (many) anomalies. In: N. Miyake, D. Peebles, & R. P. Cooper (Eds.), Proceedings of the 34th Annual Conference of the Cognitive Science Society (pp. 1149-1154). Austin, TX: Cognitive Science Society (2012)
12. Renkl, A.: Learning from Worked-Out Examples: A Study on Individual Differences. Cognitive Science, 21(1), 1–29 (1997)
13. Karpicke, J. D., Blunt, J. R.: Retrieval practice produces more learning than elaborative studying with concept mapping. Science, 331(6018), 772-775 (2011)
14. Roediger, H. L., Putnam, A. L., Smith, M. A.: Ten benefits of testing and their applications to educational practice. In: J. Mestre & B. Ross (Eds.), Psychology of learning and motivation: Cognition in education (pp. 1-36). Oxford: Elsevier (2011)
15. Rohrer, D., Pashler, H.: Increasing retention without increasing study time. Current Directions in Psychological Science, 16, 183-186 (2007)