Epistemic Cognition: A Promising and Necessary Construct for Enriching Large-scale Online Learning Analysis

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ABSTRACT

Epistemic cognition refers to the process of thinking about one's forms of knowledge and ways of knowing. Epistemic cognition becomes especially critical when learners need to, assess the validity, certainty, reliability, source, and limits of their knowledge, as when working through ill-structured problems or evaluating contradictory knowledge claims. This psychological construct is relevant to Massively Open Online Courses (MOOCs), for instance, in that researchers are modeling learner behavior and performance (i.e., how learners handle knowledge) based on inferred learner knowledge states. In this synthesis paper, I provide a brief account of epistemic cognition research, summarize the field's key findings and theories, and outline the affordances that epistemic cognition offers to online learning researchers. I also show that, without knowing it, online learning researchers have already engaged with epistemic cognition concepts and provide recommendations for future, more theoretically and practically enriching work.

Author Keywords

Online Learning; Epistemic Cognition; MOOC; Epistemology; Knowledge Modeling

INTRODUCTION

The rapid rise of Massively Open Online Courses (MOOCs) since 2012 has demonstrated the potential to bring together computer scientists, data scientists, learning scientists, and psychologists in a collaborative and coordinated manner. One of the main draws for these communities has been the promise of large, diverse, and continuous/periodic data sets that can provide the kind of sampling scale and variety to test hypotheses, run interventions, and inform theories more robustly [37]. This draw remains as attractive as ever thanks to researchers already demonstrating how the diversity and scale of these data sets can contribute to empirical as well as theoretical work.

One example is video learning, where MOOCs have produced large and varied data sets for investigating learner behavior generally [19], predicting dropout rates specifically [21], and examining interface navigation [33]. While researchers have had to create proxies for various measures, namely engagement [19], the ubiquity of video in online learning makes it an attractive research site for testing and expanding on learning theories about video learning [29]. Another example is social psychology, where MOOCs have provided a platform for studying learners from different socioeconomic [11], geographic [4,20], and political backgrounds [56] while investigating motivation [40], growth mindset [52], and sense of social belonging [38], among other psychological constructs. Starting out as replications of previous investigations and interventions in a new context, this area of MOOC research is now starting to craft new variations and kinds of interventions to contribute to the offline-based social psychology intervention literature. Yet another example is in the area of adaptive and personalized learning, as online education platforms have produced data sets of sufficient scale and complexity to enable the use of machine learning and other methods to investigate human learning problems like never before [65]. A particularly exciting line of research is the creation of new models for predicting learner behavior [9,55] and for recommending how a student moves through the many possible learning assessments [55] as well as course materials [63]. Overall, then, large-scale and diverse data sets from online education platforms have successfully shown the potential to bring together previously isolated communities of researchers, opened up new sites/media for previously offline-only research, and provided new inputs for previously unfeasible data science research.

Searching for learning-relevant psychological constructs that could enrich current and future large-scale data science methods, one can find multiple promising candidates. One of these is the construct of epistemic cognition. In this synthesis paper, I briefly introduce the history, findings, and models of epistemic cognition research and then outline some affordances of epistemic cognition for researchers using data sets originating from large-scale, online learning environments for computer science, data science, and learning science purposes. Toward the end, I also recommend possible steps for increasing fruitful collaboration among epistemic cognition, data analytics, and online learning researchers. The motivation for writing this paper is to expose online learning researchers to epistemic cognition as a promising – and in some cases even necessary – construct for enhancing their future as well as already ongoing investigations.

THE STATE OF EPISTEMIC COGNITION RESEARCH

Epistemic cognition has coalesced into an umbrella term for an increasing amount of research activity investigating human intellectual development and beliefs about knowledge, among other objects of inquiry [26]. The "cognition" part of the construct refers to people's mental processes (or, thinking) and the "epistemic" part refers to people's views and frameworks regarding knowledge and knowing. Epistemic cognition research,

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then, is the study of people's thinking about knowledge and knowing, especially critical when learners need to assess the validity, certainty, reliability, source, and limits of their knowledge. As such, the research draws heavily for inspiration from both epistemological philosophy and educational psychology, a collaboration several researchers are calling for the two fields to strengthen [5,18,62]. Epistemic cognition manifests in a variety of tangible ways in people's everyday, academic, and professional lives. Are some kinds of knowledge more valuable than others for the knowledge production goals of a particular field? For instance, many professional mathematicians consider proofs (a deductive form of knowledge) to be the gold standard in advancing their field, but that does not mean that they completely discount large-sample, computational evidence (an empirical form of knowledge) for every conjecture [66]. Presented with contradictory knowledge claims from different sources, how does a student work with and evaluate those claims? For instance, as participants in one study [15], if a student read a claim about vitamin D in a biology textbook and another claim about vitamin D in a health magazine, does the student discount one over the other because of where the student found it (the source of knowledge)? Or does the student maybe delve deeper and discount one over the other because of the research methodology used in the studies that support those claims (the process of knowledge production)? Or maybe the student does not discount at all and believes them to be equally valid! As perhaps right now: When encountering new knowledge, how does one think about integrating it with one's prior knowledge?

The point is that these are not high-minded and abstract concerns, but cognitive acts we engage in daily, informing how we operate both as individuals consuming knowledge and as collective participants contributing knowledge. These seemingly small cognitive acts can lead to a pattern of preferential behavior for handling similar situations in the future, which can, in turn, lead to establishing a stable attitude toward certain forms of knowledge and ways of knowing. This could be all the more important in online environments, where the learner is largely reliant upon the learner's own self-regulation to engage in, monitor, execute, and interpret the epistemological implications of those cognitive acts.

While philosophical investigations of epistemology stretch back to antiquity, educational psychology investigations stretch back only a few decades. In that time, much work has been done, stemming originally from Perry's qualitative study of the intellectual development of Harvard undergraduates [54]. Hofer presents the development of the epistemic cognition field as occurring in three waves that produced three models: a developmental model (primarily qualitative study of stable, synchronous epistemological beliefs) [1,34,35,43,54]; a dimensional model (primarily quantitative study of independent, asynchronous dimensions of an epistemological belief profile) [27,49,58,59]; and a situated model (primarily qualitative study of the activation and use of standalone epistemological resources) [12,13,22,46]. Each wave re-cast epistemic cognition in a new theoretical model and with a different set of methodologies. Responding to the overt focus on an individual's epistemic cognition in these three models, Kelly recently proposed a fourth, sociocultural, model [30]. Here, the focus is on qualitatively studying epistemic practices, behaviors regarding knowledge one acquires through interaction within and across different groups (each of which has its own unique take on what knowledge counts and looks like) [30]. **Table 1** summarizes these models' main characteristics. Many researchers, including Hofer, believe that the field is on the cusp of a fourth wave of research that will be marked most probably by a conceptual clarification of the epistemic cognition construct, greater collaboration with other research communities, and new and creative ways of measuring epistemic cognition [26].

The reason that researchers remain excited about epistemic cognition is because of the findings of small-scale studies related to learning, education, and psychology. From these small-scale studies, two or three particular findings stand out in relation to online learning. First, Muis and Duffy showed that student epistemological belief profiles are malleable and change over time when they are in a classroom environment that has instruction based on a sophisticated epistemology [50]. A sophisticated epistemology in this context espouses more constructivist conceptions of learning in that knowledge is tentative and complexly structured (rather than a simple structure of isolated facts) and that meaning must be actively constructed by the learners (rather than passively absorbed from authority). Student belief profiles shift in the direction of the sophisticated epistemology in their environment (their epistemic climate), though it may take 6-8 weeks [50]. Second, difference (or direct misalignment) between the epistemology of a science text and that of a student can lead to students remembering less from the text

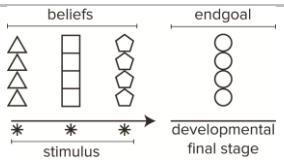
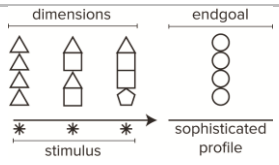
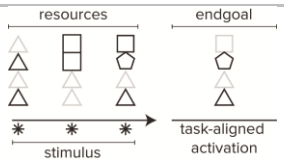
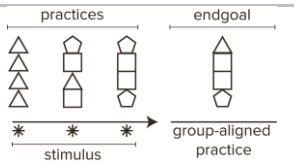
Attribute	Developmental Model	Dimensional Model	Situated Model	Sociocultural Model
Model Visualization				
Construct Definition	Stable, synchronous, naturally-occurring, and linearly-evolving beliefs	Independent, asynchronous dimensions of beliefs	Distinct, deployable, and context-sensitive mental resources/representations	Interactional, socialized, and group-based practices/habits
Measurement Methods	• Interviews • Discourse analysis • Longitudinal observation	• Likert-scale self-reports • Surveys • Activity performance	• Think-aloud protocols • Semi-structured interviews • Cognitive interviews	• Video analysis • Discourse analysis • Semi-structured interviews

Table 1. Shows a simple visualization, construct definition, and popular measurement methods for each of the four models currently dominating the epistemic cognition research literature.

and being less likely to change any prior misconceptions than under conditions of epistemic alignment [16]. Third, different sets of epistemological beliefs seem to influence student text comprehension [57] and multiple text comprehension [14,15].

While multiple quantitative and self-report measurement instruments exist for these experiments [28,60,61], the instruments' validity and reliability has been called into question in a systematic and robust manner [2,25] along methodological and measurement issues that researchers have identified over the last couple of decades [26,30,48,62]. The four dimensions [25,48] these quantitative studies tend to track now are: certainty of knowledge (ranging from knowledge being certain to knowledge being tentative); simplicity of knowledge (ranging from the structure of knowledge being simple to the structure of knowledge being complex); source of knowing (ranging from passive acquisition through authority to active construction by oneself); and justification for knowing (ranging from relying on authoritative sources to use of objective criteria for justification). It can happen that different instruments can produce opposite interaction effects between an epistemic belief measure and a learning outcome [31]. This, in turn, calls into question how coarse- or fine-grained the constructs researchers trying to measure are and if bipolar Likert-scales (from strongly disagree to strongly agree) that imply a desirable (read sophisticated) and an undesirable (read naïve) direction are the best measurement tools [3,48]. Especially in intervention research, lack of cultural diversity, lack of process data, lack of scale, and lack of instruction/environment control remain barriers for truly robust findings and analyses [3]. These problems would most probably not have arisen had the field not taken the quantitative turn from its qualitative roots, and researchers from both methodologies are now looking to re-explore and address them [18,30,48].

To that end, epistemic cognition researchers have proposed a variety of ways to move forward in terms of methodology and measurement. Multiple researchers suggest measuring epistemic cognition in a fine-grained and context-sensitive manner [3,5,48,62]. After all, the way a learner approaches quantum mechanics might be epistemologically different from how a learner approaches classical mechanics. Others suggest to focus on inferring epistemic cognition from action rather than from self-report [22,62]. The reasoning here is simple: what a learner believes might not be how a learner behaves…or at least not all of the time. This leads to another suggestion, which is to better contextualize epistemic cognition by also monitoring learner epistemic aims (i.e., one's goals for acquiring and producing knowledge) along with other psychological systems and processes (e.g., motivation, emotion) [3,59]. A learner might believe that engaging in mathematical proof is a way to arrive at the kind of understanding the learner genuinely wants, but the learner's emotional state might become a barrier to that exercise. Finally, there is a call for epistemic cognition research to focus on more culturally diverse populations and process-oriented data [3,5].

To sum up, a theoretical, empirical, and intuitive basis exists for further epistemic cognition research. As a concept, it appears to have promising explanatory and predictive potential in the context of learning processes. The field is now looking for new methods for collecting and analyzing data (that are more behavioral, process-oriented, finer-grained, and context-sensitive), new media in which to intervene (that are more scalable, editable, and replicable), and new populations which to investigate (that are larger, periodic/replenishable, and culturally diverse).

EPISTEMIC COGNITION AFFORDANCES TO LARGE-SCALE, ONLINE LEARNING RESEARCH

Building on this prior work in the field of epistemic cognition and at least two independent calls for a computer-based research agenda for epistemic cognition [17,41], I now want to make the case for two qualities of epistemic cognition that are well-matched specifically with online learning research priorities. I call these well-matched qualities affordances. For each affordance, I introduce a key concern within the online research literature, ground the concern with a specific example from prior work, re-cast the example via a narrative with an epistemological lens, and then describe possible ways to enhance the online learning research with the theoretical models from epistemic cognition. Using this structure, I hope to show both the value of the present investigative approach and the value added by an epistemologically-conscious approach.

Affordance #1 – Additional Explanatory Power for Learner States and Learning Tasks

The first affordance relates to algorithm design and data analysis methods. Online environments can offer the possibility of adapting what content and assessments a learner encounters. A key concern, then, is predicting (1) what each learner does know and does not know, (2) how each learner knows what that learner knows (this is non-trivial: one could know something, for instance, with a logic different from the instructor's and problematic for learning upcoming content), and also (3) what to present the learner with so that the learner moves from one state of knowledge to another. All three of these predictions are epistemic in nature, and yet online learning researchers have not brought philosophical or psychological epistemology to bear on them.

These predictions fall into the realm of knowledge modeling and knowledge tracing, and we can look to explanation generation, evaluation, and adoption as a prime use case. AXIS (the Adaptive eXplanation Improvement System) asks learners in MOOCs to generate explanations for statistics and mathematics problems they just finished solving that are then shown to and rated by other learners as they encounter difficulties with those problems [67]. As large-scale numbers of learners generate, assess the quality of, and refine explanations (through a process called learnersourcing [32]), the AXIS system continuously makes choices as to which explanations to show to which student based on ratings of explanations, subjective judgments regarding ability to solve future problems, and objective measures of accuracy when solving those problems [67]. This system and others like it, help externalize learner cognition and create a history of that cognition via the online interface. They also fundamentally deal with producing, communicating, and evaluating knowledge claims, thereby representing fertile ground for weaving in measures relevant to epistemic cognition to enhance the systems' pedagogical and research potential further.

Consider a learner who differentiates between formal reasoning (characterized by mathematical equations and algebraic formulae) and everyday reasoning (characterized by naturally-occurring phenomena and observations from one's direct experience). More importantly, the learner discounts in the context of learning statistics everyday reasoning as not useful and also not 'statistics-y' enough. Note that these learner qualities are actually based on those of a real-life college physics student that Lising and Elby observed during a qualitative case study [45]. Showing this learner the best possible explanation based on counting beans in a jar and predicting the color of a bean picked from said jar most likely

does not represent the path of least resistance for a knowledge state transition. For instance, it could be that the top-ranked explanation genuinely works if its epistemology matches that of the learner (the dimensional beliefs model) or if it is activating the right set of epistemological resources for each learner (the situated resources model). Otherwise, we could be forcing explanations that further deepen and enforce epistemic misalignment without being aware of it and without providing appropriate supports for addressing the misalignment once it arises. From this perspective, learnersourced explanations work for facilitating knowledge state transition only insofar as those explanations are matched with learner-matched epistemologies.

Here is how online researchers could weave epistemic cognition into designing adaptive systems for predicting and facilitating knowledge state transitions to gain a more comprehensive view of the transition process. Using the dimensional beliefs model, researchers could deploy one of the existing questionnaires or survey instruments (e.g., Epistemological Beliefs Questionnaire, EQ [60]; Epistemic Beliefs Inventory, EBI [61]; Discipline-Focused Epistemological Beliefs Questionnaire, DFEBQ [25]) in their experiments and/or environments for pre- and post-testing. Researchers could then look for demonstrated effects (e.g., epistemically-mismatched explanations facilitating slower misconception correction in learning Newton's laws [16]) and new effects (e.g., alternating between epistemically-matched and mismatched explanations facilitates faster misconception correction in statistics than only presenting epistemically-matched explanations). The measurement instruments are scalable and modifiable, enabling researchers to investigate beliefs about the knowledge in a particular chapter, course, or discipline as well as across chapters, courses, or disciplines. Researchers could also likely use learners' rankings of (equally valid) explanations as a proxy for preference toward certain epistemologies and not others.

Using the situated resources model, researchers could also classify the epistemological resources and other constructs each assessment and explanation requires learners to activate in order to extract the intended learning outcome. Particularly easy early targets for this endeavor might be learning tasks that require the activation of constructs such as epistemic doubt in evaluation of explanations (or, knowledge claims) or epistemic value in revising explanations (or, knowledge claims). Especially by collecting learners' writing about evaluating and revising the explanations, researchers could employ qualitative analysis to identify an appropriate coding scheme with which to then train a classification algorithm. Researchers could even structure short writing prompts to specifically elicit these specific epistemic constructs. Learners' revisions to their own explanations in light of the explanations they have encountered since crafting their own can also act as a proxy for what kinds of epistemological resources which explanations activate if done in a controlled enough manner.

The purpose of the examples above is to show an illustrative (rather than an exhaustive) set of ways in which epistemic cognition can enhance the investigations already underway and systems already under construction by online learning researchers. The fact of the matter is that predicting learner knowledge states is fundamentally grounded in epistemology. Therefore, epistemic cognition necessarily has a worthwhile contribution to make to the knowledge modeling foundation.

Affordance #2 – Additional Insight into for Learner and Environment Development

The second affordance relates to the design of online pedagogy and online learning environments. MOOCs have a well-documented track record of attracting large numbers of learners who are predominantly not from Western, Educated, Industrialized, Rich, and Democratic (WEIRD) countries [24]. MOOCs also have a well-documented high dropout rate or, put another way, a learner persistence problem [21,40]. Understanding these trends and constructing online learning environments that are effectively inclusive (i.e., they work) and consciously inclusive (i.e., they work by design) is a prime concern for the online research community.

This is evidenced by the plethora of research into both the kinds of learners that MOOCs attract and those learners' various behaviors and qualities: demographic and geographic differences in course navigation [20], learner persistence and achievement [10,38,40], and socioeconomic differences in course completion of learners in the US [23], to name a few. One attempt at inclusiveness online can be the deployment of value and belonging affirmations to help close achievement gaps among various nationalities by reducing the social psychological barriers that members of these groups might feel in these environments (e.g., seeing themselves as less capable and, therefore, questioning their belonging to an online learning community centered around a Western elite institution) [8,37]. The intention here is to have learners write for a few minutes about something they genuinely value in their lives (e.g., family, sports, religion) as a way to buttress their self-worth before engaging in these potentially socially threatening environments [8]. Using these affirmations or their variations, an online environment can help psychologically support learners in the learning process from the start.

Consider now a learner who enters a physics online learning environment. From the welcome video to the opinions voiced in the discussion forums to the solutions for assessment items, everything points to the norm that mathematical proof is how physicists arrive at their understanding of physics knowledge. No one appears to have a problem with this. Except, it seems, for this one learner, who has always used computational methods to understand and verify the knowledge from physics teachers and textbooks. Maybe this is how the learner's high school physics teachers propounded how physicists learn and make sense of physics knowledge. When immersed in this online learning environment that seems to not value and also even not acknowledge the learner's way of knowing physics, the learner might feel genuinely confused and isolated. At the same time, unless the teaching team and the learning community are aware that this could be happening, then the course does not adapt to provide systematic supports for being more epistemologically inclusive.

There are various ways that epistemic cognition research can be strategic in creating and studying inclusiveness in online learning environments. Using the developmental stages model, online learning researchers can analyze discussion forum and chat exchanges for the ways that learners handle disagreements and reflect upon those disagreements. How dogmatic or inflexible learners might be about holding onto a singular way to evidence a knowledge claim, for instance, can be indicative of earlier stages of epistemological development [34,35,54]. On the other hand, claiming all knowledge claims to be of equal value, while certainly more open-minded, is also not the end-point of most

developmental models because such an epistemological stance does not distinguish between knowledge produced by different means. Maggioni, VanSledright, and Alexander comprehensively review the four popular developmental models and map across the models' separate stages for easier theoretical navigation [47]. Analyzing (and in the future maybe even structuring) early forum conversations to understand where learners are in their epistemological development can inform both instruction preparation and test performance analysis.

Using the sociocultural practices model, online learning researchers can analyze the epistemic moves that the teaching team promotes and that learners adopt by coming into contact with the community. Through videos, discussions, and assessments, the instructional team is promoting a specific set of behaviors related to handling knowledge and knowledge claims both for the wider professional community of the field, but also for the tight learning community of the MOOC. Here, researchers can analyze the epistemic content especially of assessment items on homework assignments and on quizzes and examinations and look for replication of that epistemic content by learners. For instance, imagine that, in teaching physics online, an instructional team structures assignments such that the first move is to compute a numerical value, the second move is to verify that value with another computational example, and the third move is to create a generalized formula. The team further reinforces this three-step approach in online videos, solution sheets, and discussion forums (e.g., by asking learners to run through this process when addressing confusions). This could be considered an instantiation of an epistemic practice that learners can observe and partake in via interaction with the learning community and the wider epistemic climate. Online learning researchers can then investigate rates of adoption and accuracy of replication of this practice and of other practices. Based on prior work on MOOC sub-populations of interest, researchers could also segment these results by, for instance, gender [38], nationality [37], and academic background [6]. An added benefit of this approach to online learning researchers and instructors can of course be that they collectively gain a clearer and more comprehensive view of the epistemic practices within the environments that they are studying.

As with the first affordance, the examples above are meant to be illustrative, not exhaustive. Especially because large-scale online learning environments such as MOOCs attract diverse populations of learners with the aim of onboarding these learners into new knowledge and new knowledge-handling practices, neglecting the epistemic aspect of the enterprise can have unintended consequences. In the same way that the logo of an elite higher education institution could induce identity threat in someone who is might be from a low socioeconomic and non-American cultural background, course and instructional designers might be sending epistemic cues that contribute to early dropout rates (or, conversely, lack of high certification rates), a key problem in MOOC research [9,21]. Epistemic cognition can bring a new dimension to data already being collected (especially from instructional materials and discussion exchanges) and reveal new patterns in including or isolating certain learner sub-populations (based on learner development and community practices).

FUTURE WORK RECOMMENDATIONS

The most productive way to fully realize these two (and myriad other) affordances of epistemic cognition is for epistemic cognition researchers and online learning researchers to acknowledge each other's prior work and to collaborate with each other on future work. In this section, I point out additional areas of latent intersection between the two research fields and then describe possible research directions based on successes originating from serious investigation of epistemic cognition in a field such as history education.

As I have already noted, online learning researchers are investigating aspects of epistemic cognition without necessarily realizing it. Research on confusion in discussion forums [69] and on online learner sentiment/affect in general [7,39] could be recast as research into epistemic affect/emotion [53] as long as the emotions are epistemic in nature (i.e., related to thinking about knowledge and knowing). Research incorporating reflection activities in online environments [51] – again, as long as epistemic in nature – could be recast as research into epistemic resources and epistemic practices (especially if in a public venue) [30]. The knowledge tracing models in general and ones that deal with classifying, labeling, and/or predicting higher-order cognitive and learning skills/behaviors are probably in epistemic cognition territory simply because higher-order skills tend to be synonymous with or requisite of epistemic cognition [3,36]. Finally, at least one study already used student opinion on the course's epistemology as a feature in trying to understand the environment itself [64], a framework that epistemic cognition researchers can help expand upon with the concept of epistemic climate. Reframed with this lens, online research has forayed into epistemic cognition territory already, but has done so without the theoretical and practical benefits of the epistemic cognition research community's efforts.

When history educators and history education researchers seriously delved into epistemology and epistemic cognition, the result was a brand-new instructional curriculum, learning materials, and pedagogy style today called Reading Like a Historian [70]. Stemming from Wineburg's work that identified in professional historians an epistemological inclination to view historical texts as human constructions that need to be interrogated [68], the curriculum centers around work with primary sources. The curriculum encourages specific epistemic practices (or, in the language of history education, heuristics): sourcing (considering the document's source and purpose), contextualizing (placing the document in the when and where of its existence), and corroborating (comparing and evaluating accounts of multiple sources) [68]. Students are, thus, onboarded into thinking historically.

Given that multiple online learning environments can cover similar disciplines and that a single online learning environment can attract a learner population from diverse backgrounds (disciplines, cultures, and so on), could we through epistemological analysis arrive at similar innovative curricula? For instance, although physics, chemistry, mechanical engineering, and materials science might all teach thermodynamics, the way these disciplines enculture their participants into specific epistemic practices could show up in the learning process and learning performance during a well-crafted, thermodynamics-related online learning environment. These differences in disciplinary epistemological enculturation might also show up in the paths that learners take both through the course itself and through the corresponding knowledge states. We could then scale that analysis to other MOOCs in order to 'MOOC-source' a discipline's epistemology (e.g., from video transcripts, assessment items, discussion forums) and notice variations across MOOCs (across individual MOOCs and/or across MOOCs grouped by institution type or continent, for instance). By combining the disciplinary

variety and content overlap of MOOCs with the disciplinary and curricular prior work in epistemic cognition, we can entertain investigations into clarifying epistemic practices within different online learning cultures and streamlining future curriculum construction.

Of course, the online learning research community does not entirely have to follow the history education field's trajectory in leveraging epistemic cognition research. Many online learning environments possess capabilities that predispose them to certain kinds of future work. First, many online learning environments empower instructors and/or researchers to assign learners to groups according to certain criteria at scale for work [42] and for discussion [44]. How does epistemological diversity influence group work online? Some of the observational/qualitative studies of STEM students at work indicate that group dialogue can efficiently reveal epistemologies [13,30,45], but there does not seem to be in the literature of a serious learning-oriented observation of multiple teams constructed with epistemological diversity in mind. Given the learner population diversity and scale as well as the ease of assignment into groups, investigations of some kind of group work might be more beneficial to do online. Second, certain online learning environments (especially MOOCs) are beginning to employ advanced machine learning techniques such as recurrent neural networks that can help cluster learners and predict learning trajectories more efficiently than previous models [55]. These algorithms simply do not make sense in pen-and-paper or small-data settings. A few intriguing possibilities present themselves with these data analysis techniques: clustering learner trajectories by learner epistemologies; investigating whether or not certain sequences of knowledge state transitions also facilitate epistemological beliefs transitions; and collecting data around tacit (rather than only overt and/or self-reported) epistemic behaviors. All of these investigations have the potential to lend existing models greater explanatory power for clarifying how learners navigate the learning process. This is especially important for online learning research because it could add a new dimension through which to understand the online learners and because it could add a new variable with which to structure and predict mastery training. The overall point is that the online learning research community can as much translate methods from others' success as try investigative methods that only this community can uniquely attempt.

CONCLUSION

To advance their investigations, epistemic cognition researchers are calling for data sets, learning environments, and intervention possibilities that share the qualities that diverse, large-scale online learning environments offer. In turn, epistemic cognition affords online learning data and online learning researchers a fresh conceptual frame for understanding and describing online environments and a new variable for analyzing and predicting online behaviors. Various online learning researchers and data scientists either have already encountered or are about to encounter epistemic cognition in their research without realizing it and therefore not leveraging the literature of that field for its significant theoretical and practical value. Evidence of that value has been demonstrated in history education, where seriously investigating epistemic cognition produced a new and expanding pedagogy that teaches history while also giving students practice with thinking like a historian. Furthermore, it is clear especially from the discussion of the affordances of epistemic cognition to online learning research that we can use a wealth of existing data to conduct some of the investigations mentioned here. At the same time, we also need to design activities and environments that render epistemic cognition readily observable and craft assessments that render epistemic cognition absolutely necessary. The research reviewed in this paper paints a picture of a significant overlap (present and future) between epistemic cognition research and online learning research, rendering the collaboration between the two fields seem not only unavoidable, but also indispensable.

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