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The Case for Epistemologically-Conscious Computer-Based Learning Environments

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Introduction

One way to view education is that education is fundamentally about knowledge because it encourages a particular use of knowledge, produces a certain kind of knowledge, and/or even leverages knowledge as a platform for wider change. Therefore, epistemology – our views about knowledge and knowing – is at the heart of what we as educators aim to do. To make this notion more concrete, Hofer and Pintrich [17] identified four significant dimensions when defining one's epistemological[1] viewpoint: certainty of knowledge (i.e., is knowledge fixed or fluid?); simplicity of knowledge (i.e., is knowledge an assortment of isolated facts or a network of highly-interrelated facts?); sources of knowledge (i.e., does knowledge reside in authority or in one's own construction?); and justification for knowing (i.e., how does one evaluate knowledge claims?). Answers to these questions (and debates/controversies about the answers to these questions) help define and delineate particular knowledge-based communities, such as academic disciplines and even sub-disciplines. [4,29,43] Through their particular epistemological lens, instructors decide what counts as knowledge via their lectures and what ways of knowing they reward via their examinations. In light of this, a natural question arises: is epistemology significantly consequential to one's learning process? Epistemological philosophers have been investigating this very line of inquiry for centuries and, more recently, educational psychologists have been investigating it for several decades. As such, research into epistemic cognition (an umbrella term for mental processes and models about knowledge) necessarily draws heavily for inspiration from both epistemological philosophy and educational psychology. [5,11,39]

Building on this prior work in the field of epistemic cognition, I wish to advance the line of research arising from three independent calls for a computer-based research agenda for epistemic cognition [10,18,25]. Specifically, I translate insights and methods from small-scale, paper-based studies into designs for scalable, computer-based learning environments (CBLEs). This translation is especially timely because since 2012, two particular kinds of CBLEs have risen in popularity: massive open online courses (MOOCs) and blended classrooms. [12,24] MOOCs are online environments that can potentially capture hundreds of thousands of learners in them, whereas blended classrooms are courses that combine sections of online and offline pedagogy to deliver a hybrid experience. MOOCs especially have the potential to generate large, diverse, and continuous/periodic data sets that would provide the kind of sampling scale and variety to test hypotheses, run interventions, and inform theories of learning more robustly. [24] Several epistemic cognition researchers have recently encouraged the search for new ways to collect more behavioral, fine-grained, real-time data across more diverse populations [3,16], and CBLEs such as MOOCs and blended classrooms match those requirements.

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[1] Kitchener [23], among others, has called for the field to adopt the distinction that "epistemological" refers to a theory of knowledge and "epistemic" refers to merely a claim regarding knowledge. The field has not settled on a specific nomenclature between "epistemological" and "epistemic." [16] Therefore, some researchers use "epistemological" and "epistemic" interchangeably, while others might have named a construct as "epistemological" earlier in their work when "epistemic" might have become a more accurate descriptor later in their work. Because of these difficulties, in this paper, I always use the term chosen by the researchers in the work that I am citing.

The goal in this paper is to briefly outline the theoretical foundations of epistemic cognition and its influence on learning processes through specific case studies. Then, to provide instructors with tools to bring epistemology into their learning environments (digital or not). Finally, to outline the designs for two CBLEs that can collect data on student learning-relevant actions and choices to infer student epistemologies. These designs can then be deployed in MOOCs and hybrid/flipped classrooms to help students, instructors, and researchers gain insight into this ubiquitous, influential, and yet largely invisible force.

The Case for Why Epistemology Matters

Much of epistemic cognition research traces its roots to Perry's qualitative study of the intellectual development of Harvard undergraduates [33], and much has been accomplished since then. Hofer [16] presents the development of the epistemic cognition field as occurring in three waves, each of which re-cast epistemic cognition in a new theoretical model and with a different set of methodologies. The first wave introduced a developmental model of epistemic cognition with a primarily qualitative study of stable, synchronous epistemological beliefs. [1,21,22,26,33] In this model, a learner's thinking about knowledge evolves from a view of knowledge existing absolutely and concretely (i.e., knowledge is not seen as an abstraction) to a view of knowledge existing as an outcome of reasonable inquiry tied to presented and evaluated evidence. [21] The second wave introduced a multi-dimensional beliefs model, with a primarily quantitative study of independent, asynchronous dimensions of an epistemological belief profile. [17,30,35,36] In this model, a learner can hold a belief about, for instance, how certain knowledge is in history independently of how complex knowledge is in history and also independently of how certain knowledge is in mathematics. [4,30] Some beliefs can be domain-general (holding stably from history to mathematics) and others can be domain-specific (holding in the context of history, but not in the context of mathematics). [4,30] The third wave introduced a situated model, with a primarily qualitative study of the activation and use of standalone epistemological resources. [6,7,13,28] In this model, a learner builds up a repository of epistemological resources (e.g., that knowledge can be transmitted from one person to another) that the learner then activates when encountering a specific learning task. Poor performance on a learning task, then, can be interpreted as either the absence of a particular epistemological resource or the absence of activation of a particular epistemological resource. Analyzing what a task epistemologically requires become crucial. [13] Responding to the overt focus on an individual's epistemic cognition in these three models, Kelly recently proposed a fourth, sociocultural, model. [20] In Kelly's model, the focus is on qualitatively studying epistemic practices, which are behaviors regarding knowledge one acquires through interaction within and across different knowledge-based groups (each of which has its own unique take on what knowledge counts and looks like). [20]

These theoretical models do not have to be inherently adversarial. The situated resources model can, for instance, identify context-sensitive resource activations that, over time and across contexts, can solidify into a stable, context-general epistemic belief. In fact, in the two case studies below, the first approaches epistemic cognition from the situated resources perspective, whereas the second approaches epistemic cognition from the dimensional beliefs perspective.

Case #1: Epistemological Privileging

Imagine a student who is in an introductory college physics course. This student engages with the material, wanting to learn about electric fields and the forces exerted by electrostatic charges. She engages readily in conversation with her three group mates and always pushes the group for a mathematical explanation, unsatisfied with an understanding purely based on physical examples. She also does all of her homework. Here is the problem: unlike the rest of her group, she is not getting the fundamental physical concepts behind the formation of electric fields and the application of the equation $E = F / q$. The question is: why?

Lising and Elby [27] investigated this question with a thorough qualitative study that comprised an analysis of videotaped class work, written work, and interviews. Through the interviews and the transcripts, the researchers uncovered that the student, Jan, differentiates between two kinds of knowledge in physics. On one hand, she defines knowledge arrived at by what the researchers call formal reasoning: using the relationships in equations and principles in theorems to mathematically produce and validate knowledge. This is when, learning about electric fields, a student might say, "but what I am saying is *E* is equal to *F* over *q*, right? That doesn't include radius in it…If this [*q*] becomes smaller then that [*F*] becomes bigger. That's all it is, right?" [27:375] Notice that the student is reasoning through the mathematics, but not using an example like a point charge experiencing an electric field. On the other hand, she defines knowledge arrived at by what the researchers call intuitive reasoning: using everyday examples and common-sense intuition to produce and validate knowledge. This is when, learning about torque, a student might say, "I think what I can think about is like a door. You've got like the hinge here and you know you've got like the swinging door. I think if you push here [closer to the hinge] the door is going to feel more heavy that if you push it out here [farther from the hinge]." [27:377] Notice that the student is reasoning through a physical experience, but not using an equation like $T=F \cdot r \cdot sin\theta$ to make the argument. Not only did the researchers find ways to identify these two kinds of reasoning in student work, the student, Jan, points them out as well.

The researchers then mapped out the instances when and with what outcome Jan engaged in each kind of reasoning to arrive at three general conclusions. First, that Jan consciously separates intuitive and formal reasoning and "considers only the latter to be "physics-oriented."" [27:376] Epistemologically, Jan is not only separating physics knowledge into formal and intuitive categories, but also insisting that physics as a field of knowledge accepts and works on only the formal kind of reasoning. Second, that one critical way in which Jan's privileging of the formal reasoning manifests is through her preference for reconciling reasoning impasses within-type (e.g., reconciling formal reasoning with formal reasoning) than between-type (e.g., reconciling formal reasoning with intuitive reasoning). To arrive at this finding, the authors coded every line of Jan's reasoning for: (1) the kind of reasoning she engages in; (2) whether or not the reasoning requires reconciliation (e.g., she arrives at a logical oddity, impasse, or misconception); (3) whether or not she reconciles; and (4) if she does reconcile, what kind of reasoning she does so with. Jan did not reconcile every time she could have – she reconciled about 40% of the total reconciliation opportunities. In those reconciliation opportunities, however, she reconciled more often with the same kind of reasoning (46% of possible opportunities) than switching to the other kind of reasoning (13% of possible opportunities). Third, that Jan's epistemological stance (her view of physics knowledge) is a necessary but not sufficient explanatory variable in making sense of Jan's learning process and outcomes. Jan's epistemology does not explain all of her learning behaviors and actions, but the authors present five alternative explanations and show how they do not paint a complete picture without considering her epistemology. As the authors summarize:

> Jan's skills, her abilities, her store of ideas – none of these are the "limiting reagent" for her learning in these episodes. She is capable and fluid with mathematical, technical, and everyday, common-sense reasoning. She is capable of checking her understanding and reconciling inconsistencies. She is capable of working through difficult problems for which she has very little relevant formal knowledge. Despite all these strengths, her epistemology sometimes gets in the way of her learning. [27:381]

The sum-total of these findings is that epistemology not only has explanatory power alongside other variables (e.g., skills, prior knowledge), but also has a prominent (if not central) role in the explanatory model.

Case #2: Epistemological Misalignment

While Lising and Elby [27] identified a difference in epistemological preferences from observable learning behavior, Franco et al. [9] ran an experiment that engineered a situation in which differences in epistemological preferences could lead to differences in learning behaviors and outcomes.

The researchers asked students to read about Newton's First Law (inertia) and Newton's Third Law (action and reaction). The texts for both topics were of comparable length (approx. 650 words) and display a refutational style of argumentation, which means that rather than introduce concepts via exposition, the texts target a core misconception and present evidence that is contradictory to that misconception. To differentiate between the epistemological perspectives across texts, the researchers turned to two dimensions measured by the Psycho-Epistemological Profile (PEP): rationalism and metaphorism. Rationalism considers knowledge to be obtained through logical, conceptual and analytical thinking, a sample questionnaire item for which is: "Most people who read a lot, know a lot because they acquire an intellectual proficiency through sifting of ideas." Metaphorism considers knowledge to be subjective, personal, and involving integration and the use of symbols, a sample questionnaire item for which is: "When people are arguing a question from two different points of view, I would say that each should endeavor to assess honestly his or her own attitude and bias before arguing further." Therefore, in total, the authors produced four texts, with two versions for each of the two laws (see **Table 1** for excerpts from each version).[2] During the experiment, the researchers asked students to read one line at a time while also engaging in thinking aloud.

[2] While the nomenclature is different, the "rational" and "metaphorical" epistemological perspectives in the Franco et al. study [9] resemble the "formal" and "intuitive" ones, respectively, in the Lising and Elby study [27].

Concept	Rational Text	Metaphorical Text
Inertia	The properties of inertia can be represented by the equation $\sum \vec{F} = 0$ which states that when the vector sum of all forces acting on an object is zero, the object remains in its current state (in motion or in rest).	Demonstrations of inertia are when we stamp our feet to remove snow from them, shake a garment to remove dust, or tighten the loose head of a hammer by slamming the hammer handle-side-down on a firm surface.
Law of action and reaction	The third law is as follows: "Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first." The mathematical formula for Newton's third law is a vector relationship: $\overrightarrow{F_{AB}} = -\overrightarrow{F_{BA}}$ (F = force; AB = Object A on Object B; BA = Object B on Object A) One force is called the action force and the other is called the reaction force.	Consider, for example, the interaction between a hammer and a stake. The hammer exerts a force on a stake and drives it into the ground. But this force is only half the story, for there must be a force to halt the hammer in the process. What exerts this force? The stake! Newton reasoned that while the hammer exerts a force on the stake, the stake exerts a force on the hammer. Such observations led Newton to his third law-the law of action and reaction. The third law is stated as follows: "Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first." One force is called the action force and the other is called the reaction force.

Table 1. Examples of rational and metaphorical texts used for investigating epistemic misalignment. Adapted from Ref. [9].

The researchers drew three main conclusions about the alignment of the knowledge representation format (epistemology) of a text with the knowledge conception (epistemology) of a student. First, when the knowledge representation format was congruent with individuals' epistemic beliefs (e.g., metaphorical text for the high-metaphorism group of students), students used more deep processing strategies (e.g., students elaborating, paraphrasing, or reflecting on conflicts between prior and new knowledge) compared to when the format was inconsistent. The researchers found a main effect of text type, $F(1, 73) = 8.43$, $p < 0.010$, $\eta^2 < 0.10$, significant interaction between text type and epistemic beliefs, $F(1, 73) = 15.08$, $p < 0.001$, $\eta^2 < 0.17$, but no main effect of epistemic beliefs, $F(1, 73) = 2.75$, $p < 0.100$. Second, students recalled more textual information when the text representation was congruent with student epistemic beliefs than when the text representation was incongruent with student epistemic beliefs. For instance, the metaphorical group recalled more textual information from a metaphorical than from a rational text, $t(47) = 2.49$, $p = 0.010$, $d = 0.53$. Third, when the representational format of the text was congruent with the epistemic beliefs of the student, that student was more likely to change misconceptions than when the text was incongruent: $t(26) = -4.32$, $p = -0.0001$ for the rational group and $t(47) = -7.65$, $p = 0.0001$ for the metaphorical group. While the misconceptions related to Newton's Third Law were more resilient than those for Newton's First Law, the general pattern holds that conceptual change favored the congruency condition. The sum-total of these findings shows that differences in epistemic beliefs correlate with differences in learning behaviors and that congruency between those beliefs and knowledge representation in a text correlates with different learning behaviors and learning outcomes.

Designing Epistemologically-Conscious Learning Environments

The conclusions from these two studies point to two realities: (1) that epistemology is located not only in student cognition, but also in learning materials and (2) that no learning material is epistemologically neutral. This means that learning environments epistemologically favor some students and not others. Students can be experiencing greater learning struggle (e.g., recalling less from what they read and changing fewer misconceptions based on what they read as in Ref. [9]) not because of lower effort, motivation, or intelligence, but because of misaligned epistemologies. At the same time, every discipline has its own epistemological foundation (e.g., what counts as knowledge in mathematics might not count as knowledge in history [4]), and so some epistemological aligning is required – and expected – for anyone entering a new discipline. Building into instructional design supports for making sense of and navigating that experience of misalignment is a critical step forward in ensuring that students are not unintentionally funneled out of disciplines they might otherwise enjoy and excel at.

Awareness through Epistemic Climate

One way to take this step forward is to first engage in an analysis of the epistemological forces that students will encounter in a particular learning environment. The two case studies reviewed above and many others point to at least three epistemologies to consider: the epistemology of the domain [4,29,30]; the epistemology of the learner [16,35,37]; and the epistemology of the environment [3,8,31]. Below are some guiding questions to support more epistemologically-conscious analysis of instruction:

- Epistemology of the Domain
    - What are the epistemological frameworks and standards of this particular knowledge domain (e.g., physics, mathematics, history)? And does this particular learning environment espouse those same frameworks and standards?
    - One of the main functions of any discipline-based learning environment is to enculture learners into the practices of a particular discipline. As an example, several years of probing professional and novice historians' epistemologies uncovered three specific epistemic practices that set the foundation for a new curriculum called Reading Like a Historian. [29,34,45] The curriculum is now spreading beyond university walls and into American school districts. [42,45] Some of the guiding questions in this area include: How does the discipline organize its knowledge and knowing (e.g., into knowledge arrived at via formal or intuitive reasoning [27])? How do professionals in a discipline make and evidence their knowledge claims (e.g., in mathematics, computational evidence can sometimes suffice in lieu of deductive proof [43])? How do professionals in a discipline treat the sources of knowledge and/or evidence (e.g., that historical primary texts are to be critically interrogated rather than blindly accepted [44])?

- Epistemology of the Learner
  - What are the epistemological stances of these particular learners? And what kinds of epistemological shifts is the learning environment expecting them to make?
  - While the time-intensive, qualitative analyses from the situated epistemological resources model can help identify students' particular epistemologies [13,28], quantitative methods from the dimensional model can help provide a more coarse-grained overview [35,37]. The goal is to construct an epistemological belief profile (EBF) of some kind for each student. To accomplish this task, researchers have developed a variety of instruments: Epistemological Beliefs Questionnaire, EQ [37]; Epistemic Beliefs Inventory, EBI [38]; Discipline-Focused Epistemological Beliefs Questionnaire, DFEBQ [14]; Psycho-Epistemological Questionnaire, PEP [32]; to name a few. Researchers and instructors can review one of these instruments and use the one that best matches their intended needs best. As mentioned previously in this paper, Hofer and Pintrich [17] reviewed the findings from various quantitative studies and identified four dimensions that serve as a basis for gauging learner epistemologies: certainty of knowledge; simplicity of knowledge; sources of knowledge; and justification for knowing.
- Epistemology of the Environment
  - What are the epistemological standards and demands of these particular lectures, assessments, and other environmental elements? And do they unintentionally shut out or discount a particular kind of knowledge or way of knowing?
  - The epistemological beliefs and/or dispositions within a learning environment (e.g., lectures, reading materials, problem set solutions, and so on) are collectively referred to as an "epistemic climate." [8,31] In one study, Muis and Duffy created a statistics course in which they ensured that the teaching practices and homework feedback espoused the same epistemology. [31] Specifically, the epistemology of the course promoted a more constructivist view that asserts knowledge to be: complex (i.e., richly connected rather than a list of isolated facts); tentative (i.e., continuously updatable rather than permanently fixed); and personally constructed (i.e., students need to actively create their own mental models rather than passively receive them). The researchers found that student epistemologies shifted toward those of the epistemic climate halfway through the semester. This indicates both that student epistemologies can change on a six-week timeframe and that the epistemic climate can serve as a medium for that change. Therefore, analyzing lectures and readings (e.g., with the certainty, simplicity, and justification dimensions from Hofer and Pintrich [17]) and homework assignments and in-class activities (e.g., with the views from Muis and Duffy [31] as well as reasoning types from Lising and Elby [27]) can serve as a basis for gauging the epistemic climate.

The intention behind asking these questions is by no means to indicate that there is a 'good' and a 'bad' epistemological foundation for instruction. The intention behind asking these questions is to become more conscious about the epistemological choices in the design of instruction to render those choices trackable and changeable.

Awareness through Epistemology-inspired Design

The studies along with the questions outlined above serve as the foundation for several epistemology-inspired designs for computer-based learning environments (CBLEs). While at least three papers have call for a computer-based research agenda for epistemic cognition [10,18,25], computer-based or digital-enabled education has not manifested in a mainstream way. Rare exceptions include studies primarily using web-surfing as an activity to identify epistemological practices. [2,15,19,40] Therefore, the designs below serve two purposes. First and foremost, they translate insights about eliciting and interpreting epistemologies and epistemic cognition from offline, paper-based studies into CBLEs. Currently, very little research into that translation/digitization. Second, they help generate data to advance the study of epistemic cognition and its influence on learning via advanced learning analytics. [25]

Design #1: Learners Identify and Choose Learning Resources Based on Epistemology

The first design (see **Figure 1**) draws inspiration from the act of learners reporting, classifying, and/or describing the epistemology of a particular learning material. The interface presents learners with a list of topics and multiple versions of a reading for each topic. Learners can open up a reading or even presentation slides and skim them to get a basic sense of the point of view that that version is applying to the topic. After the learner establishes a reading pattern (e.g., preferring to read version 1 across topics), the interface asks the learner to explain that pattern. A simple dashboard displays the number of materials read from each version, so that the learner can make a choice to either continue with that pattern or try a different one. In later topics, the learner might encounter some readings that are not available/unlocked until the learner engages with a certain number of readings in all versions. Alternatively, for a particular topic, the instructor might constrain the choice of materials (e.g., only materials of a certain epistemology are available) to match the in-class teaching practices for that topic. Overall, the purpose of this interface is to allow learners to make reading choices based on epistemology without that choice breaking the flow of engaging with the material.

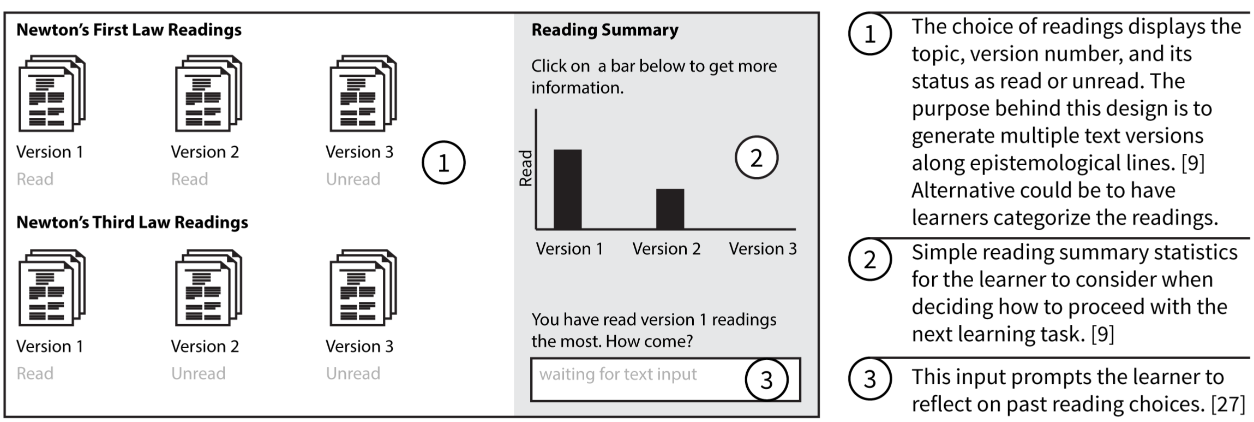

Figure 1. Shows an interface design for identifying student choice around reading materials with annotations that explain the design and reference relevant research (sidebar).

This design opens up two extremely enticing areas for epistemic cognition research. First, researchers can gauge if students becoming explicitly aware of the epistemic climate, correlates with a change in their psychological behavior. For instance, if the learning environment identifies a learner's epistemological preference early on, the environment can adapt the available reading choices. One adaptation can be to eliminate all materials related to the learner's preference and investigate if a learner can feel lack of 'epistemological belonging' the way that some learners lack a sense of social belonging. [41] If so, does that experience correlate with exam performance, course dropout/withdrawal, and/or leaving the academic discipline? Second, researchers can investigate how providing learners with varying levels of epistemological misalignment through reading materials influences the learning process for different learner groups. After all, if learners are faced with multiple epistemologically diverse resources, they might benefit from the variety (because they will be able to create richer connections among topics) or they might be paralyzed by that variety (because they will not know how to establish the connections between them). The variety might also have no effect if the student completely discounts certain ways of knowing (as the student from Ref. [27] did). These are the kinds of questions that this particular design lays the foundation for.

Design #2: Learners Reconcile and Argue in Dialogue Based on Epistemology

The second design (see **Figure 2*Figure 2***) combines the reading materials from the Franco et al. study [9] with the learner behaviors from the Lising and Elby study [27]. Learners read transcripts of dialogues between two people who are discussing a particular concept, such as one of the Newton's Laws of Motion. The people in the dialogue can have completely different epistemological viewpoints or they can have the same ones, setting up the grounds for a within- or between-type reconciliation. [27] After reading the dialogue, the learner needs to determine if the dialogue's logic is sound or not (i.e., is there a mistake somewhere in the reasoning?). Alternatively, the dialogue might explicitly point out an impasse or tension that the people in the dialogue cannot reconcile, and so turn to the learner for help. Either way, the learner's subsequent task is to clarify the tension and provide appropriate examples or arguments for reconciliation. The learner can select which example or argument to base his/her reconciliation around from a drag-and-drop menu on the right side of the screen. After the learner drags an example or argument into the response input screen, the learner can then follow up with a free-form text. By the end, the learner will have a complete response to the dialogue that is a combination of the drag-and-drop example and the learner's free-form text.

This design allows for inquiries into how students process and use different kinds of reasoning in the context of argumentation and reconciliation, as explored initially offline in [27]. For instance, a learner could craft a formal reasoning reconciliation to 90% of dialogues that are rife with intuitive reasoning. If the reconciliations are always correct, then the student is able to translate between the two kinds of reasoning, but still prefers the kind of reasoning that is incongruent with the dialogue participants. If the reconciliations happen to be incorrect, then that means something else entirely: the student could be mis-translating between the reasoning types or could be translating accurately but incorrectly reconciling. This interface allows us to ask and investigate these lines of inquiry. The resulting data on a longer timescale can reveal a potential relationship between misconception formation and epistemic beliefs.

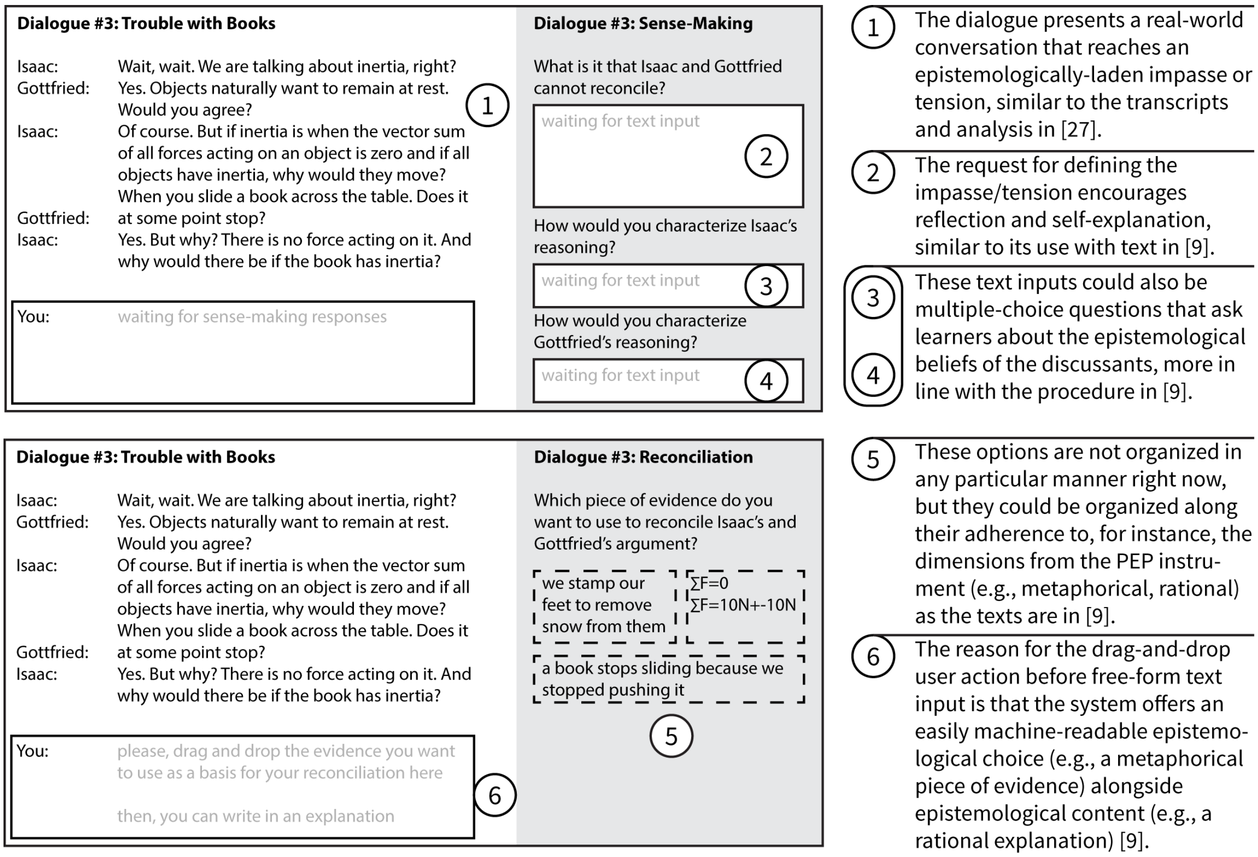

Figure 2. Shows an interface for identifying the epistemological frameworks in a dialogue and a tension for reconciliation (above) as well as selecting evidence for that reconciliation (below). The figure includes annotations that explain the design and reference relevant research (sidebar).

Conclusions

In this paper, I show both why epistemic cognition (and epistemology more generally) matters in the context of STEM education through two specific studies and the translation of the findings from these studies into two computer-based learning environments. The need for greater epistemological awareness of the domain, learner, and environment, I argue, is not only a promising area for learning science research and pedagogical innovation, but also necessary for facilitating high-quality and genuinely inclusive learning. Epistemology is not something learners or instructors can choose to turn off – they are immersed in it whether they like it or not. Therefore, instructors, instructional designers, and researchers have a choice about how willingly they embrace epistemology as a core consideration in learning environment design. Because of epistemology's influence on learning, and especially discipline-based learning, engaging with it and investigating it further is a wise investment. CBLEs offer a platform for maximizing that investment because they enable behavioral data collection at scale that can be contextualized with other student actions/inputs and adaptation of what the learner experiences in a fine-grained and controlled manner. Therefore, these digital, data-collecting interfaces represent a break from the current self-report, paper-based methods of inferring student epistemologies. By creating epistemologically-conscious learning environments (i.e., environments that include epistemology as a core part of their design, analysis, and adaptation), the hope is that instructors, researchers, and learners make informed choices as knowers.

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