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"I guess my question is": What is the co-occurrence of uncertainty and learning in computer-mediated discourse?

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Abstract The purpose of this study was to contribute to a better understanding of learning in computer-supported collaborative learning (CSCL) environments by investigating the co-occurrence of uncertainty expressions and expressions of learning in a graduate course in which students collaborated in classroom computer-mediated discussions. Results showed that uncertainty expressions appeared related to the kinds of intellectual work engaged by students in online discussion, co-occurring with learning in systematic ways. For example, direct expressions of uncertainty were likely to co-occur with learning categories associated with presenting a new idea and with applications of an idea whereas indirect expressions were more strongly associated with elaborating on a new idea. These findings suggest that the ability to deal with and express uncertainty appropriately may be related to learning as it takes place in online environments. We contend that the role of uncertainty in learning is currently undervalued, and

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that educators and researchers may benefit from considering how uncertainty can be productive for learning in CSCL environments.

Keywords Learning theory · Computer-mediated discourse · Hybrid course · Uncertainty

Introduction

Since the mid1990s, a growing body of research has investigated learning in computer-supported collaborative learning (CSCL) environments, some of which has been theoretically grounded in socio-constructivist (e.g., Bonk and Cunningham 1998; Hughes and Daykin 2002) and sociocultural (e.g., Na 2004) frameworks. Previous studies suggest that CSCL can promote metacognitive processes (Pifarre and Cobos 2010), facilitate knowledge construction (Schellens et al. 2007), and foster critical inquiry (Duffy et al. 1998; Ryser et al. 1995). We propose that CSCL can also present opportunities to generate, entertain, and resolve uncertainty, opportunities that are productive for learning.

To foreground the critical but often overlooked notion of uncertainty in CSCL, we focus here on learning in formal academic contexts in which computer-mediated discourse (CMD) is a significant component of a course design. Defined by Herring (2001) as "the communication produced when human beings interact with one another by transmitting messages via networked computers" (p. 612), CMD has been noted for its ability to foster collaborative dialogue in academic contexts (e.g., Wade and Fauske 2004). CMD frequently comprises a major portion of students' activities in hybrid and online courses (Brookfield and Preskill 2005; Knowlton 2009) and will likely continue to play a significant role in formal learning as institutions of higher education increasingly offer online and hybrid courses (DeSantis 2012; Parry 2010).

Our goal in this study was to develop a deeper understanding of how individuals learn in CSCL environments by examining the co-occurrence of uncertainty and learning as expressed in the discourse of graduate students participating in online discussions of academic texts. Extending our prior work describing the prevalence of uncertainty expressions in CMD and the nature and dynamics of that expression (Jordan et al. 2012), we hypothesized that differences in how uncertainty is expressed might be related to different processes of learning. We framed this study in terms of two issues of interest to learning scientists and education scholars: learning as it is associated with uncertainty in collaborative contexts, and language reflecting uncertainty. Our contention was that entertaining uncertainty during online discussions can prompt inquiry and stimulate new ideas that promote cognitive change.

Uncertainty and Learning

Uncertainty has a venerable, if somewhat peripheral, history in theoretical thought on learning. John Dewey (1929) observed that individuals are often "impatient with doubt and suspense… A disciplined mind [on the contrary] takes delight in the problematic" (p. 228). Bruner (1986) was emphatic that education should bestow "some sense of the hypothetical nature of knowledge, its uncertainty, its invitation to further thought" (p. 126). He expressed concern that teachers often represent to students a world that is settled and non-negotiable and "close down the process of wondering by flat declarations of fixed factuality" (p. 126). Bruner's concern illuminates the importance of the role of expressing uncertainty in piquing students' curiosity and encouraging them to generate thought experiments, suspending certainty in

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service to wondering, marveling, conjecture and speculation. Yet, few studies have empirically investigated the relationship between uncertainty and learning in collaborative environments.

Although rare among learning scientists and educational researchers, scholarly interest in subjective uncertainty has been pursued across fields as disparate as communication, psychology, and organizational management. *Uncertainty* can be defined as a cognitive feeling (Clore 1992; Schwarz and Clore 2007) that encompasses experiences of wondering, doubting, or being unsure. Individuals experience uncertainty when they are conscious of having incomplete knowledge or understanding of issues related to self, other people, or aspects of one's environment (Jordan et al. 2012; Smithson 1989). Thus, cognitive feelings of uncertainty have a metacognitive aspect. Uncertainty applies to probabilistic judgments (e.g., How well do I understand my group member's idea?) and evaluative appraisals (e.g., Which explanation do I prefer?) (Babrow 2001; Jordan and Babrow 2013). Because both of these figure prominently in learning, attending to the role of uncertainty can illuminate processes of learning as they occur in CSCL environments.

It is our contention that the ability to manage and express uncertainty in interactions with others is related to students' intellectual work and learning goals (Jordan et al. 2012), first, because learning may naturally accompany or engender cognitive feelings and expressions of uncertainty. As Barnes (1992) noted, "Most learning does not happen suddenly: we do not one moment fail to understand something and the next moment grasp it entirely" (p. 123). We have previously noted that students engaged in CMD rarely seem to learn by appropriating new ideas completely and with certainty. Instead, they often experience learning as a lifting of fog or clearing of muddy waters as ideas gradually become clarified and specified (Schallert et al. 2003–2004), much in the ways described by Rumelhart and Norman (1978) as accretion, tuning, and restructuring. Thus, rather than moving quickly between states of not-knowing and knowing, online collaborative learners are likely to spend much of their time in a state somewhere between, experiencing varying degrees of uncertainty related to newly encountered ideas and previously-held beliefs.

Likewise, uncertainty may reciprocally engender learning. Chan et al. (1997) described knowledge building as arising out of cognitive conflict, much as Piaget (1972) described learning as resulting from disequalibration brought about by a disconnect between a learner's previous and current experience. When individuals encounter new ideas that are at odds with prior beliefs, they often engage in resistance and struggle (Almasi 1995; Lee et al. 2011). If learning is to take place, resistance must give way to doubt or uncertainty that paves the way for a change in beliefs or understandings. Furthermore, although learning is frequently assumed to be a process of reducing uncertainty, scholars have suggested that learning sometimes requires intentional cultivation of uncertainty (Bereiter and Scardamalia 1993; Hiebert et al. 1996; Reiser 2004; Sieber 1969). When individuals generate, sustain, and express uncertainty during a collaborative activity such as CMD, opportunities arise for the types of social interactions that facilitate learning: probing, explaining, critiquing, elaborating, and generating multiple representations, among others (e.g., Chi 2009; Kapur and Bielaczyc 2012). Social interaction can both reduce and cultivate uncertainty (Babrow 2001; Jordan and McDaniel 2014; Radinsky 2008) and this allows individuals to make connections, synthesize ideas, or question beliefs, values, and ideologies. Thus, we hypothesize that uncertainty frequently co-occurs with learning, taking the form of four trajectories. Learning can (a) reduce a learner's uncertainty, (b) generate or increase uncertainty, (c) shift a learner from one state of a state of uncertainty to a different ground for uncertainty, or (d) move a learner to a state of knowing or greater clarity without evoking uncertainty. Such paths may help learners consider beliefs, values, and understandings in conflict with their present beliefs and values.

Uncertainty and language

Our fascination with the construct of uncertainty comes from an interest in how an individual's experience of uncertainty is revealed in language and discourse practices. Individuals often seek to reduce uncertainty through communication (Berger 2005). However, the language through which they communicate has characteristics of uncertainty that can make detection of factual or communicative errors problematic (Channell 1994), and communication failures rampant (Sacks et al. 1974). At the same time, the very fuzziness of language allows one to do things not possible using a more precise system, such as expressing various degrees of belief or attitude towards propositions (Rowland 2000), being polite (Brown and Levinson 1978), and maintaining good social relations (Smithson 1989). Thus, individuals sometimes seek to maintain or increase uncertainty through communication, as when supporters respond to news of a possibly terminal diagnosis by expressing hope or offering alternative reasons for symptoms (Ford et al. 1996). Here, we join the small community of scholars who have examined the expression of uncertainty in collaborative learning contexts, exploring issues about and purposes for which participants express uncertainty (Radinsky 2008; Wegerif et al. 1999), and how they influence one another's expressions of uncertainty during face-to-face (Anderson et al. 2001) and online (Kim et al. 2007) discussions.

The ability to deal with and express uncertainty appropriately is an important skill in many learning contexts, and uncertainty has particular qualities in CSCL. Although some research has indicated that participants in online discussion tend to use few uncertainty markers (Brennan and Ohaeri 1999), other studies have found the CSCL environments are inherently imbued with uncertainty (Jordan et al. 2012; Nguyen and Fussell 2013). In addition to uncertainty about complex course materials and evaluative risks, online platforms induce uncertainty stemming from social/relational considerations. Online students may never meet each other; they also come from diverse sociocultural backgrounds and exhibit rich, complex linguistic moves in text-based CSCL environments. Such diversity and inclusion may naturally be a source of communicative uncertainty. Furthermore, the medium through which discourse occurs can influence the ways uncertainty is expressed. Despite its affordances for collaborative learning, the format of CMD entails constraints in transmitting various non-verbal cues to lubricate interactions among participants, and this poses special problems for expressing uncertainty. Whereas participants in face-to-face discourse can convey uncertainty through intonation or physical gesture (McNeill 1992), CMD does not afford those options (Herring 2001). Neither can resolutions of uncertainty and ambiguity be carried out as quickly, because there is a time and space displacement in computer-mediated communication. Hence, there is a double sense of uncertainty in CMD: CSCL environments are riddled with uncertainty, and expressing uncertainty is difficult in text-based discussions.

In the face of these constraints, CMD nevertheless offers its own way of allowing uncertainty to be expressed and negotiated. Previous analysis of the data used in the current study indicated that students expressed uncertainty often and in many ways while interacting with peers in synchronous and asynchronous online discussions (Jordan et al. 2012). Taking an exploratory approach that considered CMD as representative of intellectual and academic discourse work, we catalogued participants' uncertainty expressions into four main categories: (a) *indirect expressions of uncertainty* through which writers attribute uncertainty to environmental factors/conditions without explicitly stating that they are personally experiencing uncertainty, (b) *questions* used to explicitly request help with uncertainty and elicit feedback (Turner and Pickvance 1971) (c) *direct expressions of uncertainty* acknowledging a writer's own current psychological state of mind, and (d) *meta-uncertainty* referring to uncertainty as a concept or general characteristic of the world, other people's uncertainty, or a writer's own past

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uncertainty. Indirect expressions of uncertainty were further differentiated into three subcategories: *hedges* such as modal verbs and adjuncts (e.g., may, might, maybe) that convey referentially ambiguous states (Feldman and Wertsch 1976; Lakoff 1973), *probability statements* (e.g., often, sometimes) that convey relative frequency and event occurrence likelihood (Green 1984; Schunn 2010), and *hypotheticals* used to explore the possible (e.g., I can imagine, What if…). Direct expressions of uncertainty were further subdivided between "*I*" *statements* that include explicit self-reports reflecting metacognitive awareness of one's own psychological uncertainty using parenthetical adverbs and suppositions (I'm not sure; I guess; I doubt) (Anderson et al. 2001; Turner and Pickvance 1971) and *nonverbals* most commonly depicted by "hmm…" or "…" as stand-ins for hesitations in verbal speech (Barr 2003). We used these categories to code participants' talk in CMD transcripts. Exploring the antecedents and consequences of uncertainty expressions, we found that uncertainty attracted responses coinciding with the emergence and prolongation of topical threads. Furthermore, expressions of uncertainty encouraged similar expressions from others. This previous study, however, did not systematically explore the relationship between learning and expressing uncertainty in CMD.

Defining and operationalizing learning

Just as we operationalized uncertainty through the words and ways students expressed themselves, we also found a way to capture the learning process. Against a backdrop of vigorous debate about what learning means, we set forth here our definition of learning, unit of analysis, and theoretical grounding as they pertain to CMD and to uncertainty. First, in order to track students' learning experience in CSCL environments, we find it useful to distinguish between learning as outcome (i.e., knowing) and learning as process (Alexander et al. 2009; Cheng et al. 2013). For this study's purposes, we were most interested in learning as process, the dynamic means through which changes in an individual's knowledge or understanding occur moment-by-moment as revealed in online postings (Schallert et al. 2003–2004). Learning processes are influenced by an individual's experience and motives and by social interaction, all of which are in continual flux and intertwine with the surrounding and changing context.

Influenced by socio-constructive and sociocultural theories of learning, we see learning as a meaning-making endeavor and a social act shaped by interaction, a "process of transformation of participation" in culturally valued activities (Rogoff 1994, p. 209). Learners actively engage in constructive processes aimed at making sense of the relationship between their past experiences and new information, often through social interaction (Jonassen and Land 2012). In the case of our participants then, the ground for learning was enacted in interaction among CMD partners as they encountered content and participated in the forms of discourse valued in the academic communities in which they were striving to acquire membership. Although interactive participation in CMD may be valuable in and of itself, learning is not simply participation; learning is the residue that transformative participation leaves, a relatively enduring footprint. This residue may be represented by an acquisition or appropriation of new ideas, attitudes, beliefs, skills, or practices, but it can also be a transformation of the old, such as when knowledge, attitudes, skills, or practices are re-conceptualized (Moje and Lewis 2007). The grounds for learning are laid when learners attend to and interpret (i.e., notice) new information, juxtaposing it against their past experiences and expectations. Because interactional partners have different perspectives, they can help each other generatively discern critical and relevant aspects of new situations that otherwise might have escaped their attention

(Schwartz and Bransford 1998; Kapur and Kinzer 2009). Such noticing can lead to active struggle for understanding, and this struggle too can be efficacious for learning (Stigler and Hiebert 2009).

Relatedly, we take a dialogic view of learning. In collaborative learning environments where discussion is a central activity, participants co-construct knowledge and socially negotiate meaning (Hatano and Inagaki 1991; Wells 1999). Language not only causes or shows learning, it affords learning opportunities for others to take up and build on (Bloom 2002; Mercer 2000; Wells 1999). Several lines of scholarly work have proposed processes and functions whereby discourse has its effect on learning (e.g., Chi 2009; Bereiter and Scardamalia 2003; Schwartz and Martin 2007). For instance, research on productive failure suggests that the rich, divergent and complex nature of collaborative discourse can facilitate learning by activating and differentiating prior knowledge related to targeted concepts (e.g., connecting to disciplinary knowledge, applying previous experience), explaining and elaborating on critical features of new concepts, and increasing flexibility/adaptability as participants generate and explore ideas (Kapur and Bielaczyc 2012). Learning opportunities can also come in the form of sociocognitive conflict (Almasi 1995) or resistance (Lee et al. 2011) grounded in collaborative meaning-making activities that act as mediators of conflict in conceptual change (Chan et al. 1997). As individuals act and react to each other through words, the juxtaposition of "multiple voices, meanings, and possibilities" (Aukerman et al. 2008) leads to the transformation and development of understandings (Nystrand 1997; Wells 1999). For such reasons, McAlister et al. (2004) maintained that educational dialogue should be regarded as the most important characteristic of online learning. In CMD, learners co-create the environment that enables them to learn from their interaction as they enact their responsibility for regulating individual and shared goals and promote generativity by posting comments that invite response (Beth et al. 2013). Wade and Fauske (2004) noted: "As students [in CMD] find that their peers have different interpretations of texts, they are forced to confront alternative perspectives and understandings and to negotiate those understandings in collaboration with others" (p. 137).

Finally, whereas we recognize groups of students who are interacting in an online discussion as situated (Greeno and van de Sande 2007) sociocultural meaning makers (Bruner 1981), we also recognize learners as biological beings embedded in nested ecological systems that are themselves changing (Jordan et al. 2007). Influenced by theories of complexity science (Byrne and Callaghan 2014; Davis and Sumara 2006; Kapur and Kinzer 2008), we see learning as ongoing change arising continuously as individuals adapt to mostly local interactions, as when, for example, individuals respond to other participants' comments during an online classroom discussion. Furthermore, learning is unpredictable in its unfolding in a group and within an individual due to non-linear interdependencies and contingencies in the learning process, in learning environments, in the learners themselves, and in the interactions among these aspects (Jordan et al. 2007). Thus, expressions of uncertainty may refer to fundamental unknowability associated with the dynamic processes of learning, rather than only to uncertainties due to content being new or complicated.

If defining learning is challenging and contested, operationalizing learning is at least as much so. Learning as process is frequently illustrated through analysis of talk because one of the ways learners indicate what they have learned is through their talk that reveals what they know or are thinking at the moment. Thus, eexamining discourse is commonly used to study learning (e.g., Herrenkohl and Guerra 1998; Hmelo-Silver and Barrows 2008) and is an appropriate method if we take learning to be both constituted and reflected in discourse (Wells 1999; Wertsch 1991). As Moje and Lewis (2007) explained, learning can "involve taking up and taking on existing discourses or disrupting and transforming fixed discourses"

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(p. 180). Through a close reading of discourse, it is possible to trace the moment-by-moment development of new ideas and understandings as they unfold during engaged participation in learning events (Engle and Conant 2002). The examination of talk in CMD can yield different (sometimes more powerful) understandings than other methods of examining learning, such as standardized measures that focus on a pre-determined set of facts or skills and are more suited to examining learning as product, or self-reports of learning that may over-rely on a learner's ability to describe explicitly when learning has occurred and what has been learned (Alexander et al. 2009).

What is particularly felicitous about CMD as a site for the study of learning and uncertainty is that it constrains the process of learning to a text-based environment. The correspondence between cognition and talk is never transparent, and yet, as we claim elsewhere (Schallert et al. 2004), it is fruitful to analyze the words learners are producing as they interact in an online environment for what they can reveal about underlying thought processes and experiences, including new understandings and feelings of uncertainty. We endeavored in this study to describe participation in CMD in terms of learning as change in knowledge or understanding resulting from a process of dialogic interaction in a dynamic system of influence. More interested in the moment to moment genesis of understanding than in what has been learned, we focused on how change might be evident message by message to show learning "in the making."

Research purpose

The aim of this study was to investigate to what extent and in what ways uncertainty co-occurred with learning in academic online discussions. Two research questions guided analysis:

- To what extent do uncertainty and learning co-occur in participants' online messages?
- How are learning processes reflected in expressions of uncertainty?

To address these questions, we first examined how and to what extent students expressed uncertainty during CMD and how and to what extent students indicated that they were learning. We then analyzed the co-occurrence of learning and uncertainty in each message, examining how different types of uncertainty appeared in messages with different types of learning. Finally, we explored the interleaving of uncertainty and learning within and across participants' messages as they evolved in topical threads.

Method

The context of our study was a graduate level course on psycholinguistics offered at a large public university in the Southwestern U.S. The course was taught by an educational psychologist who approached the topic as an opportunity to introduce the major theoretical and empirical works on language and thought, first language acquisition, classroom discourse, and literacy processes. She chose the course readings according to the themes of affective influences and cultural diversity on the thought-language connection. Course activities, including CMD, were designed to facilitate interactive meaning making through which students could construct their understandings (and help/support their classmates construct their understandings) about concepts, perspectives, and theories important to these academic fields.

Participants were 24 graduate students (19 women and 5 men; 8 international students), and their teacher, a professor in an educational psychology program experienced in teaching and researching in the content area. There were six students from Educational Psychology, five from Foreign Language Education, four from Language and Literacy, two from Instructional Technology, six from other Curriculum and Instruction programs, and one Fulbright Fellow. Although most of the students had some relevant background either in the psychological and educational literature or in linguistics, the course was also open to first-year graduate students with little previous experience reading this literature.

In addition to 12 face-to-face meetings, this hybrid course included three asynchronous online discussions and three synchronous discussions, spaced regularly across the semester. For each online discussion, the teacher assigned students to two or three groups of five to nine members (changing membership for each discussion) and encouraged them to discuss theoretical concepts and empirical findings as presented in the three or four articles she assigned. She herself joined the discussions. Each asynchronous discussion (mediated by a Blackboard course management system) spanned 36 to 48 h during which students were asked to make at least three postings to their group's forum. Each synchronous discussion took place in a computer lab via a local-area network synchronous chat program (Interchange through Daedalus) during the last 45 min of a face-to-face class meeting.

We micro-analyzed 10 discussion transcripts generated by the class (five synchronous and five asynchronous) for evidence of uncertainty expressions and learning. These were taken from the second and third discussions of each mode (synchronous and asynchronous) so as to capture what students were doing online after they had achieved some familiarity with the interface. Altogether, there were 1,048 total comments: 254 in the five asynchronous and 794 in the synchronous discussions; 462 paragraphs in asynchronous and 796 paragraphs in synchronous; average of 50 comments per participant (sd=37.73). Secondary data sources that helped us interpret the data included coherence graphs of each discussion (Schallert et al. 1996), and written reflections by each student after every discussion.

We took an inductive, interpretivist approach to data analysis (Lincoln and Guba 1985; Merriam 2009), an appropriate choice given that uncertainty is an internal experience, one that is dynamic, ever changing forms as an individual tries to respond to that experience. Meanings in constructing and resolving uncertainty are only partly manifest in discursive interactions, and identifying a learner's cognitive feelings of uncertainty is always an interpretive task (Gill and Babrow 2007). Using open and axial coding (Corbin and Strauss 2008), we analyzed the naturally occurring discourse in CMD transcripts. As an overview of our procedures, we created coding schemes for uncertainty expressions and for learning from the emergent categories we saw as a result of several passes through the transcripts. We then counted instances of each category of learning and uncertainty and conducted a descriptive analysis of their co-occurrence.

To ascertain how and how frequently participants expressed uncertainty, we relied on the coding scheme and a sub-set of the data reported in a previous study (Jordan et al. 2012). Through iterative rounds of individual examination of the data and consensus building in weekly team meetings, we developed a final coding scheme using contextual cues and our knowledge of words and phrases that often indicate uncertainty (for example, see Channell 1994; Feldman and Wertsch 1976; Lakoff 1973). This process yielded four major categories of uncertainty with two of the categories divided into subcategories (described in the section above; also see Table 1). Note that in this scheme, we omitted instances where uncertainty would need a speaker's tone to be taken into account. Vocal inflection, so much a part of interpreting uncertainty in face-to-face discourse, is not an available source of information to CMD participants. Nor was it available to us as researchers. The meanings of such expressions

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t1.1 Q12 **Table 1** Uncertainty coding scheme

t1.2 Uncertainty codes	Language examples	*Examples from transcripts*
t1.3 Indirect expression of uncertainty		
t1.4 U1A Hedges: degree of truth	maybe, sort of, could, seems, perhaps [includes suppositions based on perceptions; e.g., seems like]	•*Maybe I should read on it more and make the decision afterwards.* •*You might feel a bit of what Fox is talking about –sort of as if you are being asked to be a different person.*
t1.5 U1B Probability statements (likelihood of occurrence)	likely, sometimes, probably, frequently	•*…then she likely would have written with more authority.* •*I think this could have gotten me in trouble.*
t1.6 U1C Hypotheticals	I can't imagine…, What if…	•*I can't imagine having to construct a different self identity in order to fulfill academic requirements on top of the stresses of being a college student.* •*In other words, what if these constrained skills are only a PART of the problem.*
t1.7 Requesting help that might address uncertainty		
t1.8 U2 Questions	includes indirect questions (Holtgraves 1986) and tag questions (Dennis et al. 1982).	*Question*: *Would humor be an example of animation?* *Tag Question*: *Perhaps writing and reading is hard for us all, huh?* *Indirect Question*: *See what you think about appropriate or not appropriate.*
t1.9 Directly expressing feelings of uncertainty		
t1.10 U3A "I" statements	I wonder…, I'm not sure…, I'm curious…	•*And I wonder – since writing is such a creative act, could it be that it is more censored when cultures change? I would guess not, but these aren't my fields.*
t1.11 U3B Nonverbal indicators	Hmm…, mmm, (the use of …)	•*mmm…motivation…that's such a unique lens to think about classroom discussion.*
t1.12 Discussing uncertainty itself		
t1.13 U4 "Meta"	Directly acknowledging uncertainty in the world; other people's uncertainty or your own past uncertainty	•*I always struggled with my writing instruction. I felt it pulled me in so many directions. There were so many things I wanted to teach…* •*She [Moje] defends the slipperiness of their conversations* really well. *Were they telling the truth? Trying to protect friends? Showing off?* •*Kids will never admit it, but the fact that these kids get out of bed, come to class and actually sit in a deck—for 8 h a day—that is, I think, an extremely hopeful move.*

as "I feel," or "I think" differ depending on the vocal inflection with which they are stated, and we did not code them in our CMD data. Because uncertainty was coded on the basis of the actual words or phrasings used by the students, there was no limit to the number of codes that could potentially be applied to a single comment. After determining our final coding scheme, each of the 10 transcripts was randomly assigned to pairs of team members who first coded

independently and then met to negotiate agreement. Inter-rater reliability of 85 % initial agreement was obtained before resolving disagreements through consensus, first in pairs and then in whole-team meetings.

Our procedure for coding learning followed much the same process as our coding for uncertainty but used different cues from the messages. Rather than basing our codes on language explicitly expressing learning, we attempted to surmise from participants' words the underlying psychological process of learning (Potter 2003) that occurred during and was reflected in CMD. Based on socio-constructive theories (Jonassen and Land 2012; Pear and Crone-Todd 2002) and our own previous analysis of learning in online discourse (Schallert et al. 2003–2004, Cheng et al. 2013), we strongly believe that one way learners reveal learning-in-process is through statements they make that show what they know or are thinking as they write and respond to messages in online discussions. Thus, through our emergent learning categories we attempted to capture the complex dynamic nature of the process of learning online by identifying the variety of ways individuals expressed learning "in the making" as they deliberated, struggled, and reconciled novel material with prior knowledge while posting, reading and, responding to each other during CMD. We focus here on learning at the individual level as it can be inferred from participation in the system being co-created through online messages. Although this approach has limitations for understanding learning as a multidimensional activity, it has an advantage in making learning visible in terms of how participants' make meaning of course concepts for themselves and their interlocutors. It also helped us achieve the study objectives to connect learning with uncertainty, which was coded at the individual level.

Our first step in developing our coding scheme for learning was to examine two transcripts, identifying where each of us saw instances of learning occurring, for example, in postings in which students stated that they had "seen" or "learned" or "now understood" something previously not known or understood. Whereas uncertainty was operationalized in terms of linguistic markers, our codes for learning required a more contextualized interpretation. Taking a perspective that individuals are embedded in dynamic nested ecological systems of influence, we interpreted online messages in the context of their occurrence within unfolding threads of discussion. Looking for evidence of change as individuals adapted to local interactions, we examined each message in the context of its utterance, using coherence graphs to identify the thread to which it belonged, the writer's previous related posts, and the message (s) to which it was responding and that responded to it. We added dimensions to our definition of the construct as analysis proceeded. Thus, we labeled emergent categories to reflect their connection to the learning literature. For example, we noted messages in which a writer applied a newly learned label to a life experience or prior knowledge. We came to call these *naming* in recognition that the "concepts we use to make sense of the world direct both our perception and our actions" (Wenger 1998, p. 8; see also Weick et al. 2005). We also found messages in which a writer generated an original proposal that went beyond what had been presented in a course reading or forwarded by another participant. We labeled this *proposing a new idea* in recognition of the powerful role invention plays in learning (e.g., Bereiter and Scardamalia 2003; Bransford and Schwartz 1999; Kapur and Bielaczyc 2012). As a research team, we discussed the emerging categories and, after several iterations, many discussions, and consultation with the literature, we came to a consensus about the codes. We then applied these emergent categories to all our data, adding and re-grouping codes as needed. Using these processes of open and axial coding, we developed nine categories of learning (see Table 2).

We chose the paragraph as our unit of analysis for learning and then re-sorted the uncertainty codes that had been applied to messages to the proper segments of the messages. For the synchronous discussions, nearly all messages were exactly one paragraph long. For the

t2.1 **Table 2** Learning coding scheme

t2.2 Learning codes	Description of the code	*Learning Examples from Transcripts*
t2.3 LC1 Noticing	Initial recognition or noticing of a new idea Considering an idea	*I was also shocked that the student who had THE highest grade never said anything. That made me think…*
t2.4 LC2 Struggling	Grappling/wrestling with understanding of a new idea; trying to comprehend Interrogating the meaning of a concept	*I too struggled with parts of this article…I have no idea how to use this information in a classroom setting. I was raising my fist during parts of this article and scratching my head during other parts… I would really like to hash this out with more folks.*
t2.5 LC3 Constructive resistance	Challenging a new idea and arguing against it	*I would argue* [*against the article*] *that even in "private" certain types of humor can come back to haunt you…*
t2.6 LC4 Elaborating/ extending	Making distinctions based on new concepts (e.g., clarifying, narrowing, specifying, stretching, expanding or refining prior knowledge)	*I think the finding of this study* [*are*] *very interesting. The result of the study shows that input modification did enhance comprehension for native speakers but not for nonnative speakers* [goes on for 8 lines]
t2.7 LC5 Applying	Considering how an idea could be applied (often an example) Re-interpreting life experiences in light of a new concept If one accepts this idea, it means that…	*When I think of my students, who are at least 20 years old, they are definitely bored when they read children's books, so the materials should be easier, but appropriate for their age as you states. Is it that hard to make it?…*
t2.8 LC6 Naming	Applying a newly learned label to a life experience or prior knowledge	*I find that breathing* (*like meditative breathing*) *helps me to not tune out… plus it is so frustrating to "tune out" & miss something.*
t2.9 LC7 Connecting to other disciplinary knowledge	Making connections between other articles or disciplinary knowledge	*I thought this article was very similar to… Fox's article on international students and academic writing.*
t2.10 LC8 Evaluating	Metacognitive assessment of the utility of a new idea Seeing its value or evaluating its usefulness	*I wish I could have learned how to redirect students' interest or learning skills into classroom.*
t2.11 LC9 Proposing a new idea	Proposing an idea that goes beyond what was presented in a class reading or by another participant	*I wonder if they might have participated in peer interaction more actively if I had explained or demonstrated the advantages of peer interaction before group work.*

asynchronous discussions, message writers often used paragraph breaks to indicate a new idea being included. We followed a decision rule that learning had to refer to something new to a person and could not refer only to something that had been learned in the past. We coded a paragraph as indicating learning whether the learning was coming from course readings, other participants' messages, or another source. Inter-rater reliability of 86 % was assessed by comparing the coded results from the research team with those of one graduate assistant (trained by the second author) who had not seen the dataset before and who coded 30 % of the data.

After coding all messages in the transcripts, we looked for the degree of coincidence between learning and uncertainty, using nonparametric statistics and visually inspecting graphs showing the distribution of the various uncertainty codes in each of the learning categories,

and vice versa, to ascertain how specific types of uncertainty expressions are related to specific learning processes. In order to identify whether the uncertainty codes differentially co-occurred with learning and because the data were categorical nonparametric variables, chi-square tests were used to assess to distribution of uncertainty and learning codes, with alpha set at 0.05.

Finally, we focused on the final asynchronous discussions to conduct a more contextualized microinteractional analysis, exploring the sequential occurrence of uncertainty and learning within individuals' messages and also across the messages within each topical thread to examine how specific types of uncertainty management related to specific learning processes, to illuminate the uncertainty trajectories we hypothesized to accompany learning, and to highlight the collaborative functions of the learning experience. Through this close reading, we attempted to trace the moment-by-moment development of new ideas and understandings and their interweaving with uncertainty in order to deepen understanding of the relations between uncertainty and learning in collaborative learning.

Results

Our results are presented in three parts. First, we examine the prevalence of uncertainty and identify characteristics of its expression. We then briefly outline the results of coding for learning before examining the co-occurrence of expressions of uncertainty and learning. Finally, we present examples representing how four proposed trajectories of uncertainty were enacted through comments in which learning and uncertainty intersected in order to illustrate how participants' messages served to reveal the uncertainty inherent in learning processes.

Cataloguing uncertainty expressions and instances of learning

We found that uncertainty markers were prevalent throughout the 10 online discussions. Of a total of 1,258 paragraphs from all transcripts, 50 % (625) contained at least one uncertainty expression (see Table 3, top row). These 625 paragraphs received 1,037 uncertainty codes (see Table 4, bottom row), making for a mean of 1.7 uncertainty expressions for paragraphs with any uncertainty, and a mean of 0.82 uncertainty expression per paragraph across all paragraphs.

t3.1 **Table 3** The likelihood of the co-occurrence of uncertainty and learning

t3.2		Learning	No learning	**Total**
t3.3	Uncertainty*	453	172	625
t3.4		36 % of total	14 % of total	50 % of total
t3.5		72 % of uncertainty category	28 % of uncertainty category	
t3.6		57 % of paragraphs with learning occur with uncertainty	37 % of paragraphs with no learning occur with uncertainty	
t3.7	No uncertainty	343	290	633
t3.8		27 % of total	23 % of total	50 % of total
t3.9		54 % of no uncertainty category	46 % of no uncertainty category	
t3.10		43 % of paragraphs with learning occur with no uncertainty	63 % of paragraphs of with no learning occur with no uncertainty	
t3.11	**Total**	796	462	1,258 paragraphs
t3.12		63 % of total	37 % of total	

t4.1 **Table 4** Number of paragraphs with learning codes and uncertainty expressions

t4.2	Type of learning codes	Paragraphs	Paragraphs with uncertainty	Uncertainty moves	Mean uncertainty moves per paragraph with uncertainty moves
t4.3	LC1 Noticing	146	49	61	1.2
t4.4	LC2 Struggling	72	63	98	1.6
t4.5	LC3 Constructive resistance	69	46	85	1.8
t4.6	LC4 Elaborating/extending	192	104	175	1.7
t4.7	LC5 Applying	153	77	145	1.9
t4.8	LC6 Naming	15	7	10	1.4
t4.9	LC7 Connecting to other disciplinary knowledge	34	22	35	1.6
t4.10	LC8 Evaluating	21	14	36	2.6
t4.11	LC9 Proposing a new idea	94	71	162	2.3
t4.12	**Total**	796	453	807	1.8
t4.13	Number of paragraphs with no learning	462	172	230	1.3
t4.14	Total number of uncertainty moves			1,037	

The frequencies of our uncertainty codes are tallied in Table 5. Three codes were grouped together as subcategories of *indirect expressions of uncertainty*: *hedges* (U1a), *probability statements* (U1b), and h*ypotheticals* (U1c). Altogether, the three coding categories of indirect uncertainty accounted for 33 % of the uncertainty expressed (348 instances). The second category of uncertainty, *questions* (U2), made up 38 % of all uncertainty expressions in our 10 transcripts, partly inflated by the fact that participants were likely, if they asked one question, to follow up with more questions. The third coding category, *direct expressions of uncertainty*, encompassed two subcategories of uncertainty codes, "*I*" *statements* (U3a) and *paralinguistics* (U3b). Together, these codes accounted for 25 % of all uncertainty expressions in the discussions. The final category of uncertainty expressions, *meta* (U4), made up only 4 % of all uncertainty moves.

Learning was also prevalent in our data. Of the 1,258 paragraph in our 10 transcripts, 796 (63 %) received a learning code whereas 462 (37 %) were coded as not exhibiting any learning marker (see Table 3). Thus, roughly two-thirds of all paragraphs contained some indicator of learning. In Table 4, we present a tally of the paragraphs representing each category of learning.

Noticing (LC1) accounted for 18 % of all the learning codes attributed to the discussions. This code pertained to paragraphs in which the writer intimated somehow that the idea was new but the message provided no further elaboration. The second learning code, *struggling* (LC2) accounted for 9 % of all the learning codes. Although participants wrote about struggling with many things, this learning code was reserved for comprehension struggles, often a large part of the learning process. The third learning code, *constructive resistance* (LC3) also accounted for 9 % of all the learning attributed to these discussions. We included resisting in our codes because, when individuals objected to an idea being negotiated in the discussion, they necessarily made their ideas clearer by explicating them in order to justify the resistance. The next code, *elaborating*/*extending* (LC4), pertained to instances when writers expanded on new ideas and made up 24 % of all the learning codes in our CMD transcripts. The fifth code, *applying* (LC5), made up 19 % of the codes. These frequently came in the form of examples drawn from personal experience. Participants in the process of learning often

t5.1 **Table 5** Co-occurrence of uncertainty and learning codes

t5.2		Uncertainty							
t5.3	Learning	U1A	U1B	U1C	U2	U3A	U3B	U4	% of Total
t5.4	LC1- Noticing	12	4	4	24	12	2	3	8 %
t5.5	LC2 - Struggling	7	0	0	61	27	2	1	12 %
t5.6	LC3- Constructive Resistance	22	6	4	21	30	2	0	11 %
t5.7	LC4 – Elaborating/extending	60	18	5	39	32	14	7	22 %
t5.8	LC5 - Applying	32	17	7	39	38	1	11	18 %
t5.9	LC6 - Naming	3	1	1	4	0	1	0	1 %
t5.10	LC7 – Connecting to disciplinary knowledge	10	5	0	15	4	1	0	4 %
t5.11	LC8 - Evaluating	5	0	5	8	12	0	6	4 %
t5.12	LC9 – Proposing a new Idea	31	13	15	65	32	5	1	20 %
t5.13	Paragraphs with no learning but with uncertainty	40	13	8	115	45	1	8	
t5.14	Number of uncertainty moves	222	77	49	391	232	29	37	
t5.15	Percentage of all uncertainty codes	21 %	7 %	5 %	38 %	22 %	3 %	4 %	

considered how a new idea could be applied by re-interpreting life experiences in light of a new concept. The sixth learning code *naming* (LC6) was fairly rare, accounting for only 2 % of all the learning codes. Nevertheless, we think this is an important category because the ability to label an experience or conception with a term one has recently acquired is critical not only to understanding and talking about ideas, but also for participating in the practices of academic disciplines (Bloom 2002). The seventh code, *connecting to other disciplinary knowledge* (LC7), was also rare, making up just 4 % of all codes.

The next learning code, *evaluating* (LC8) made up 3 % of all the learning codes. In the process of learning, CMD participants sometimes metacognitively assessed the utility of new ideas, appraising their value based on prior knowledge, conjecturing about possible applications or past experience (e.g., "I wish I had known X because it would have been so useful"). Although learning coded as LC8 is similar in some ways to learning coded as *applying* (LC5), paragraphs coded with LC8 were distinguished by their evaluative component. The final learning code, *proposing a new idea* (LC9), made up 12 % of all learning codes. The distinguishing feature of this code that separated it from LC4 was that the proposed ideas were new not only to the writer but also went beyond what had previously been expressed in the articles or in the discussion. New ideas could come in many forms such as expanding the range of application of an idea previously presented, moving a previously introduced concept into another context. This is knowledge change (learning) because new knowledge is causing the person to come to a new insight or a new question (wondering).

An analysis of the co-occurrence of uncertainty and learning

In addressing the study's purpose to explore the relationship between uncertainty expressions and learning, we examined their co-occurrence across all messages making up the 10 coded transcripts. As shown in Table 3, uncertainty and learning were more likely than not to co-occur: 453 paragraphs (36 % of all paragraphs) were coded as showing some type of learning and also had at least one uncertainty code, and of these, there was an average of 1.8 uncertainty codes per paragraph. Contrast this with 343 paragraphs (27 %) that showed learning but did

not contain any uncertainty expressions. Also, 172 paragraphs (14 % of all paragraphs) contained at least one uncertainty code but were coded as not exhibiting learning, with 230 uncertainty codes distributed among these, an average of 1.3 uncertainty expressions per paragraph. Finally, 290 paragraphs (23 %) did not exhibit learning and also did not contain any uncertainty expressions. Thus, by a ratio of approximately 3 to 1, paragraphs with no learning were likely to be free of uncertainty expressions. Although we acknowledge that our observations of co-occurrence violate the assumption of independence, we offer that results of a chi-square test indicated that uncertainty markers differentially co-occurred with learning, X^2 (d.f. = 1)=45.3, $p<.001$. All four follow-up pairwise tests of significance across cells of the 2×2 contingency table were significant: Uncertainty/learning versus uncertainty/no learning, X^2 (d.f. = 1)=126.39, $p<.001$; No uncertainty/learning versus no uncertainty/no learning, X^2 (d.f. = 1)=4.49, $p<.05$; Learning/uncertainty versus learning/no uncertainty, X^2 (d.f. = 1)=15.2, $p<.001$; No learning/uncertainty versus no learning/no uncertainty, X^2 (d.f. = 1)=30.14, $p<.001$. We next concentrate on the ways in which our categories of uncertainty were associated with each category of learning as depicted in Table 5. Among the nine categories of learning, we found that three showed low incidence, two had a similar pattern; and one (*noticing*) had a low co-occurrence with uncertainty (8 %). In the following section we describe four categories that have high frequency of co-occurrence with uncertainty.

We first discuss the co-occurrence of uncertainty and LC2. Of the 72 paragraphs coded as indicating *struggling* (LC2), the great majority (63 of 72, or 88 %) contained uncertainty expressions, with an average of 1.2 uncertainty expressions per paragraph. *Struggling* made up 9 % of all the learning codes and garnered a similar proportion of the uncertainty codes (12 % of total). *Struggling* was almost two times as likely to co-occur with *questions* (U2; 61 times, 22 % of all U2s) as with any other uncertainty category, suggesting that a response to struggling is to ask questions directly as a form of help seeking. *Struggling* (LC2) also frequently occurred with direct expressions of uncertainty (U3a). For example, Linda (Grp 2, 3rd Synch) expressed that she was still unsure of her understanding (LC2) as she pondered the meaning of her teacher's message: "*I am still pondering your question – and going back to re-examine the article*." Only rarely was *struggling* associated with indirect uncertainty (U1a, U1b, U1c).

Next, of the 69 paragraphs coded as indicating learning of the *constructive resistance* type (LC3), 46 (67 %) were associated with 85 expressions of uncertainty, an average of 1.8 per paragraph. Resisting was nearly equally likely to be associated with *hedging* (U1a), *questioning* (U2), and "*I*" *statements* (U3a). Such an association seemed reasonable: as participants expressed a form of constructive resistance to a new idea, they likely felt uncertainty and the need to express it. For instance, having read Linda's assertion that she would want to be corrected when speaking Spanish to native speakers, Donna (Grp 2, 3rd Synch) stated: "*Linda – maybe* (U1a) *you feel that you'd want to be corrected some of the time when you're making casual conversation but imagine* (U1c) *that you had gone to the pharmacy to get medicine because your child was throwing up and you were trying to explain yourself. I bet* (U3a) *you wouldn't want your Spanish corrected. You'd want to be understood and helped*." By resisting Linda's idea, and differentiating casual from critical conversation, Donna was making clearer her ideas about politeness and corrective feedback in cross-language interactions.

Another type of learning code, *elaborating/ extending* (LC4), was almost evenly associated with expressions that either represented some type of uncertainty or no uncertainty at all. Of the 192 paragraphs coded as LC4, 104 (54 %) received at least one uncertainty code. There was an average of 1.7 (175) uncertainty codes across these paragraphs. They made up 24 % of

the total learning codes and garnered a similar proportion of uncertainty codes (22 % of total). Although distributed across all uncertainty codes, *elaborating/extending* was slightly more likely to be associated with *hedging* (U1a) (60, 33 % of all U1as). Perhaps when someone is stretching an idea, his or her statement is likely to be expressed with some tentativeness, as shown in the following message: "*Isaac and Linda, it probably* (U1a) *works differently for everyone but the whole 'eyes on me' thing is a problem in schools because we expect it but it doesn't necessarily mean focused attention*" (Grp 3, 2nd Synch). This message seemed to convey that Zelda was clarifying, narrowing, specifying, or stretching her understanding of "tuning out," a concept about which she had read in one of the assigned articles.

Finally, instances of learning code *proposing a new idea* (LC9) were over three times more likely to co-occur with some sort of uncertainty expression, of which there were a total of 162, than to have no uncertainty coding. Thus, 71 paragraphs (76 % of 94 coded as LC9) had at least one uncertainty marker, and many had more than one as indicated by the 2.3 mean number of uncertainty codes per paragraph. LC9 made up 12 % of the learning codes but co-occurred with 20 % of the total uncertainty codes. In particular, this form of learning garnered a high proportion of *probability statements* (U1b) (20 %), *hypotheticals* (U1c) (36.5 %) and *questions* (U2) (23.5 %). *Proposing a new idea* was twice as likely to be associated with *questions* (65 out of 162, or 40 % of all uncertainty markers occurring with LC9) as *hedges* or "*I*" *statements*, and three times as likely to be associated with *questions* as *probability statements* or *hypotheticals*. Interestingly, *hypotheticals* (U1c) were more likely to occur with LC9 than with any other learning code (15 out of 39, 38 % of total). For example, Donna stated, "*Luke – I love your analysis of your own past as a writer. I wonder* (*U3a*) *if you would have been* (*U1c*) *someone who like Surya would have suffered a lot from the feedback you'd have received if you'd moved to Japan, say, to go to college. I'm pretty sure* (*U3a*) *there are others who are less sensitive or whose identities are less expressed by or reflected in how they express themselves. And, I would bet* (*U3a*) *these others may* (*U1a*) *find it less painful but less satisfying also to communicate in new cultural contexts*" (Grp 1, 3rd Asynch). By constructing a hypothetical situation, Donna proposed the idea that individuals may vary in how they respond to communicating in new cultural contexts, expanding on ideas presented in an assigned article about foreign students doing academic writing in a second language.

How learning processes are reflected in expressions of uncertainty

To address further our second research question, how learning processes are reflected in expressions of uncertainty, we looked within and across the messages of topical threads to examine the trajectories of uncertainty through which learning progressed as participants interacted in CMD. Although participants sometimes expressed their learning in ways that implied moving from one state of clarity to another, more often they expressed changes that reflected far from settled understandings. Analysis revealed that such changes happened as a learner reduced or resolved uncertainty, generated or increased uncertainty, shifted from uncertainty about one issue to uncertainty about a new issue, or took up a new idea or experienced greater clarity without evoking uncertainty. Below, we use three examples to highlight how messages revealed uncertainty intrinsic to learning in the collaborative context of CMD. All three examples show one or more trajectories of uncertainty. They also show how such trajectories are contextualized in a discussion and how they provided grounds for the interleaving of uncertainty and learning across messages and across participants.

In the first example, we see how inherently intertwined are experiences of learning and uncertainty. Fred entered his group's conversational thread related to Moje's (2004) article about the cultural embeddedness of writing without reference to any of the eight comments

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that preceded his message. Having connected Moje's ideas to another assigned reading in the first paragraph of his post [LC7], Fred went on to write:

> *Thinking of these two articles in the cultural context makes me think that literacy is not that difficult a task. Seems people can create their own literacy or make the shift to a new cultural literacy (like graduate level writing). The hardest challenge is understanding and maneuvering through the cultural differences between the types of literacy. Acceptance in the culture, emotional tone, the economic challenges, etc., all have a major impact on literacy. I think it is hard for me now to see literacy as a construct in itself. It must be tied to the culture. This makes me want to go back and reread some of our past articles with this viewpoint.* [*LC4*] (Grp 3, 3rd Asynch)

Although Fred used few uncertainty expressions, he nevertheless conveyed a sense of experiencing uncertainty. He first claimed that his thinking had been changed by two class readings, so that he now thought "*literacy is not that difficult a task*." He used no uncertainty to discuss his new ideas, asserting that maneuvering through cultural differences is "*the hardest challenge*" and naming several factors that "*have a major impact on literacy*." Here we see how a learner seemingly shifted his understanding without apparent uncertainty. When trying to explain how he was thinking differently now about literacy issues, Fred softened his assertion, "*I think it is hard for me now to see literacy as a construct in itself*." His closing statement of a desire to "*go back and reread some of our past articles with this viewpoint*," revealed that he was still in flux on these issues. Despite a lack of explicit uncertainty expressions, Fred's expressed desire to re-read past articles suggests that he had developed a new uncertainty about his interpretation of past readings induced by his new understanding of literacy as tied to culture. Uncertainty was now fueling a need to return to what he had previously thought he understood.

Our second example is also from the same thread in which Fred posted his first message. Fred's second post to this thread shows how learning can take an individual from one state of uncertainty to a different ground for uncertainty induced by social interaction. Three participants responded to Fred's initial message. All three elaborated on the interconnectedness between culture and literacy as they interpreted it in Fred's post and introduced the idea that any interpretation of "incorrect" writing is a cultural assessment. These messages triggered Fred to further stretch his idea of what it means for writers to attend to particular details and styles that may or may not be valued by the majority of a society and to consider a new issue, power. Fred finally posted this message expressing uncertainty about an idea he had been developing based on his reading of other's responses to his first message.

> *…you read my mind…writing is subjective to what the collective majority view as correct or good…Literacy in itself does not hold values, it reflects values.* [*LC4*]
> *This may be a stretch, but gangster writing is meant to defy the power system, to rebel somewhat. I wonder if when academics who write very dense, very hard to read articles, if part of that writing style is a way of gaining power? If it's too hard, but his idea is good, does the write* [*sic*] *gain in social power or professional rank because he/she becomes perceived as intelligent in the field?* [*LC9*]

Fred first expressed complete agreement with a previous message before going on to propose a new idea [LC9] with some tentativeness. The peer feedback Fred received for his first message expanded his understanding of literacy as cultural practice. In his first post he had recognized that navigating literacy requires understanding and maneuvering through cultural differences. But this understanding did not include recognition that literacy choices can be used intentionally as a means to defy and gain power. The uncertainty expressions in this

second message show that this is a new idea for Fred. His uncertainty helped him bridge between two worlds (gangsters and academics) to create a hypothesis about writing as a tool for manipulating power. As discussed in the section above, code LC9 often co-occurred with such uncertainty markers, perhaps in recognition that one needs feedback to help evaluate and improve one's most nascent ideas.

Fred's message represented a pattern we found common in the CMD discussions: first agreeing with one's interlocutors and re-stating their ideas using no uncertainty markers, then bridging between a confidence borne of shared understanding and uncertainty used to explore more tentative ideas. We take this as a sign that agreement among participants can increase certainty about one's viewpoints, certainty that becomes the ground for entertaining new uncertainties that further facilitate learning. Furthermore, our analysis shows how the interleaving of learning and uncertainty was spurred by social interaction. Fred's first message did not connect to any previous posts, nor did it explicitly invite response. Yet, following the response of other participants, Fred now requested more social interaction [U2] to resolve the very uncertainty social interaction had elicited.

In our third example, a posting by Doris illustrates how learning can take a learner from a state of certainty to a state of uncertainty, and that this should sometimes be a goal of learning. It also shows how one individual's expressed uncertainty can become a ground for other's learning. Through this posting, Doris initiated a topical thread on an article by Penrose and Giesler (1994) about the role of academic expertise in reading and writing with (out) authority.

> *…I grew up never thinking to question an author. I truly believed that the author had complete authority and that if I didn't agree, I must be wrong. I'm learning how to have a critical mind and to think for myself a bit more deeply.* [*LC5*]
> *So I guess my question lies with how do we help our students realize that they can question the author and that they don't have to take everything word for word as it's written? I mean, I know the simple answer is we teach them that. But with a society and world where I feel this is not encouraged in some ways, can change truly come about? I think so…but I still wonder.* [LC9] (Grp 2, 3rd Asynch)

In her first two sentences, Doris used no uncertainty expressions when describing her past beliefs and practices regarding authors of texts. She used several terms conveying great certainty such as *never*, *truly*, *complete*, *really*, and *must be*. The remainder of her message suggests that she had moved from a state of certainty that the authority of authors is above suspicion to a new belief that authors should be questioned. This change introduced new sources of uncertainty for Doris: how to become more critical in her own reading and how to teach students to question the author. It was those uncertainties on which she focused in the next five sentences, where she used seven uncertainty expressions. Describing herself as engaged in a process of learning, she claimed that this process had led her to think for herself "*a bit more deeply.*" Her uncertainty was further revealed in the "I" statement claiming that she was not certain even of what question to ask ("*So I guess my question is…*") (U3a). Equally interesting is the question expressed in Doris' message, "*how do we help our students realize that they can question the author*?" (U2) Through this question Doris revealed her newly appropriated belief that increasing students' uncertainty about an author's assertions is a worthy, if elusive, learning goal.

Four CMD participants responded directly to Doris's message, illustrating how her expressed uncertainty and attendant learning provided a platform not only for her own future learning, but also for others' learning. First Isaac and then Beatrice agreed with Doris and followed her suit in emphatically interpreting their past experiences and practices in light of the article expressing little to no uncertainty (e.g., "*High school definitely didn't prepare me to question authors*")

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[LC5]. Beatrice then went on to explicitly express her learning in relation to Doris's questions ("*I agree with Doris that this does make me realize the importance of having my elementary students think critically and write about their opinions and viewpoints. I am now more aware…*") [LC4]. Donna and Connie took up the dialogic inquiry that Doris's post invited through its uncertainty markers. Donna proposed several new ideas for how to teach young students to write with authority [LC9]. She communicated that these ideas were new and tentative by using seven uncertainty markers in one paragraph (e.g., "*it could be…*", "*I wonder if…*"). Connie, using no uncertainty markers, reported Penrose and Giesler's recommendations for teaching students to read and write with authority, but then went on to critique those recommendations in more tentative terms [LC3]. Thus, Doris's message provided a ground for her discursive partners to learn and to help her learn. Tacking between the language of certainty and uncertainty, participants interpreted and reinterpreted aspects of the assigned reading, connecting and re-connecting them to their own past experiences and to their projected futures.

The examples above show how interaction among CMD participants provided learning opportunities for writers and readers. In the first example, other's messages prompted Fred's learning that then generated new uncertainties. Doris's message, interwoven with uncertainty and learning, spurred learning opportunities for others to experience and express, learning that could then feed back into Doris's own learning. Across threads and within messages, students oscillated between new realizations and uncertainty by re-interpreting and evaluating prior knowledge and imagining possibilities for future actions as they tentatively suggested interpretations of others' ideas and requested feedback from others.

Discussion

The intersection of learning and uncertainty in our data illustrates how participants' messages served to reveal uncertainty inherent in online learning processes. The findings of this study suggest that social interaction through the messages of online collaborative learners produce opportunities to reduce and to take up uncertainty in the service of learning. Participants in this study did not seem to shy away from expressions of uncertainty as they collaborated in synchronous and asynchronous classroom CMD to increase their own and class members' understanding of course-related readings. Because the participants in these online discussions were trying to learn concepts presented in assigned articles, and because they were discussing sophisticated, nuanced ideas, there was much uncertainty surrounding the task. Expressing uncertainty was associated with learning in our CMD data because it enabled students to conduct thought experiments, wonder about new concepts, reinterpret past experiences, and explore novel ideas as they interacted with their teacher and academic peers. Using uncertainty expressions allowed learners to accomplish both the goal of decreasing their uncertainty about course content or about their participation in classroom CMD, and the goal of increasing their uncertainty in ways that prompted learning. By hedging their propositions, creating hypothesized scenarios, asking questions that extended the range of ideas the group was considering, and engaging in wonderings, students created safety and space in which to explore ideas and imagined experiences. The expression of uncertainty possibly enabled CMD participants to play with new intellectual ideas without running the risk of sounding like a know-it-all, of being impolite, or being held accountable for the truthfulness of their propositions. Perhaps it also allowed them to acknowledge that the world is in many ways a fundamentally uncertain and unpredictable place.

The prevalence of learning in the messages can also be attributed to the nature of CMD that requires participants to use written messages to communicate. CMD can be particularly

conducive to learning because writing is a dialogical act that is likely to occasion learning (Langer and Applebee 1987). As a CMD participant attempts to communicate understandings or beliefs through written messages to an audience of others, to one's self at a future time, and/or to the unfolding text itself, writer and text are reciprocally transformed. This process often occurs with an envisioned audience, and in most cases, responsive feedback is available only after a text has been composed and "published" (Haneda and Wells 2000). However, in online environments in which written discussion occurs, the process is greatly speeded up and highly interactive, shaping writers more quickly because audience responses come more quickly. Haneda and Wells (2000) contended, "There is much to be gained from working with peers on a question to which no one knows the answer in advance, and where each learns through collaborative knowledge building as they attempt to construct answer or solution" (p. 449). We conjecture that expressing uncertainty is crucial to learners' accomplishment of this collaborative construction process.

Results of this study underscore the importance of careful attention to discursive processes in designing CSCL environments and instructing learners about how to communicate with their peers during collaborative work. Study results particularly call attention to the need to attend to how learners express uncertainty as they interact in online spaces. In some learning contexts, the primary source of interaction comes from the teacher, but CSCL involves interaction primarily with peers. Thus, social support for managing uncertainty in CSCL environments is most likely to come from peer interaction (see Jordan and McDaniel 2014). At the same time, social interaction itself is often a source of uncertainty (Babrow 2001). Learning through online discourse might be enhanced if collaborators are instructed about the potentially productive role of uncertainty for learning and instructed to help their peers manage uncertainty. Students may benefit from opportunities to reflect explicitly on their uncertainty prior to or following online discussion, either individually or as a group. Because people often try to resolve uncertainty immediately or ignore it altogether (Smithson 1989), some learners might need help developing their capacity to generate, acknowledge, and communicate about uncertainty (Jordan 2012) in order to use uncertainty productively to facilitate learning. Moreover, because there are times when learning in CMD decreases one's uncertainty, times when the conversation increases uncertainty, and other times when it shifts uncertainty, instructors may want to consider when and how nudging students toward or away from one or another of these trajectories may facilitate learning in different situations.

Despite these findings, instructors and students may have the mistaken idea that uncertainty inhibits learning and should be reduced as much as possible. Such beliefs may lead instructors to limit uncertainty when designing CMD or other CSCL environments or when structuring assignments; learners might shy away from expressing uncertainty of their own or from prompting uncertainty in their discursive partners. However, as indicated in previous research and supported in the current study, uncertainty in collaborative contexts can be productive for learning (e.g., Hiebert et al. 1996; Jordan and McDaniel 2014; Radinsky 2008). We also find great complementarity between our findings and research related to Productive Failure (Kapur 2008), especially in the role of noticing, struggling, elaborating, connecting, constructive resistance, and other processes associated with learning and uncertainty. As Bruner (1986) alluded, expressing uncertainty can be an invitation for learners to share their experimental ideas and questions, even when these ideas are still unclear and uncertain. Based on the results of this study, we would caution against continually avoiding or prematurely reducing uncertainty.

Limitations and future research

Although we are confident in our research findings that point to the connection between learning and uncertainty, we also see limitations in our study. One limitation is related to the

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challenges inherent in accurately capturing learning, as identified in previous research (Schallert et al. 2004; Schallert et al. 2003–2004). There is always the possibility that participants may have avoided writing about new ideas they were learning. Also, there were times when we could not tell how new an idea was to a message writer, and may have miscoded a posting when, for example, the writer was feigning an experience of novelty for social reasons or reporting on an idea that he or she had previously considered. Finally, in a discussion of learning, there is the question about the "residue" the discussions left on participants, what long-term changes in thinking resulted from their participation in these online discussions. Because learning involves ongoing transformation, it typically occurs incrementally over time (Alexander et al. 2009). Therefore, it is difficult to pinpoint learning as it occurs on particular occasions. Rather than concentrating on learning as a product of a sustained exchange, we captured learning as a process in the small steps it took as participants grappled with ideas.

When all is said and done, our holy grail remains: to understand how people show their learning in the words they use. A challenge we face in our quest is that individuals rarely explicitly say, "I'm learning right now." At best, learners offer tidbits in their discourse that invite us to ponder whether they are learning something new, as they borrow words from articles they have never read before, show expressions of surprise, and acknowledge receipt of an idea. In our coding, we have tied uncertainty expressions to learning because we saw such expressions as signaling some aspect of the learning process, hypothesizing that learning is more likely in messages in which uncertainty is expressed. An alternative, not explored here, is that uncertainty co-occurs with learning but may not coincide with learning in the same message or by the person expressing the uncertainty. Such an analysis, and one we welcome (Jordan et al. 2007), would require a more dynamic sequential analysis of the co-incidence of learning and uncertainty.

Further attention to the relationship between uncertainty and learning is warranted by the study's findings. For instance, to further strengthen understanding of the role of uncertainty in learning, it may be useful to contrast the occurrence of certainty expressions with the occurrence of uncertainty expressions in CMD. Also, the results of the current study were obtained in text-based online learning contexts where learners are limited to written expressions. Whether they would hold across other CSCL environments, in discursive face-to-face learning environments, or in settings in which individuals primarily work alone, requires further investigation. Future research should also examine variation in how individuals express uncertainty and indicate learning during CMD and in the co-occurrence of learning and uncertainty in their online comments. Additionally, because the expression of uncertainty cannot be unreservedly taken to mean that a writer is experiencing uncertainty, as we have previously noted (Jordan et al. 2012), the relationship between expressed uncertainty and experienced uncertainty needs further investigation. Finally, scholarly work is needed to understand how learners balance between certainty and uncertainty, perhaps purposefully generating uncertainty in the service of learning.

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