Education Tech Research Dev (2011) 59:181–198
DOI 10.1007/s11423-011-9190-9

RESEARCH ARTICLE

Curiosity, interest and engagement in technology-pervasive learning environments: a new research agenda

Marilyn P. Arnone · Ruth V. Small · Sarah A. Chauncey · H. Patricia McKenna

Published online: 27 February 2011

Abstract This paper identifies the need for developing new ways to study curiosity in the context of today's pervasive technologies and unprecedented information access. Curiosity is defined in this paper in a way which incorporates the concomitant constructs of interest and engagement. A theoretical model for curiosity, interest and engagement in new media technology-pervasive learning environments is advanced, taking into consideration personal, situational and contextual factors as influencing variables. While the path associated with curiosity, interest, and engagement during learning and research has remained essentially the same, how individuals tackle research and information-seeking tasks and factors which sustain such efforts have changed. Learning modalities for promoting this theoretical model are discussed leading to a series of recommendations for future research. This article offers a multi-lens perspective on curiosity and suggests a multi-method research agenda for validating such a perspective.

Keywords Curiosity · Interest · Engagement · New media - ambient learning · Contextual factors · Cyberlearning · Personal factors · Situational factors · Technology-pervasive learning environments · Learning modalities · Curiosity research

Introduction

Curiosity can be a powerful motivator of behavior, initiating actions directed at exploring one's environment to resolve uncertainty and make the novel known. Curiosity has been considered a basic instinct, an innate mechanism that enabled intelligent species to learn about and master new things in their environments, promoting survival, use of tools, and ultimately technological advances. However, curiosity does not automatically progress to a well-developed, individual interest, and a level of engagement that leads to desired

M. P. Arnone (✉) · R. V. Small · S. A. Chauncey · H. P. McKenna
Syracuse University School of Information Studies, 105 Hinds Hall, Syracuse, NY 13244, USA
e-mail: mparnone@syr.edu

outcomes of greater learning and mastery. Students may be curious, but the relevant resources may not be available to satisfy that curiosity. Even when resources are available, however, curiosity does not necessarily lead to these outcomes. A student searching online may become overwhelmed or distracted by too much information. Running out of time to complete an assignment can occur as an unintended side effect of being overly stimulated resulting in neglect of another responsibility.

How do we maintain momentum ignited by curiosity and interest and keep students purposefully engaged? Used effectively, technology can play a role in stimulating curiosity and interest and in facilitating and sustaining purposeful engagement. Moreover, technology can play a role in triggering and addressing personal, situational, and contextual factors that support autonomy and competence and engender active, deep learning. It can also overwhelm and distract by providing more information than can be organized and processed to determine relevance.

Student behavior has been perplexing and disruptive in formal educational settings where traditional ways of delivering instruction and engaging students may collide with learning preferences and proclivities of the digital student. Students who have "grown up digital" or have been "born digital" exhibit behaviors which challenge us to reconsider personal, situational, and contextual factors in light of a technology-pervasive world (Tapscott 1997, 2008; Palfrey and Gasser 2008).

We consider the following in our proposed research agenda:

- How students who have grown up in a technology-pervasive world address their curiosity and interests.
- Personal, contextual, and situational conditions which pique curiosity and sustain engagement or that have the potential to dampen the same.
- Situational and contextual issues which need to be addressed in order to allow technologies to more fully occupy formal learning spaces.
- Identification of information seeking skills necessary to resolve curiosity.

We also raise questions about how students process information in technology-pervasive environments:

- How does the curious student know which of the immediately available 23,600,000 hits provide answers that she is looking for and how long will her curiosity be sustained as she starts to explore the resources?
- As a student begins to address her curiosity through exploration, what happens when her research takes her in an unexpected direction?

We begin with a review of the literature on curiosity and the role of curiosity in learning. A new research agenda will be proposed for curiosity in view of current and emergent technology-pervasive learning environments. The new research agenda is based on a definition of curiosity that incorporates the concomitant constructs of interest and engagement. A theoretical model for curiosity, interest and engagement in technology-pervasive learning environments will be advanced, taking into consideration personal, situational and contextual factors as influencing variables. Learning modalities for promoting curiosity, interest and engagement in technology-pervasive learning environments will be discussed leading to a series of recommendations for future research. While the path associated with curiosity, interest, and engagement (CIE) when involved with learning and research has remained essentially the same, how we are able to tackle tasks associated with research and learning has changed.

Background

In the 1950's–1970's, curiosity was studied across a number of perspectives from Berlyne's (1954, 1960) neurophysiological view of curiosity as a state of moderate arousal brought about by uncertainty in the environment resulting in exploration to Beswick and Tallmadge's (1971) cognitive process theory of curiosity in which curiosity is experienced when an individual receives an incoming signal or stimulus that does not fit the cognitive map of one's world as he/she has experienced it. While not the primary focus of their theories, curiosity has been associated with a need for competence in White's (1959) view of effectance motivation and Deci's theory of intrinsic motivation (1975) and with interest in novelty in the work of Piaget (1952).

Researchers generally agreed with the association between curiosity and exploratory behavior yet attempts to articulate its dimensionality continued into the 1980's (Naylor 1981; Ainley 1987) with a continued focus on curiosity as it relates to formal learning (Engelhard and Monsaas 1988). Furthermore, many studies relied primarily on self-report measures, showed inconsistent results, and placed a disproportionate emphasis on trait curiosity. While curiosity research flourished in earlier decades, the volume of research on curiosity seemed to ebb, finding renewed attention in recent years.

With few recent exceptions, curiosity is often explored tangentially in other research areas (e.g., social media, information literacy, innovation, advertising, and marketing) and without the rigor demanded of the construct. Of the more recent research that does explore curiosity in depth, there is continued interest in and attempts to devise measures for curiosity that tap into its multidimensional nature. For example, Reio et al. (2006) put forth a 3-factor model of curiosity that includes cognitive curiosity, physical thrill seeking, and social thrill seeking. Litman and Jimerson (2004) created a measure of curiosity based on feelings of deprivation which seems to build on Loewenstein's (1994) information gap perspective of curiosity. Building on earlier work Litman (2005) "… proposes a new theoretical model of curiosity that incorporates the neuroscience of 'wanting' and 'liking'…" (p. 793).

It's challenging to study curiosity without considering related constructs such as interest and engagement. If researchers exploring these three constructs could agree on the relationship among them, shared research agendas would be possible. The first challenge is coming to consensus on a workable definition of curiosity.

Evidence that acting on one's curiosity may be related to perceptions of competence in finding and using information (i.e., information literacy) to resolve a curiosity stimulus was supported in a study by Arnone et al. (2009). White (1959) associated curiosity with a need for competence and E. L. Deci (personal correspondence, 2005) suggests that need for competence is at the heart of curiosity. Kashdan and Silvia (2009) study curiosity in everyday life while Kashdan and Yuen (2007) consider the benefit of curiosity for academic achievement and the moderating influence of social environments and, as such, "provide preliminary support for a person-environment fit approach to curiosity" (p. 269). Kashdan et al. (2007) include the *aversive* dimension of curiosity as well as individual difference and context. This brings us back to the issue of competence and our earlier question; what if some students just do not have the information-seeking skills or support to fully engage in exploration until curiosity is satisfactorily resolved? The student must feel competent in his ability to use what he knows to engage with the information which aroused his curiosity. Perception of competence is a prerequisite for sense making which leads to sustained interest and the desire to explore until curiosity is satisfied.

Social context and learning is addressed by Tapscott (2008) who notes that 11–31 year-olds "show signs of learning differently" (p. 10) while Palfrey and Gasser (2008), referring to those born after 1980, claim that "major aspects of their lives—social interactions, friendships, civic activities—are mediated by digital technologies" (p. 2).

A new research agenda: bringing it all together

One reason for developing new perspectives on the study of curiosity, is to contribute to the emergent body of research on curiosity in the context of today's pervasive technologies and unprecedented information access in formal and informal settings. In these new media contexts, children have seemingly unlimited opportunities to invoke and exercise their curiosity. Individual and group gaming represents a particular digital environment where uncertainty, a vital curiosity trigger, is actually the attraction. Group gaming, chat rooms, instant messaging, social networks, virtual worlds and the like, invoke a collaborative curiosity which may reinforce individual curiosity and potentially contribute to sustained interest and engagement at both the group and individual level. While some researchers may believe these environments could lead to problems, we believe such environments provide opportunities for understanding how and why learning occurs in technology-based and other less formal new media learning environments in which children spend much of their time. For example, if parents and educators do not recognize the role of curiosity in both informal and formal learning environments, how will they know when curiosity has the potential to enhance a learning experience versus when it may actually detract from learning?

Research on curiosity, interest and engagement conducted only in the context of formal learning environments may limit understanding of these constructs in alternative settings. Harter (1980, 1981) found a steady decline in children's motivation (including curiosity) at about third grade and continuing through grade 9, never returning to its original high level. One scholar poses the question: Is curiosity vanishing? (Engel 2009). Little is known about the factors that contribute to this apparent decline in formal learning contexts but we might suspect that the emphasis on mandated curricula and testing may account for educators having little available time for strategies that foster curiosity. Children who do not enjoy learning about science in the evaluative environment of school, for example, may enjoy talking about science concepts at home (Solomon 2005) or in an informal science learning context such as a science camp or an after-school science club (Renninger 2007). Research focused on out-of-school learning contexts may provide a clearer picture of the role of curiosity and the maintenance of interest and engagement in learning and offer important directions for how to address the lack of student motivation often present in today's classrooms.

Jenkins et al. (2006, p. 4, 8) encourage us to think in terms of 'participatory cultures' rather than 'interactive technologies' since the former, they claim, emerge from the latter as a type of cultural response. Literacy skills then shift from "individual expression to community involvement" where "collaboration and networking" inform and define what we understand as "social skills" and "cultural competencies". Describing unique elements of new media technologies, Jenkins et al. (2006, p. 9) draw on Gee's (2004) concept of 'affinity spaces' to describe 'informal learning cultures', a dimension of 'participatory culture' having implications not only for skill development but also involving the interest construct. Affinity spaces are characterized as experimental, innovative, having provisional rather than institutional structures, adaptable to short-term and temporary interests, ad hoc and localized, easy to enter and exit on demand and very generative. Jenkins et al. (2006) identify eleven core media literacy skills (play, simulation, performance, appropriation,

multi-tasking, distributed cognition, collective intelligence, judgment, transmedia navigation, networking, and negotiation) necessary to engage with these affinity spaces in the 'new media landscape', and it is the core skill of 'play' where strong connections are made with engagement. We propose extending this connection beyond play and engagement to incorporate CIE as integral to all eleven core skills and others that may emerge.

A lack of consensus on an appropriate definition of curiosity and its relationship to interest and engagement has seriously inhibited the potential for establishing rigorous research agendas in which some of the issues mentioned could be addressed. Earlier researchers have looked at these constructs through their own theoretical lenses and rarely has an attempt been made to see if it might be possible to cross disciplines and perspectives to forge a more unified definition that could be acceptably operationalized across a number of theoretical viewpoints in new media contexts.

Proposed definition for curiosity research: considering new media environments

Our definition for curiosity is applicable to curiosity in general although we are focusing specifically in this paper on the power of new media environments enabled by pervasive technologies to support or detract from curiosity. Curiosity viewed episodically is a desire for new information or experience afforded by new media environments and includes a trigger (stimulus characterized by uncertainty) or multi-trigger scenario evoked by dynamic media environments; reaction (which may involve any number of new media skills such as multi-taking, distributed cognition, collective intelligence); and resolution (satisfied/not satisfied based on the participatory collaborative). The curiosity episode, if resolved satisfactorily, initiates new learning [as in sense-making] but it is curiosity's power to both trigger and be triggered through the development and deepening of interest and consequently, the forms of engagement that result in deep learning and effective participation, collaboration, and affinity. Curiosity behaviors, at the group and individual level, in new media environments are moderated by personal, contextual and situational factors that influence perceptions of value and expectancy for success.

Contextual factors can be formal (classroom) or informal (i.e., a museum, online spaces, mobile device applications, casual exploration on- and offline). *Situational factors* include those "in the moment" happenings as well as personal traits, predispositions, and maturation within a context that help explain the direction of behavior. Situational factors could influence how one acts on curiosity, in collaborative affinity spaces for example.

In the remainder of this paper, we will examine each part of the definition and rationale, show how a model emerged, discuss technology-pervasive learning and, provide recommendations for research activities that bring the study of curiosity into the twenty first century.

Curiosity and interest

Examining the first part of our proposed definition—*Curiosity viewed episodically is a desire for new information or experience afforded by new media environments and includes a trigger (stimulus characterized by uncertainty) or multi-trigger scenario evoked by dynamic media environments; reaction (which may involve any number of new media skills such as multitaking, distributed cognition, collective intelligence)*; and resolution (satisfied/not satisfied based on the participatory collaborative). In their review, Hidi and Renninger (2006) define interest as a psychological state that in later phases of development is also a

predisposition to re-engage particular content over time. It applies to, in and out-of-school, or in informal learning environments, and characterizes the engagements of both old and young (Renninger 2007). Interest has been found to impact attention (Hidi et al. 2004), goals (Sansone and Smith 2000) and levels of learning (Renninger et al. 2002). Thus, understanding the relationship between curiosity and interest should help clarify the role of curiosity in learning. Hidi and Renninger (2006) note that while research indicates that the level of a person's interest has repeatedly been found to be a powerful influence on learning, little is known about whether, how and why interests develop nor how to help children develop that interest. Hidi and Renninger (2006) propose a four-phase model of interest development that describes how the predisposition to reengage particular content over time develops and deepens through four sequential phases, each of which is characterized by affect and increasing levels of knowledge and cognitive processing.

Loewenstein (1994) proposed an "information-gap" theory of specific epistemic curiosity describing curiosity as a feeling of deprivation which occurs as an individual recognizes a gap in his/her knowledge and is motivated to seek the information that will ameliorate this feeling of deprivation. The information gap is effectively the difference between "what one knows and what one wants to know" (p. 87). New media technology environments allow students to not only fill an information gap individually but to simulate collaboratively what it would be like to see a volcano from the inside before, during and after it erupts, for example.

Renninger (2000) suggests that the dynamic interplay between curiosity questions and the phases of interest can lead to successively deeper and more developed levels of engagement and learning. While curiosity is often discussed primarily in relation to triggered situational interest, we propose that curiosity should be studied as a potential motivator at each deepening level of interest, as well as the reverse, i.e., each level of interest as a potential motivator for curiosity, affecting the amount and type of a child's engagement in learning. Furthermore, while there are a number of other approaches to interest development (Alexander 2004; Krapp 2002; Silvia 2001), Hidi and Renninger's model is the most relevant to current research because it acknowledges the potential role curiosity can play in each phase, considers interest in a variety of learning contexts, acknowledges the importance of supportive learning environments in order for interest to develop, is applicable to children, and recognizes the relationship of interest to differing levels of engagement.

Curiosity, interest and engagement

Examining the next part of our proposed definition—*The curiosity episode, if resolved satisfactorily, initiates new learning [as in sense-making] but it is curiosity's power to both trigger and be triggered through the development and deepening of interest and consequently, the forms of engagement that result in deep learning and effective participation, collaboration, and affinity.* Learner engagement has been described as both critical and complicated because there is a need for better detail about how students behave, feel, and think (Fredericks et al. (2004)). There is strong evidence that engagement and support can foster feelings of self-efficacy (Eccles and Wigfield 2002) and sustain and deepen interest (Eccles et al. 1993; Csikszentmihalyi et al. 1993; Renninger and Hidi 2002).

Renninger et al. (2004) describe three ways in which a child may choose to engage in a learning activity. He may exhibit participative engagement, in which he engages in learning because of some imposed goal, for example by a parent or teacher, with little intrinsic need to learn. He may demonstrate affective engagement in which he engages

simply because the experience is enjoyable; this type of engagement may provide the catalyst for interest. Finally, he may experience cognitive engagement in which he is fully and intrinsically committed to learning more about a phenomenon. In new media environments, collaborative and participatory frameworks, together with the social dimensions of affinity spaces, facilitate individual and group cognitive engagement in which students make sincere efforts to learn more. It is in these environments that curiosity triggers interest and cognitive engagement. In the course of cognitive engagement, it is also possible that curiosity is re-triggered (i.e., a new related question) and individual and group learning deepens as it moves through phases of interest (and engagement), possibly even resulting in a well-developed individual and group interest, sustained cognitive engagement, deep learning, and effective participation and collaboration.

Additionally, the social and new media technological context may influence if, or the extent to which, curiosity is acted upon and whether interest and engagement emerges and is sustained. The social and technological contexts are important in that the student may engage others in her quest for information; perhaps sharing her resources and requesting input using social media tools (blogs, Wikis, Twitter, etc.), and in so doing, stimulates peer curiosity in the topic and in its exploration for answers. How will the value that friends place on a topic influence their future engagement and/or the likelihood that they would entertain new curiosity questions about the topic? How will new technologies affect acting on curiosity? Recent research has shown a connection between curiosity and the frequency of going online to find information to satisfy curiosity about something (Arnone et al. 2009), but little research has explored social media and new technologies with respect to curiosity in learning situations.

And finally, our definition proposes—*Curiosity behaviors, at the group and individual level, in new media environments are moderated by personal, contextual and situational factors that influence perceptions of value and expectancy for success*. Reactions or behaviors associated with a curiosity-provoking stimulus containing uncertainty elements such as ambiguity, novelty, conceptual conflict, etc. exist along a continuum from total immersion in exploratory behavior to disengagement or withdrawal. Hypothetically, and in the context of expectancy-value theory (Wigfield 1994), if the prospect of satisfying curiosity holds (1) value and (2) expectancy for success (i.e., the child perceives she has the competence to be successful in her attempt at resolution) she may enter into what Day (1982) has referred to as a "Zone of Curiosity" in which she is motivated to seek information, manipulate the object of curiosity, ask questions, and generally persist in exploration until the conflict or ambiguity, for example, is resolved.

Our proposed model demands that personal factors (e.g., self-efficacy beliefs, individual differences, developmental levels) as well as contextual/situational factors (e.g., social influences, homes, museums, and new media technology) be studied. For example, our investigation must explore how the activities and contexts in which a curiosity episode, once resolved, continues into some level of interest, returns at different levels of interest, or is extinguished once the conflict is resolved or information gap is closed.

A model of curiosity, interest and engagement for new media technology-pervasive learning environments

As the definition of curiosity described above began to solidify, the following model emerged. This model encompasses the key components of curiosity, interest and engagement in new media technology-pervasive learning environments while simultaneously

Fig. 1 Model of curiosity, interest and engagement (CIE) in new media technology-pervasive learning environments

considering personal, contextual and situational influencing factors. By exploring the types of research questions such as those posed at the beginning of this paper, and discussed in various ways throughout the paper, researchers using this model may discover some of the critical connections between new media technology-pervasive learning and CIE (Fig. 1).

Viewed in greater detail, the model consists of several components each with a particular dynamic in itself and in relation to all other elements of the model.

Curiosity dynamic

The curiosity component (see Fig. 2) leads to interest and engagement but only if resolution to the trigger or multi-triggers in new media environments occurs, that is, curiosity is satisfied. If curiosity is unresolved due to a lack of perceived competence to find solutions or other suboptimal occurrences, the outcome may be withdrawal, anxiety, frustration, disinterest, reconfiguration of participatory collaboration and affinity spaces, etc. Interest and engagement are thus preempted. When curiosity is ignited, the interest component can then enter into the dynamic.

Interest dynamic

The interest component (see Fig. 3) is based on Hidi and Renninger's (2006) four-phase model of interest development beginning with a *triggered situational interest*. While the previous graphic shows that curiosity can lead to interest and ultimately to engagement, the model also suggests that interest can re-trigger curiosity—depending on the environmental conditions (e.g. reconfiguration of participatory collaborations and affinity spaces, etc.) and, if sustained, interest may evolve into a *maintained situational interest*. This could then lead to an emerging individual and group interest which, in turn, holds the potential of growing into a *well-developed individual and group interest*. This model also recognizes the relationship of interest to differing levels of engagement.

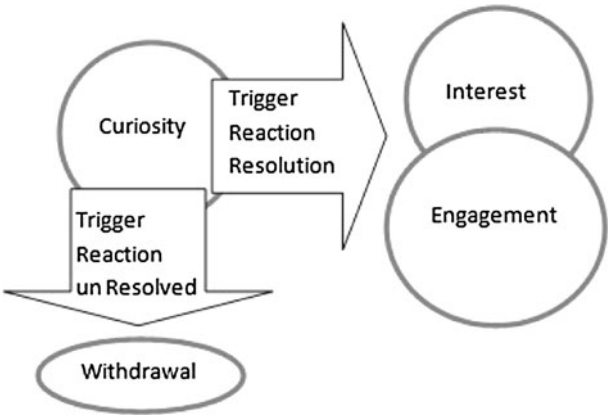

Fig. 2 Curiosity component

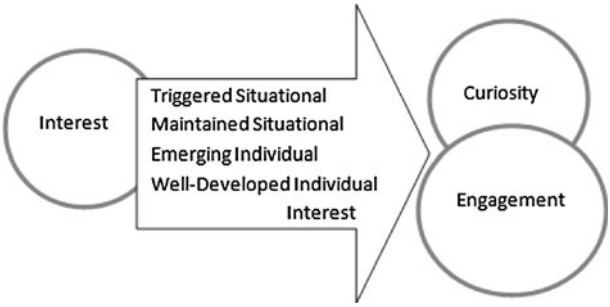

Fig. 3 Interest component

Engagement dynamic

The engagement component (see Fig. 4) can occur in three ways as described by Renninger et al. (2004). *Participative engagement*, involving learning because of some imposed goal (e.g., by a parent, teacher, affinity space), with little intrinsic need to learn, or *affective engagement* simply because the experience is enjoyable and this may provide the catalyst for interest. Finally, *cognitive engagement* may occur where the individual or group is fully and intrinsically committed to learning more about a phenomenon.

Fredericks et al. (2004) note that researchers have identified at least three types of engagement: behavioral, emotional and cognitive. Reeve (2006) states: "Engagement includes on-task behavior, but it further highlights the central role of student's emotions, cognition and voice. When engagement is characterized by the full range of on-task behaviors, positive emotions, invested cognition, and personal voice, it functions as the engine for learning and development" (p. 658). As indicated earlier, curiosity behaviors are moderated by personal and contextual/situational factors in new media environments that influence perceptions of value and expectancy for success. In a collaborative environment enabled by social networking technologies, these perceptions might be experienced by the group. At the group level these perceptions may lead to empowerment around a mutual cause, for example.

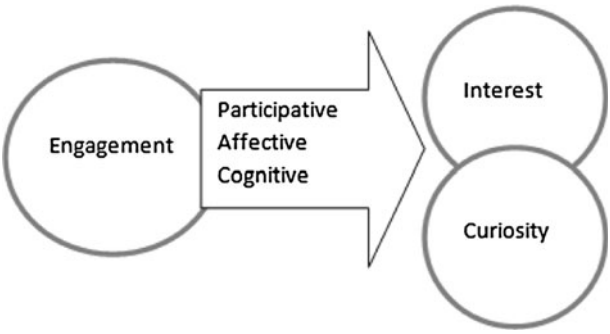

Fig. 4 Engagement component

Personal, contextual and situational factors component

Considering new media technology as pervasive is powerful. This view of technology acknowledges what today's students take for granted and expect—technology which merges seamlessly into their work and play. The use of technology in schools ranges along a continuum from avoidance to total immersion supporting 1:1 computer initiatives, mobile devices, and the use of social networking. Here we address technology-related research questions posed earlier: Have new media technological advancements provided new venues which pique curiosity and interest? Have they changed the way students act on their curiosity and interests to effect learning? These questions are considered in relation to personal and contextual/situational factors.

Personal factors

Among the personal factors (Arnone et al. 1994) which differentiate students as learners are motivation, self-regulation, self-efficacy, competence, developmental differences, and cognitive abilities. As noted earlier, newer media technologies facilitate diversions by web browsers allowing users to follow their "reasoning" back to where they started; and embedding content rather than linking to content supports the delivery of engaging multimedia and text on a single web page allowing the user to explore in situ. Visible search results provide a context for a particular instance of curiosity allowing the student to more easily grasp the broader landscape for his curiosity and interest.

Understanding how technology-pervasive environments enable us to function differently and more expansively through real-time information creation and sharing, multi-person interactions, mixed-reality environments and the like is key to appreciating these new paradigms for learning. Such collaborations and interactions necessitate a reevaluation of personal factors in the CIE new media technology-pervasive research model.

Contextual and situational factors

Context refers to something that helps to explain meaning. For example, if you are discussing learning, it could be in a formal setting (e.g., classroom) or informal settings (e.g., museum, library, mobile device) or online. *Situation* includes all those factors "in the moment" that help explain the direction of behavior. For example, a child may enjoy learning about science in an informal learning setting such as visiting a museum (context),

but the situational factors in a visit to a museum could include specific interactions with his friends, attention-focusing devices within the museum, an unexpected question, an incoming text message coming from a friend who was unable to come to the museum, an opportunity that presents itself, peer pressure, etc. These could influence how one acts on curiosity, for example. Also affecting a particular situation would be personal factors such as general traits or predispositions, maturation, etc.

In the past, a student may have been unable to gain immediate access to relevant information. Today, students have such access to generalized web information and an informal educational network, complemented and supported by collaborative efforts in their personal learning networks (PLNs). More rigorous research would require additional time and expertise in identifying, accessing and learning to use the costly and fragmented peer reviewed resource tools and repositories of information held by local schools and public libraries. And even then, students would be challenged with relative and uncertain success, given the myriad and fragmented sources. Students thus encounter in their research a 'digital disconnect' (Nagel 2009) when seeking reliable and credible information. The fragile curiosity dynamic is challenged by information seeking that diverts attention, energy, time, and focus from open source searching to more demanding 'closed source' searching. We notice though that emerging participatory cultures and affinity spaces may play critical roles in the individual and group curiosity dynamic.

Our new media technology-pervasive model assists in understanding where personal, situational and contextual gaps may exist in the CIE dynamic; i.e., if information seeking cannot be satisfied in a timely manner, with minimal effort, interest is compromised and engagement may not occur, or may not occur to the depth that is desirable and possible. Figure 5 illustrates, in practice, this new media technology-pervasive environment and how different technologies support different parts of the learning process. CIE play a role in each part. For example, once curiosity is ignited and interest is piqued, certain technologies may help students focus their curiosity inspired learning through goal setting and planning; others may help to sustain CIE in the process phase while the entire dynamic may come into play when choice of communication venue is encouraged.

Learning modalities

While our research notes various theories that are specific to curiosity, there are many learning modalities and frameworks that acknowledge the role of curiosity within their broader theory. We draw particular attention to ambient learning, cyberlearning, inquiry learning, and PLNs, to name a few (see Fig. 6). We address these types of learning that occur in new media technology-pervasive learning spaces as a means of further transferring concepts and theoretical constructs to practical instructional design strategies for promoting CIE.

Ambient learning

Ambient learning may be considered the next generation of mobile learning (Bick et al. 2007) in which digitally sensitized learning environments "provide contextualized, personalized knowledge for learners" (p. 103) and occurs within daily life, anytime or anywhere (Li et al. 2009). For example, learning opportunities occur in daily life and such episodes ignite curiosity and stimulate interest and, with information afforded through the new media technology-pervasive model, we can move into the ambient learning domain with the potential for deeper learning, engagement, and collaboratories.

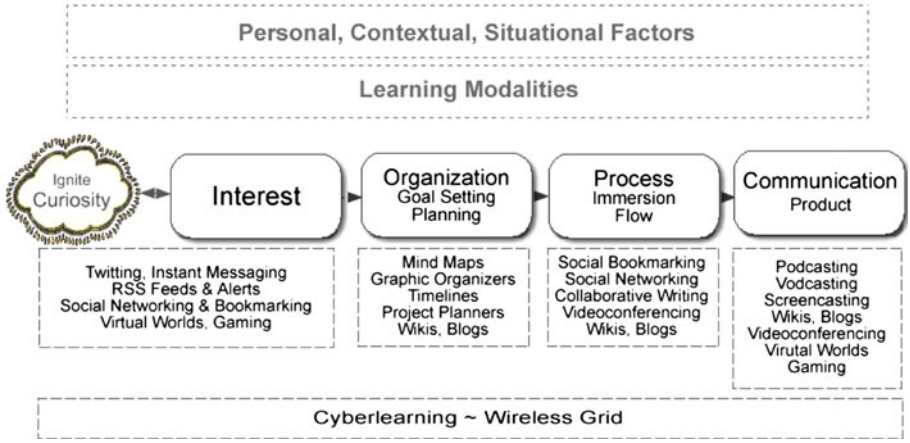

Fig. 5 New media technologies supporting the learning process

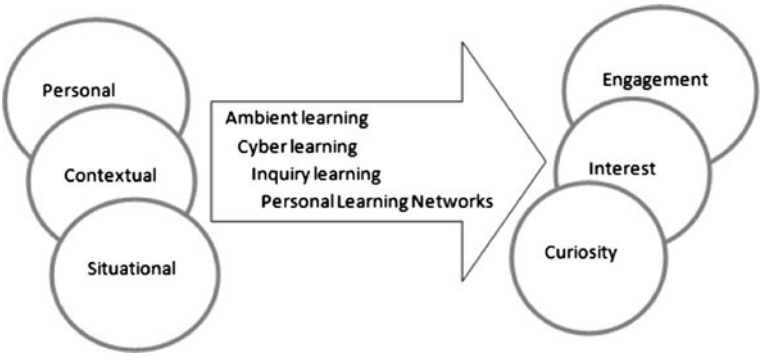

Fig. 6 New media technology-pervasive learning modalities in the context of curiosity, interest and engagement

Related work being conducted by the Center for Embedded Networked Sensing (CENS) is focused on 'making the invisible visible' by supporting linkages between the physical world and the Internet. Connecting physical spaces to digital content is referred to as a 'mixed-reality environment' where, "Visualization is enhanced dramatically, which creates opportunities for new modes of interaction, new audiences, and new models of assessment. With mixed-reality environments emerging sensing technologies can be used to diagnose a learner's interests and patterns of activity…" (Borgman 2008, p. 39). From the perspective of our CIE new media technology-pervasive learning model, CENS-type information capabilities facilitate questions and curiosity as yet unimagined by students while encouraging perhaps less diversive and more focused research behaviors (e.g., involvement in participatory collaborations and affinity spaces).

Cyberlearning

Cyberlearning incorporates inquiry-based learning, collaborations, and virtual learning that uses technology and network technologies. Calls have been made for "… advancing

seamless cyberlearning across formal and informal settings…" with seamless cyberlearning defined as "…learning supported by cyberinfrastructure so that it can be pursued productively either through learner intent, driven by interests or demands in the moment and regardless of location, or through intentionally designed educational activities, which learners can take advantage of as needed or when the situation requires" (Borgman 2008, p. 35). For example, the technological perfect storm of increasingly capable handheld wireless devices (e.g., smartphones, iPads, mobile applications), the explosive use of cloud computing, the increasing ubiquity of wireless connectivity for both Internet access (WiFi) and for cell phone communications and the convergence of wireless cell phone technology with wireless Internet and traditional network technology has resulted in the development of wireless grids (Anderson 2009) technology, facilitating student learning by the use of a variety of seamlessly integrated wireless technologies (e.g., radio software, handhelds, social media) for learning anytime, anywhere. Our CIE new media technology-pervasive learning model serves as an ideal framework for conducting cyberlearning research. We believe that being "driven by interests or demands in the moment" is an example of cyberlearning which could play a leveraging role for students in their learning interests, situations and contexts and as such, is fully amenable to the research model we are proposing.

Personal learning networks

In their most basic implementations, PLNs provide an environment to efficiently organize and manage resources and personal social connections. In their most powerful implementations, PLNs facilitate connections to a global network of people, ideas, and resources which have the potential to challenge and expand thinking. A PLN which reaches out to others reveals the complexity and richness of thought associated with topics of personal interest. Expectations for 'digitally rich learning experiences' are summed up in the Project Tomorrow report (2010): "Students see the use of relevancy-based digital tools, content and resources as a key to driving learning productivity, not just about engaging students in learning" (p. 1). PLNs considered in the context of the CIE new media technology-pervasive model serve as a mechanism to provide support, focus, and depth for student curiosity about a particular topic or issue.

Social media and collaboratories

Collaborative activities among students are very much in evidence, actually and potentially, as described by the MacArthur Foundation report (Jenkins et al. 2006). Exploring collaboration in social media venues, may also reveal something to us about curiosity, interest and engagement in new media technology-pervasive learning environments. For example, social networking technologies may serve as catalysts to invoke curiosity and establish connections among individuals with similar interests. However, they do more than provide a venue for collaboration. We suggest that they also provide the types of observational learning and vicarious reinforcement which foster positive self-belief and self-efficacy as defined by Bandura (1977, 1997). Additionally, participants scaffold one another and co-construct knowledge and understanding (Bandura 1977, 1997; Wood et al. 1976; Vygotsky 1978; Piaget 1952). Social networks operating in supportive contextual and situational environments welcome "newbies" and offer guidance from experienced mentors. As an example, students who participate in multi-gaming and virtual reality environments develop their skills over time with an eye toward mastery.

Social networking is effective in focusing our attention but can also become a source of distraction (Carr 2010). Students are likely to have real-time incoming and outgoing data running on various mobile and desktop devices via twitter, email notifications, facebook and instant messaging, chat windows, RSS feeds, and Google alerts. The CIE new media technology-pervasive learning model can be used for research into these 'un-tethered learning' spaces.

Recommendations for future research

A new research agenda is needed that explores children and adolescents' CIE in contemporary new media technology-pervasive environments and their effects on children's dispositions to learn and ultimately on performance. This article's definition of curiosity combined with the new media technology-pervasive model described, provides a basis for research on curiosity's relationship to interest and engagement in an integrated, cross-disciplinary approach. In the model, new media pervasive technologies operate as levers or compelling forces to bring about better chances for the relationship model dynamic to occur. This approach helps in (1) determining how children's dispositions for learning and learning behaviors are influenced by personal, contextual and situational contexts *external* and *internal* to school settings in new media technology-pervasive learning environments (2) identifying which dispositions can be modified by exploring relationships within new media technology-pervasive learning environments, and (3) developing and implementing targeted interventions and additional practical strategies in the context of new media technology-pervasive learning environments that will ultimately enhance learning. Some potential research questions are: What is it about today's new media technology-pervasive contexts that ignite curiosity and sustain interest and engagement? Can we discover and leverage these factors to positively foster children's curiosity and dispositions for learning, both in and out of school? What types of strategies will most effectively support learners who are easily distracted, lack confidence, etc.? Through well-researched instructional interventions, children can develop habits and skills which support movement from curiosity to interest, essential to sustain their engagement in new learning in all social settings—families, offline and online communities, cultural and recreational organizations, in addition to formal educational settings.

Several major and interrelated research thrusts are recommended: (1) *Preliminary research* that focuses on the further development and enhancement of children's curiosity and interest measures that go beyond the self-report (e.g., identify the neuro-correlates of curiosity in the brain; 'quality of attention' as part of the curiosity construct as identified by Kashdan (2009); (2) *Longitudinal research*, focusing on contexts that impact learning, including informal learning environments such as museums and libraries, families/homes, new media technology environments (participatory cultures of collaboration and affinity spaces), and social and recreational community-based organizations, as well as formal educational settings, any or all of which could inform the third recommendation; (3) *Short-term and cross-sectional research*, focusing on redesigning learning contexts: new media technology-rich, and learner-centered ecologies that can be used by children to promote their CIE in learning, and on new media technology-based and enhanced environments for finding and sharing information located within any of the above contexts; (4) Reconsideration of research methods for conducting research into curiosity and learning in new media technology-pervasive environments where netnography (Kozinet's 2002), a form of ethnographic research for example, may have particular relevance for 'culture-sharing groups' (Creswell 2007, p. 93) characteristic of participatory collaborations and affinity spaces.

Web 2.0 and beyond technologies should be included in both the short-term and the longitudinal research. New media technology-pervasive learning modalities—such as ambient learning, cyberlearning, augmented learning—incorporating Web 2.0–5.0 (Kambil 2008) (and beyond) capabilities need to become part of the research agenda. With new media technology-pervasive spaces permeated by and supportive of social networking and collaboration, an opportunity exists to conduct research into the "advantages of being curious in social relationships" (Kashdan and Silvia 2009, p. 367).

Conclusion

As part of our new research agenda we propose a revised and extended view of a new media technology-pervasive learning timeline (Kambil 2008; Johnson et al. 2010a, b) that addresses more particularly the constructs of curiosity, interest and engagement (see Fig. 7). Personal, contextual and situational factors are not mutually exclusive, but rather, interact and overlap in any given learning environment. Types of learning are placed in an organized space on this timeline but are in fact finding their way into emergent new media technology spaces defined by the Web X.0s. The graphic in Fig. 7 captures the notion of: (a) increasingly pervasive new media technology learning environments, and (b) the incorporation of existing and new types of learning into these new media technology-pervasive spaces.

We are all born curious, as evidenced by the way babies evoke all of their senses as they constantly explore their environment. It is curiosity that ignites our internal fire, our passion, for learning in the present moment and for a lifetime. It is the curious child that becomes tomorrow's innovator—discovering a cure for a disease, creating a technology for harnessing low-cost, alternative, eco-friendly energies, developing a service that increases independence for people with disabilities. This article offers a multi-lens perspective on curiosity and suggests a multi-method research agenda for validating such a perspective. Where Jenkins et al. (2006) identify a series of core media literacies noting connections with interest and engagement, we propose extending these connections beyond play and

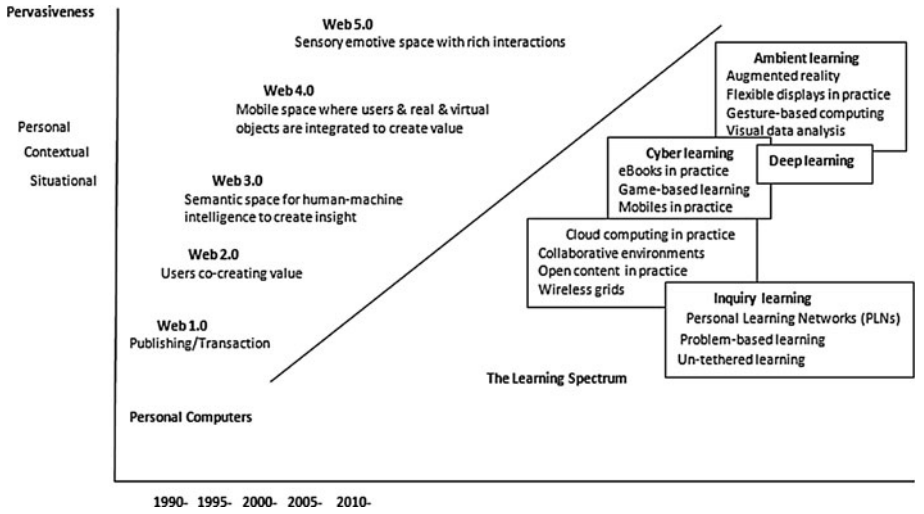

Fig. 7 Trajectory of curiosity, interest and engagement in new media technology-pervasive learning environments

engagement for example to incorporate CIE as integral to all eleven core skills and others that may emerge. By understanding the factors that ignite and nurture children's curiosity and sustain engagement in learning into adulthood, we can prepare our young citizens to face and embrace the global diversity, competitiveness, and constant change of a workplace or workspace that requires lifelong learning.

Acknowledgments This research was supported in part by a Science of Learning Catalyst Grant from the National Science Foundation. We would like to recognize the following members of the NSF Science of Learning catalyst research team who contributed to this work: Phyllis Blumenfeld, University of Michigan; Edward Deci, University of Rochester; Jacquelynne Eccles, University of Michigan; Suzanne Hidi, University of Toronto; John Keller, Florida State University; Barbara Koslowski, Cornell University; Tiffany A. Koszalka, Syracuse University; Carol Sansone, University of Utah; and Ann Renninger, Swarthmore College.

References

Ainley, M. (1987). The factor structure of curiosity measures: Breadth and depth of interest curiosity styles. *Australian Journal of Psychology, 39*(1), 53–59.

Alexander, P. A. (2004). A model of domain learning: Reinterpreting expertise as a multidimensional, multistage process. In D. Y. Dai & R. J. Sternberg (Eds.), *Motivation, emotion, and cognition: Integrative perspectives on intellectual functioning and development* (pp. 273–298). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Anderson, J. (2009, October 2). *Documentary coverage of IGF-USA by the Imagining the Internet Center: Response from Lee McKnight, Wireless Grids, to Lee Rainie's 'What We Don't Know About the Future of the Internet'*. Elon, NC: Imagining the Internet Center, Elon University. Retrieved July 1, 2010 from http://igfusa.wordpress.com/2009/10/02/response-from-lee-mcknight-wireless-grids-to-lee-rainie%E2%80%99s-%E2%80%98what-we-don%E2%80%99t-know-about-the-future-of-the-internet%E2%80%99/.

Arnone, M. P., Grabowski, B. L., & Rynd, C. P. (1994). Curiosity as a personality variable influencing learning in a learner controlled lesson with and without advisement. *Educational Technology Research and Development, 42*(1), 5.

Arnone, M. P., Reynolds, R., & Marshall, T. (2009). The effect of early adolescents' psychological needs satisfaction upon their perceived competence in information skills and intrinsic motivation for research. *School Libraries Worldwide, 15*(2), 115–134.

Bandura, A. (1977). Self-efficacy: Toward a unifying theory of behavioral change. *Psychological Review, 84*, 191–215.

Bandura, A. (1997). *Self-efficacy: The exercise of control*. New York: Freeman.

Berlyne, D. E. (1954). A theory of human curiosity. *British Journal of Psychology, 45*(3), 180–191.

Berlyne, D. E. (1960). *Conflict, arousal and curiosity*. New York: McGraw-Hill.

Beswick, D. G., & Tallmadge, G. K. (1971). Reexamination of two learning style studies in the light of the cognitive process theory of curiosity. *Journal of Educational Psychology, 62*(6), 456–462.

Bick, M., Kummer, T., Pawlowski, J. M., & Veith, P. (2007). Standards for ambient learning environments. In B. Konig-Ries, F. Lehner, R. Malaka & C. Turker (Eds.), *MMS 2007: Mobilität und mobile Informationssysteme; Proceedings of the 2nd Conference of GI-Fachgruppe MMS* (pp. 103–114). Bonn, Germany.

Borgman, C. L., (Chair) (2008). Fostering learning in the networked world: The cyberlearning opportunity and challenge, a 21st century agenda for the National Science Foundation. *Report of the NSF Task Force on Cyberlearning*. Virginia, US: NSF.

Carr, N. (2010). *The shallows: What the Internet is doing to our brains*. New York, USA: W. W. Norton & Company.

Creswell, J. W. (2007). *Qualitative inquiry & research design: Choosing among five approaches*. Thousand Oaks, CA: SAGE.

Csikszentmihalyi, M., Rathunde, K., & Whalen, S. (1993). *Talented teenager: The roots of success and failure*. New York: Cambridge University Press.

Day, H. I. (1982). Curiosity and the interested explorer. *NSPI Journal*, May, 19–22.

Deci, E. L. (1975). *Intrinsic motivation*. New York: Plenum.

Eccles, J., & Wigfield, A. (2002). Motivational beliefs, values, and goals. *Annual Review of Psychology, 53*, 109–132.

Eccles, J. S., Wigfield, A., Harold, R., & Blumenfeld, P. B. (1993). Age and gender differences in children's self- and task perceptions during elementary school. *Child Development, 64*, 830–847.
Engel, S. (2009). Is curiosity vanishing? [Editorial]. *Journal of the American Academy of Child and Adolescent Psychiatry, 48*(8), 777–779.
Engelhard, G., Jr., & Monsaas, J. A. (1988). Grade level, gender, and school-related curiosity in urban elementary schools. *Journal of Educational Research, 82*(1), 22–26.
Fredericks, J. A., Blumenfeld, P. C., & Paris, A. H. (2004). School engagement: Potential of the concept, state of the evidence. *Review of Educational Research, 74*(1), 59–109.
Gee, J. P. (2004). *Situated language and learning: A critique of traditional schooling*. New York: Routledge.
Harter, S. (1980). *Manual: A scale of intrinsic versus extrinsic orientation in the classroom*. Denver, CO: University of Denver.
Harter, S. (1981). A new self-report scale of intrinsic versus extrinsic orientation in the classroom: Motivational and informational components. *Developmental Psychology, 17*, 300–312.
Hidi, S., & Renninger, K. A. (2006). The four-phase model of interest development. *Educational Psychologist, 41*(2), 111–127.
Hidi, S., Renninger, K. A., & Krapp, A. (2004). Interest, a motivational variable that combines affective and cognitive functioning. In D. Y. Dai & R. J. Sternburg (Eds.), *Motivation, emotion, and cognition: Integrative perspectives on intellectual functioning and development* (pp. 89–114). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.
Jenkins, H., Purushotma, R., Clinton, K., Weigel, M., & Robison, A. J. (2006). *Confronting the challenges of participatory culture: Media education for the 21st Century. Building the field of digital media and learning: an occasional paper on digital media and learning*. Chicago: MacArthur Foundation.
Johnson, L., Levine, A., Smith, R., & Stone, S. (2010a). *The 2010 Horizon Report*. Austin, TX: The New Media Consortium.
Johnson, L., Smith, R., Levine, A., & Haywood, K. (2010b). *2010 Horizon Report: K-12 Edition*. Austin, Texas: The New Media Consortium.
Kambil, A. (2008). What is your Web 5.0 strategy? *Journal of Business Strategy*, 29(6), 56–58.
Kashdan, T. B. (2009). *Curious? Discover the missing ingredient to a fulfilling life*. New York, NY: William Morrow.
Kashdan, T. B., & Silvia, P. (2009). Curiosity and interest: The benefits of thriving on novelty and challenge. In S. J. Lopez (Ed.), *Handbook of positive psychology* (2nd ed., pp. 367–375). Oxford, UK: Oxford University Press.
Kashdan, T. B., Steger, M. F., & Breen, W. E. (2007). Curiosity. In R. Baumeister & K. Vohs (Eds.), *Encyclopedia of social psychology* (pp. 213–215). Thousand Oaks, CA: Sage Publications.
Kashdan, T. B., & Yuen, M. (2007). Whether highly curious students thrive academically depends on the learning environment of their school: A study of Hong Kong adolescents. *Motivation and Emotion, 31*, 260–270.
Kozinets, R. V. (2002). The field behind the screen: using netnography for marketing research in online communities. *Journal of Marketing Research, 39*(1), 61–72.
Krapp, A. (2002). Structural and dynamic aspects of interest development: Theoretical considerations from an ontogenetic perspective. *Learning and Instruction, 12*, 383–409.
Li, X., Feng, L., Zhou, L., & Shi, Y. (2009). Learning in an ambient intelligent world: Enabling technologies and practices. *Knowledge and Data Engineering, 21*(6), 910–924.
Litman, J. (2005). Curiosity and the pleasures of learning: Wanting and liking new information. *Cognition & emotion, 19*(6), 793–814.
Litman, J. A., & Jimerson, T. L. (2004). The measurement of curiosity as a feeling of deprivation [abstract]. *Journal of Personality Assessment, 82*(2), 147–157.
Loewenstein, G. (1994). The psychology of curiosity. A review and reinterpretation. *Psychological Bulletin, 116*(1), 75–98.
Nagel, D. (2009, April 24). Students as 'free agent' learners. *The Journal: Transforming Education Through Technology*. Retrieved July 1, 2010, from http://thejournal.com/articles/2009/04/24/students-as-free-agent-learners.aspx.
Naylor, F. D. (1981). A state-trait curiosity inventory. *Australian Psychologist, 16*, 172–183.
Palfrey, J., & Gasser, U. (2008). *Born digital: Understanding the first generation of digital natives*. New York: Perseus Books Group.
Piaget, J. (1952). *The origins of intelligence in children*. New York: International Universities Press.
Project Tomorrow. (2010, May). *Unleashing the future: Educators "speak up" about the use of emerging technologies for learning - Speak Up 2009 national findings, teachers, aspiring teachers &*

administrators. Irvine, CA: Project Tomorrow. Retrieved July 1, 2010, from http://www.tomorrow.org/speakup/.
Reeve, J. (2006). Extrinsic rewards and inner motivation. In C. Everston, C. M. Weinstein, & C. S. Weinstein (Eds.), *Handbook of classroom management: Research, practice and contemporary issues* (pp. 645–664). Mahwah, NJ: Erlbaum.
Reio, T. G., Petrosko, J. M., Wiswell, A. K., & Thongsukmag, J. (2006). The Measurement and conceptualization of curiosity. *The Journal of Genetic Psychology, 167*(2), 117–135.
Renninger, K. A. (2000). Individual interest and its implications for understanding intrinsic motivation. In C. Sansone & J. M. Harackiewicz (Eds.), *Intrinsic motivation: Controversies and new directions* (pp. 373–404). San Diego, CA: Academic Press.
Renninger, K. A. (2007). Interest and motivation in informal science learning. *IEEE Computer Society Press*. Retrieved from http://www.informalscience.com/researches/Renninger_Commissioned_Paper.pdf.
Renninger, K. A., Ewen, L., & Lasher, A. K. (2002). Individual interest as context in expository text and mathematical word problems. *Learning and Instruction, 12*, 467–491.
Renninger, K. A., & Hidi, S. (2002). Student interest and achievement: Developmental issues raised by a case study. In A. Wigfield & J. S. Eccles (Eds.), *The development of achievement motivation* (pp. 173–195). New York: Academic Press.
Renninger, K. A., Sansone, C., & Smith, J. (2004). Love of learning. In C. Peterson & M. E. P. Seligman (Eds.), *Character strengths and virtues: A classification and handbook*. New York: Oxford University Press.
Sansone, C., & Smith, J. L. (2000). The "how" of goal pursuit: Interest and self-regulation. *Psychological Inquiry, 11*(4), 306–309.
Silvia, P. J. (2001). Interest and interests: The psychology of constructive capriciousness. *Review of General Psychology, 5*, 270–290.
Solomon, J. (2005). Home-school learning of science: The culture of homes, and pupils' difficult border crossing. *Journal of Research in Science Teaching, 40*(2), 219–233.
Tapscott, D. (1997). *Growing up digital*. NY: McGraw Hill.
Tapscott, D. (2008). *Grown up digital: How the net generation is changing your world*. NY: McGraw Hill.
Vygotsky, L. S. (1978). In M. Cole, V. John-Steiner, S. Scribner, & E. Souberman (Eds.), *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.
White, R. W. (1959). Motivation reconsidered: The concept of competence. *Psychological Review, 66*, 297–333.
Wigfield, A. (1994). Expectancy-value theory of achievement motivation: A developmental perspective. *Educational Psychology Review, 6*(1), 49–78.
Wood, D., Bruner, J., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of Child Psychology and Psychiatry, 17*, 89–100.

Marilyn P. Arnone is research associate professor in the School of Information Studies and director of educational media at the Center for Digital Literacy, Syracuse University. Her research explores the contribution of motivational factors to digital and information literacies.

Ruth V. Small is Laura J. & L. Douglas Meredith Professor, director of the school media program, and founding director of the Center for Digital Literacy in the School of Information Studies at Syracuse University. Her research focuses on the motivational aspects of information use.

Sarah A. Chauncey is currently the Director of Information Resources and Learning Technologies for Rockland BOCES. Her research interests focus on information management, active learning modalities, and the motivating influence of technology in learning environments.

H. Patricia McKenna is an information consultant and researcher interested in the transformative potential of ambient information and ambient technologies. Her research interests also extend to collaborative practices for learning, for work, and for everyday life.