EAGER: Cyberlearning: Towards virtual worlds that afford knowledge integration across project challenges and disciplines

Project Summary

Our vision is of an educational system where learners engage in project-based education on a regular basis—within and across disciplines, and in and out of school. Educational settings will become places for solving problems, experiencing phenomena, getting excited about possibilities, and making sense together. Project sequences will "cover" important content and foster mastery of important project, expressive, collaborative, disciplinary, and other skills. The practices of successful project work and successful learning from project work will become second nature to learners, and their flexible facilitation will become second nature to teachers. *We believe that if challenges are framed appropriately and their associated figured worlds (real and virtual) and scaffolding are designed to afford it, such education has the potential to help learners integrate the content and practices they are learning across projects and across disciplines.*

Our goal in the proposed Cyberlearning EAGER project is to begin to learn how to use technology to afford such knowledge integration. Informed by literature on project-based education, transfer, case-based reasoning, encoding specificity, preparation for future learning, and incidental knowledge and implicit learning, we will carry out our exploration through a combination of close observation, micro-genetic analysis, situated memory probes, and interviews to begin to identify (i) conditions under which learners most richly interpret their experiences while working towards achieving engaging challenges, (ii) the content and quality of their memories of those experiences under several conditions, and (iii) the conditions under which they desire to revisit a completed project challenge after learning new content that can help them better understand or resolve the challenge. Our best hypotheses right now are that elicitation of intense and/or sustained emotional reactions, feelings of being able to have real impact, and real immersion in the world of the challenge are all important to rich memory-making and learners' desire to revisit completed challenges, that some incidental aspects of the figured world will help them make connections, and that a combination of emotional factors and ability of the figured world to support investigation from a new perspective will affect their desire to revisit completed challenges. Our exploration will help us understand more about the actual elements in the experiences of learners that lead to different emotional responses and the impacts of such responses on their memory making and desires.

Intellectual Merit: The results of our exploration will inform the cyberlearning community and our own research team in several ways. First, our results will form the foundations for design of virtual worlds and project challenges with affordances for supporting knowledge integration across projects and disciplines. Second, our results and the development of several exemplar virtual worlds and associated project challenges will inform development of design principles for design and use of a new virtual world genre — with characteristics built in that anticipate the cross-project and cross-discipline knowledge integration that can be afforded and ready learners for future connection making as well as knowledge deepening. Third, our explorations will identify issues that need to be addressed to further good design and systematic effective implementation of project-based education.

Broader Impacts: There is a great need to make the activities of education, whether formal or informal, more engaging to more of our youngsters; this is a prerequisite for to getting better results from educational efforts. There is a need, as well, for our citizenry to make connections between what they are learning across disciplines. Project-based education, done well, has affordances for helping learners make connections between what they are learning in school and the lives they live, and thus becoming more engaged in educational activities. It also has affordances for fostering deep learning and mastery of a large variety of important skills and practices. We are aiming to take advantage of those affordances to

also help learners make connections across disciplines that will be important to using what they are learning in real-world situations.

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The Opportunity:

Our vision is of an educational system where learners engage in project-based education on a regular basis—within and across disciplines, and in and out of school. Educational settings will become places for solving problems, experiencing phenomena, getting excited about possibilities, and making sense together. Project sequences will "cover" important content and foster mastery of a wide range of important project skills, as well as expressive, collaborative, disciplinary, and other skills. The practices of successful project work and successful learning from project work will become second nature to learners, and their flexible facilitation will become second nature to teachers. *We believe that if challenges are framed appropriately and their associated figured worlds (real and virtual) and scaffolding are designed to afford it, such education has the potential to help learners integrate the content and practices they are learning across projects and across disciplines.*

The literature suggests that fostering such knowledge integration in learners requires rich memory making while working on learning activities, contact with elements of the figured worlds they are engaging in that are only incidental to the challenge they are achieving but important to integrating what they are learning across projects and disciplines, passion for achieving challenges they are engaging, and the desire to achieve each as best they can. The literature further suggests that more intense emotional engagement and reactions will result in richer memory making and reminding. As well, our experiences with project-based education lead us to believe that when a figured world is rich enough for learners to develop their own interests within that world and/or when their experiences in that world have been compelling, learners have the desire to return to it over and over again.

We propose to do foundational exploratory work needed to identify initial design criteria for virtual worlds to be used in project-based education that afford rich exploratory and investigative experiences in the context of achieving emotionally-engaging challenges and also afford knowledge integration across projects and disciplines and within disciplines. These virtual worlds will not only have fidelity to the challenge to be addressed but will also provide access, as the real world does, to naturally-occurring phenomena in the environment that are only tangentially related to addressing the challenge. They will be so emotionally engaging that learners will want to return to old challenges to understand them better and refine their solutions to them based on new phenomena they are learning about, and the technology will be built to support revisiting the challenge with new perspectives and with new phenomena taken into account. We propose this EAGER project as a start to learning the characteristics of such worlds and the framings of project challenges that will foster such emotional engagement and allow such revisiting and refinement.

Our idea for this new virtual world genre derives from the literature on mental-model building, and the case-based reasoning and encoding specificity literatures support it. Such revisiting was built into early knowledge integration units (KIE; refs) and is built in to some extent in WISE (refs) and Project-Based

Inquiry Science (refs) units and approaches. Our claim is that the time is right for exploring how modern virtual-world-building technology and what we know about project-based learning (Kolodner. Schank, Krajcik, …), encoding specificity (refs), transfer (refs), incidental and implicit learning (refs), and preparation for future learning (Schwartz refs) can be built upon to create a new genre of virtual-world technology and associated curriculum units that are designed to systematically bring such a vision to fruition — in ways that support successful implementation across a broad range of courses, grade levels, and teacher capabilities and styles. There currently exist a multitude of engines and infrastructure for building such worlds (e.g., EcoMuve, Quest Atlantis, Tom's stuff, Jim Slotta's stuff), and we know how to design successful project-based units and provide systematic scaffolding (on paper) for success (see PBIS evaluations; SRI, Penuel and Harris). As we move into the future of designing new project-based units and curricula and virtual worlds that allow immersion into figured worlds challenges are based in, it seems appropriate to use those implementations to learn about how to intentionally design project-based units, the figured worlds they are carried out in, and the ways they are scaffolded to support productive interpretation of experiences, reminding, and revisiting and re-exploring phenomena across challenges learners take on.

Our Goals:

Our long-term goals are two-fold: (1) to learn how to design and use curriculum challenges and the figured worlds that go with them to support such knowledge integration and sustained engagement and excitement (2) to learn how understanding develops when learners have the chance to encounter and revisit phenomena and processes from several figured worlds as they integrate what they are learning across units and disciplines.

Bringing such a vision to fruition requires knowing the ins and outs of the cognition of forwards and backwards transfer and how to foster such transfer and also knowing how to foster in learners enough excitement about or interest in challenges they are addressing so that they want to revisit them, deepen their understanding of phenomena they were learning about, and derive better solutions based on those new understandings.

Our goals for this proposed EAGER, therefore, are to learn enough about each to be able to achieve the longer-term goals. We propose to begin to (1) understand how the modern (since 2000) literature on encoding specificity, transfer, preparation for future learning, and learning in figured worlds can best inform the design of figured worlds used in project-based education, the framing of project challenges, and the design of project sequences and systematic scaffolding that foster interpretation of experiences and development of the kinds of rich mental models and other representations that will support later reminding, application of what was learned in new situations, and the want to use what is being learned to further understand phenomena from earlier challenges and (2) derive criteria to be used in the design of challenges, scaffolding, figured worlds, and advice for teachers/facilitators so that learners will recognize and experience the interactions between processes and phenomena in ways that draw them into engaging in the forward and backward transfer of what is learned across several units and the deepening of their understanding of concepts and phenomena from across the many project-based units they address. While we have high-level understanding of such design and scaffolding (refs), our goal is to dig deeper, given new cognitive, socio-cognitive, and neuro-cognitive findings of the past decade and a half.

Based on the literature cited below, we guess that carrying out missions in environments learners can immerse themselves in and actually engage with (we call this 1st person engagement) will have better affordances for achieving these goals than units in which learners are looking in on a situation, as is often done in project-based units, but we don't know that conditions under which this would be true. We wonder the extent to which a feeling of immediate risk might be a condition for such engagement; we wonder how the opportunity to try out different ways of doing something versus needing to get it right the first time affect such engagement; we wonder what experiences elicit the emotional engagement that will cause learners to richly interpret their experiences and build rich mental representations; we wonder what the contents of those representations are in different conditions; and we wonder when and the extent to which learners' opportunity to really make a difference in something plays a role in their emotional engagement and mental model building.

We will carry out our investigation in the context of two project-based units that focus on understanding water ecosystems and that have different affordances for evoking emotions and supporting memory making. We will then specialize the activities and software of an existing air quality unit to develop challenges that we will use to probe the memories and desires of learners who engaged in the two ecosystems units. In Living Together, a unit in the Project-Based Inquiry Science (PBIS) unit, learners look in on a town and give advice to its town council; they play roles as outside consultants (though later they engage in argumentation as if they are part of the town community). In Eco-Muve, learners embed themselves in a pond and its watershed; they get to experience the dying off of the fish and the changes in the water chemistry over time and first-hand. In Living Together, they work towards having an effect on a fantasy town; in Eco-Muve, they work towards explaining. The literatures cited below inform our hypotheses and questions, but they do not give us specifics about what kinds of experiences will be emotionally rich for learners or the contents of representations they will build.

An Example:

Students exploring ecosystems in the context of Dede's Eco-Muve (refs) notice that the fish in the pond are dying off; they resolve to explain why. To achieve this mission, they explore the environment in and around the pond. What activities are people engaging in around the pond? What kind of flora and fauna are in and around the pond? How many of each of the types they find do they see? How large are they? How well-formed or deformed or energetic are they? What is the chemical makeup of the water? The concentration of different chemicals? How oxygenated is the water? How does the existence of each of the species in the environment affect the existence of other species in the environment? What has the weather been, and how is it affecting the environment? And so forth. Students generate questions and investigate to answer them in the context of actually "moving around" the pond environment; learners "walk" around the environment and "talk" to people they encounter, and they "go underwater" to "see" life underwater and to take measurements.

Figuring out what is killing the fish is reportedly an engaging and affect-pleasing endeavor. Facilitated well, the experience enables learners to successfully achieve the challenge and feel good about their achievement. They learn quite a bit about this ecosystem and how it has become unbalanced and, as a result of classroom discussions and readings, they learn more generally about ecosystem processes and the influences on those processes. But achieving this challenge does not require learning about molecular formulas, stable and unstable molecules, or chemical reactions; it does not require learning about the water cycle, biomes, the wind, weather, or climate change (though learners do have the opportunity to explore several phenomena only secondarily associated with their challenge (e.g., they can watch a water molecule as it moves through the environment)); and learners do not actually go back in history and put regulations in place that maintain the health of the eco-system.

Now imagine this: Later that school year, or the next school year, learners are challenged to identify sources of poor air quality and make recommendations about addressing air quality problems in another locale (real or imaginary). Achieving this challenge requires determining human impact and natural impact on air quality, impact of bad air quality on ecosystems and humans living in this local, flow of matter in the atmosphere, identifying sources of pollutants, understanding how air quality changes over time, as well as learning about molecular formulas, unstable molecules, and chemical reactions. Having figured out what was poisoning the fish, learners know some things about how systems interact, and they've experienced that chemicals running off into a body of water can poison life in the water and damage the ecosystem. But they do not yet understand these things at the molecular level. Once introduced to chemistry, however, they have another way of understanding what happened to the fish. After having new insights about the pond, they can use insights gained through re-examining what happened to the fish to better understand what is happening in the atmosphere. In the process, they have the opportunity to connect together content and phenomena encountered across the two challenges, and, indeed, across two disciplines (eco-systems in the life sciences and chemistry content in physical sciences and environmental science) and to deepen their understanding of systems and their interactions.

Or, imagine that learners engage in the air quality unit first and then the pond unit. Then they will be able to bring what they learned about chemistry to explaining what is happening to the fish, better suggest ways of managing the pond's watershed, and revisit the air quality unit thinking more about interacting systems. Now imagine that the first challenge is the pond challenge and later they are challenged to come up with emergency plans for local dangerous weather conditions that are happening more frequently as a result of global warming. As they consider weather patterns and global warming issues, they have the opportunity to use their understanding of complex systems gained from the ecosystems unit and add to that understanding, and we want them to recognize that weather over time might have affected the pond and to want to revisit the pond and consider the effects of changing weather conditions, and perhaps precipitation and runoff on that ecosystem. Upon revisiting the pond, they then use what they are learning about the processes involved in influencing the weather to gain further insight into the complex ecosystem of the pond, in the process connecting content from life sciences (ecosystems) to content in earth sciences (weather and climate).

These scenarios suggest that when learners learn via achieving a challenging mission, there is opportunity to learn the targeted disciplinary (or multi-disciplinary) knowledge and skills needed to achieve the mission and also to make contact with and experience the connections between that targeted content and other phenomena happening in the context in which project work is being done. The water cycle is always cycling, for example; gravity is always acting; Earth continually rotates on its axis and revolves around the sun; the winds blow, circulating the air, whether it is important to the assigned mission or not; people and other lifeforms inhabit and move around in ecosystems; and so forth. We argue that it is sometimes worthwhile building such reality into a figured world even when it is tangential to the targeted challenge. We want to find out how and when to do that and also the most important of the conditions under which the targeted knowledge integration will be afforded.

Why an EAGER:

We ask for a Cyberlearning award because our ultimate goals, as specified above, are consistent with the mission of the Cyberlearning program — to learn how to design and use a new genre of virtual worlds and to understand the development of understanding and how to support it when learners are put in situations that afford sense making forward from an old experience and backwards to an old experience. It seems early, however, to propose anything even as exploratory as a Cyberlearning EXP, as it is not yet clear how the literatures cited below inform the design of the new genre. We don't know enough yet to propose a first pass at a minimally viable virtual world representative of the new genre. Nor do we know enough yet to carry out a systematic investigation of the elicitation of rich memories. We therefore request funding for an EAGER award. Our intuition is that learning to design such units, their figured worlds (whether real or virtual), and their sequencing and scaffolding will require learning under which conditions learners develop the kinds of rich interpretations and representations of their project experiences that will support knowledge integration and under what conditions they get excited enough to want to use and deepen what they learned previously. We need to know more about each of these issues, we believe, before we can credibly propose to design such units, sequences of units, figured worlds, and scaffolding, and certainly before being able to propose a new technological genre.

The proposed FY2016 Cyberlearning EAGER funding would ready us to apply for a Cyberlearning EXP in December, 2016 (FY2017). This work will also help us understand issues needed for other programs as well; we imagine that achieving the ultimate goals will require funding beyond the Cyberlearning program. A CORE award would allow more systematic learning about backward and forward transfer and sense making, and DRK-12 and IUSE funding would allow development of particular units and their figured worlds so that learners will have the resources and desire to actively engage in the proposed forward and backward sense-making. Our team for this proposed project includes expertise in memory retrieval and representation, project-based education, design of project-based challenges, design of virtual worlds, and methodological issues with respect to studying learners in action in real learning settings. We thus anticipate being able to follow through on many of the interesting issues and possibilities we will uncover while engaging in the proposed EAGER investigation and to proposing projects for peer-review to several NSF programs.

Foundations

We are led to the hypotheses listed above by the literature on case-based reasoning, transfer, encoding specificity, and project-, problem-, and design-based education, and also by the experiences with a range of project-based educational approaches and virtual worlds in which they are carrie out. Both PIs (Kolodner and Pallant) and the primary consultant (Grotzer) have similar intuitions and questions about challenge framing and the affordances of worlds (virtual and real) where learners achieve challenges. When Kolodner, for example, first saw Eco-MUVE, her reaction to seeing it in action was that exploration in Eco-MUVE seemed so emotionally engaging and the possibilities so exciting that she expected that much of the experience of using it and achieving the pond challenge would stay with the learners and be accessible to reason from if they had a chance to return to the environment for reasons other than achieving the pond challenge. At the same time, but independently, Grotzer's direct experience with Eco-Muve has been leading her and the Eco-Muve team to wonder about the conditions under which this happens and when it doesn't and how to reframe challenges and refine Eco-Muve for better emotional engagement and learning. The literature on learning from problem solving, design, and other mission-driven experiences, as well as the literature on thick authenticity, we believe, can all be called upon to inform exploration of these hypotheses.

<u>Case-Based Reasoning:</u> The case-based reasoning model of cognition informs what we propose in three ways. First, it proposes that one of the very powerful and primary means of storing memories is storing one's experiences as cases — interpretations of what one has experienced. Second, it posits that the extent to which one is able to apply what one learned in the context of an experience depends on the extent to which connections have been made between the pieces of the experience as it is being interpreted — causal and sequential connections, as well as recognition of the more general or abstract categories the actors, props, and contextual features represent. Third, it posits that the extent to which one is able to retrieve from memory an old experience relevant in a new situation depends on a combination of the extent of interpretation of the old experience while making sense of it as it is being stored in memory (or refined later) and the extent of interpretation the new situation while making sense of it. The better they match on important features, the more chance of retrieval. Evaluations of Learning by Design (refs) and the more general Project-Based Inquiry Science (refs), approaches to project-based education informed by these three propositions, have proven effective at fostering learning of targeted content and targeted scientific, project, communication, and collaboration practices; thus, we have reason to believe that project-based education carried out similarly but better taking into account the conditions under which learners form their richest interpretations and representations should extend efficacy of the approach to more learners and be a foundation to build on in fostering learning across challenges, disciplines, and areas of a discipline. This model, as well, informs our choice of what to focus on in the proposed project; it tells us that what will be most important to learn is the conditions for making rich memories, that we

can learn about that through probing by putting learners in situations that share a considerable number of qualities, and that reminding under those circumstances (whether learners are reminded themselves or someone else reminds them) will lead to access to and reconstruction of those old experiences and the attempt to apply them to the new situation. This combination, we believe, will give us an excellent perspective on the memories learners are making.

<u>Encoding specificity:</u> Case-based reasoning and the encoding specificity literature make similar predictions about when someone will be likely to remember something learned or encountered previously (refs). Both the interpretations one does at the time of the first experience and those one does at the time of a second experience affect what one can recall. But foundational work on both approaches was silent on the role of affect on what is remembered. More recent work in encoding specificity focuses on affect's role and is consistent with my intuitions about the added power for fostering retrieval and deeper learning when learners have experiences with targeted phenomena and processes as part of solving a personally-meaningful challenge and in an environment that grabs their attention (refs). The experience of intense emotion while having an experience leads to richer encoding, and the experience of intense emotion during retrieval, this literature suggest, fosters retrieval of other memories where similar emotions were experienced. This suggests the need to learn more about under what conditions learners engage emotionally and the representations they form under those circumstances. The candidate hypotheses that will arise from investigating these questions, we expect, can be used to inform ways of framing project challenges and designing the worlds in which they are carried out. This literature informs our exploration by pointing out the importance of focusing on the memories learners make when engaged emotionally and learning more about how to elicit such engagement.

<u>Transfer:</u> The LBD and PBIS approaches already include in them reflection activities designed to foster recall and transfer based on what CBR, encoding specificity, and transfer literatures proposed about fostering transfer up to the late 1990s (e.g., Gentner, Thagard, Brown, ….). Labato's more recent agent-based approach to transfer (refs) adds to that literature in ways that can further inform the activities learners should engage in and the reflection they should do. The agent model looks at transfer from the point of view of the learner. Rather than from the point of what we (as educators want to happen), this approach explores what is possible and probable with respect to being able to access and use understandings. According to this model, learners need to attend to what's needed for transfer, be given to agency (and scaffolding) for making sense, and engage in activities that will foster recognition of similarities. The focus, as in case-based reasoning's model, is on learner experiences, and I am hoping that this approach will add to our understanding of how to design and scaffold the exploration of figured worlds. In addition, Schwartz's preparation for future learning (refs) focuses on the reasoning a learner must do as he/she is having experiences in order to remember and use what has been learned previously. We expect to build on both models to inform scaffolding and teacher responsibilities (after we know conditions under which learners engage emotionally), and we have asked both Schwartz and Labato to join our advisory board. Our intuition is that work on preparation for future learning will inform the facilitation of project-based education and may inform the elements that should be built into a figured virtual world designed for knowledge integration. With respect to

<u>Incidental and implicit learning:</u> Implicit learning means (roughly) learning without awareness (refs), and incidental learning is learning that happens along the way and without intention (refs). There are arguments about the actual mechanisms behind both of these (refs), but the point is that we do notice things that we are not aware of noticing and learn things we are not intending to learn as we navigate the world around us. When learners learn via achieving a challenging mission, there is opportunity to learn the targeted disciplinary (or multi-disciplinary) knowledge and skills needed to achieve the mission and also to make contact with and experience the connections between that targeted content and other phenomena happening in the context in which project work is being done. The water cycle is always cycling, for example; gravity is always acting; Earth continually rotates on its axis and revolves around

the sun; the winds blow, circulating the air, whether it is important to the assigned mission or not; people and other lifeforms inhabit and move around in ecosystems; and so forth. We "intuit" that some of the otherwise irrelevant goings on in an environment in which learners are achieving project goals, if included in the virtual world they are exploring, could provide grist for helping learners recognize and appreciate the interactions between phenomena and processes encountered in different project-based units, (2) that while engaging in achieving some other mission in which those types of phenomena or processes are relevant to project goals, revisiting those phenomena in the first virtual world can serve to help learners come to better understand both the newly targeted and previously targeted phenomena and to grasp interactions between phenomena, processes, and disciplines. Our intention is to understand the extent to which learners will notice goings on in the environment they are embedded in in addition to those they are focusing on to address a challenge and to derive some initial hypotheses about the conditions under which learners will become aware of "extraneous" phenomena, include them in their memories, can be reminded of them, and use them to wonder about what else might have been going on in a situation that they did not focus on while originally addressing a project challenge. Jodi Asbell-Clarke has been addressing implicit learning in the context of games, and we will call on her as an advisor to help us weave what is known about implicit and incidental learning into our exploration.

<u>Mission-driven education:</u> I include here all of the different approaches to learning in the context of solving problems and achieving challenges — project-based, problem-based, and design-based education, capstone projects, and goal-based scenarios are all included. Eco-MUVE, listed above, was designed to be used in the context of achieving a mission, and its developers designed, as well, a curriculum unit that takes big advantage of Eco-MUVE's capabilities to foster learning of ecosystems concepts. Mission-driven education, as implemented in PBIS, addresses issues of preparing young learners to be members of a collective that achieves missions together and prompting the kinds of reflection that will lead to learning. PBIS illustrates how a good mission can foster disciplinary learning as well as learning a range of sophisticated practices. The goal-based scenarios literature (refs) provides guidance about how to coherently tie together the many things that need to be done to achieve a mission. Game-based approaches to education (refs) focus on eliciting the excitement and sustained engagement needed to achieve a tough challenge. We also expect to use what is known about eliciting excitement in mission-driven games to inform the way we investigate conditions for eliciting strong emotion in project-based approaches to education and as part of what informs initial guidelines for design of the new genre and its implementation.

<u>Thick authenticity:</u> Shaffer's and Resnick's (refs) paper on authenticity suggests characteristics that challenges and learning experiences should have so that learners will sustain engagement and interest over long periods of time — challenges and activities should have personal meaning to learners, be consistent with the challenges people in real-world situations engage with, afford use of the same kinds of resources and tools that would be available in real-world situations, and afford self-assessment that allows learners to know when they are on the right track and what else they need to learn and take into account. PBIS units are already designed with such thick authenticity in mind. These units are also authentic in one other way that is consistent with the hypotheses we have proposed: Learners get a chance to experience affective highs of the sort practitioners experience; our guess is that with virtual worlds that allow closer and easier access to phenomena and allow more exploratory possibilities, more learners will experience such affective highs.

Overall, this foundational literature suggests that because technology will allow learners to get closer to phenomena than they could otherwise and play roles as scientists, engineers, and policy makers with resources and tools available to them that are like the resources and tools practitioners have available, more of the students will engage enthusiastically over longer periods of time, and there will be possibilities for more of the students to learn more deeply than could happen without such tools. Such learning, these literatures suggest, will be in the form of well-interpreted cases with rich indexes and rich emotional descriptors attached. As well, the interpretation of new experiences, also rich with phenomena and emotionally laden, will result in remembering those stored experiences. When both new and remembered experiences are both richly interpreted, there are potentially powerful opportunities for connecting and developing deeper understandings of the content embedded in both. We will use what we learn about what is actually remembered in these circumstances and the conditions that elicit rich interpretations and memory representations to inform a first approach to framing project challenges, designing figured worlds and scaffolding to interpret experiences in those figured worlds, and the kinds of knowledge integration that can be expected and supported when students have affect-rich experiences across several figured worlds.

As an aside, we want to note here why we do not include "affective computing" as a literature that informs development of these ideas. Our understanding of affective computing is that it is about interpreting the affect of computer uses and adapting interaction to those affects or working to improve the user's affect. While such capability may be useful as learners are engaging in project work, our focus is on designing the learning environment and learning activities so that learners are, in general, experiencing positive affect as they engage. We do not rule out, of course, the need for an interactive system to provide encouragement when work gets tedious (as it can, even when a challenge is, itself, exciting) and will include such facilities in the new genre if we find that they are needed.

Proposed work:

We will address three issues in this EAGER project: (1) what conditions give rise to intense emotional engagement and what conditions give rise to sustained emotional engagement, (2) what is remembered by learners when they have (enthusiastically) engaged with a challenge in a virtual figured world and reflected on it in ways appropriate to learning (as exemplified in the PBIS approach) and what seems to affect what is remembered, (3) how the challenge and/or virtual world need to be configured so that learners notice phenomena that are not central to addressing the challenge but that are important to making connections with content outside of the content of the challenge without being overwhelmed by complexity. We will not directly address reminding or transfer themselves in our explorations; rather our focus is on identifying the factors that will be most powerful in setting learners up for reminding and transfer. One reason for this is that the transfer literature already tells us that analogies made when one is reminded by oneself of a previous situation or when one is reminded by someone else are more or less equivalent (refs).

We will carry out our exploration in the context of middle school science in particular, using project-based approaches and units that our team is familiar with and carrying out our studies in local venues (Boston area) where teachers are already using these materials in their classrooms. We choose to focus on water eco-systems for three reasons: (1) we know learners get excited by these units, (2) there are many potential connections to be made between what learners are learning in these units and other content targeted in middle school science, and (3) we have available two different units with similar goals and different approaches and know they are being implemented in the local area.

The two units we will use are Chris Dede's and Tina Grotzer's Eco-MUVE and the middle school science unit built around it, and *Living Together* from Project-Based Inquiry Science (PBIS). Both focus on water ecosystems. Both will be implemented in Boston-area schools. Tina will advise us in identifying teachers using Eco-MUVE and its curriculum unit in their classrooms. Mary Starr, who trains PBIS teachers, will help us identify teachers implementing *Living Together*. Eco-MUVE is used over a 3 or 4 week period; *Living Together* is an 8-week unit.

We will explore using methodologies of qualitative research. However, we are proposing an exploration that will help us identify important factors to take into account in designing a new genre and in learning in more depth about fostering learning across projects and disciplines. Rather than constraining ourselves to any particular research design, we will carry out a sequence of exploratory activities designed to help us uncover these factors.

We will begin with close observation and video capture for purposes of initial case study preparation; continue by designing probes for identifying the richness of the memories learners have made; probe learners through a combination of engaging them in a second project challenge and interviews; and use micro-genetic analysis methods to uncover the paths towards development of particularly rich memories and the reasons for lack of development in instances where our initial analyses predicted development of memories learners failed to make. We expect that comparisons across the natural variations that arise will allow us to draw out initial hypotheses related to each of our three targeted issues. We provide some details of the activities intend to carry out; the depth with which we carry out any of them will depend on what we are finding and interesting phenomena that arise and require our attention. We will use our advisory board several times during the exploration to help us know best ways of focusing.

<u>Observation:</u> We will observe up to 6 groups of students (2 to 4 students per group) in up to 3 classes where each of the two ecosystems units are being carried out to understand how the students are experiencing the units, in particular, focusing on (i) their emotional responses and what elicits those, (ii) their encounters with science content and phenomena and their sense making around that content, and their encounters with extraneous phenomena. Before carrying out these observations, we will convene our advisory team to get additional advice on where to focus the attention of our observations — from the point of view of each of the contributing literatures, theories, and approaches listed above.

<u>Video capture:</u> We will also have students we are focusing on wear Go-Pro cameras on their foreheads so that we will collect more specific data about their attention focus, encounters, and sense making. We will also use video screencasts to capture discussions and computer use while students are using Eco-MUVE. While we will not interpret all of this data, we want to have it available to use for later analysis of the development of their interests and memories. Recordings from the Go-Pro cameras will allow us to understand learners' perspectives on their individual and small-group activities and on whole-class discussions. This will be important to taking an agent-based approach to predicting learners' memory making.

<u>Initial case analysis:</u> We will use the observation data we collect to do initial identification of learners' high-affect experiences, the memories we expect they made at those and other times, and the memories of extraneous phenomena they might have made, looking at video as necessary to fill in details we may have missed in our field notes. For each of the high-affect instances we identify, we will use a combination of field notes and video to try to explain what the conditions that led to and sustained those emotional reactions. We will not be doing a full micro-genetic analysis of learners' developing understanding; rather, we will be trying to identify at a higher level the approximate content of the representations they are building. At this point, we will call our advisory team together again — to present to them our case studies and the memories we think our learners made and to get their advice about probing learners' memories.

<u>Probe development:</u> Based on our initial case analyses, we will develop variations of an air quality challenge and its activities and use those to probe the memories of our focal groups of learners. The challenge will be based on activities and dynamic models developed for the High-Adventure Science Air Quality module (developed by Concord Consortium, National Geographic, and UCSC), and learners will have the software from that module available while working toward achieving the new challenge. The air quality challenges and their associated activities will be developed to evoke reminding of experiences during their water-based ecosystem work. We will develop small but engaging challenges related to air quality (we don't know how many that will need to be) to evoke memories of the water-based ecosystems

experiences learners have — to evoke memories we expect learners to have made and to see if some memories we wonder about were made. We hope learners will be reminded, but if not, we will remind them of their ecosystems experience. Our goal here is to use the new challenge and its activities to identify the memories learners actually made while working on the ecosystems challenge. Each of these challenges will be designed to be enacted in a few hours so that they can be carried out over a small number of afternoon sessions or a weekend afternoon.

Memory probing: We will bring learners into the lab or gather them after school in small groups several months after they engaged in the ecosystems challenge. As ecosystems is generally done in life science and air quality in physical science, we do not expect our learners to have studied air quality during the school year. Our current intention is to have learners work in the same small groups they were in for the ecosystems challenge. We will present an appropriate air quality challenge and have their teacher facilitate their work on it. Students will again wear Go-Pro cameras. We will observe their emotional states, what they are remembering, and how they are using what they remember from their ecosystems challenge. Whether they are reminded of their ecosystem experiences themselves or reminded by others, our focus will be on their use of the memories they made as they address the new challenge. Their use of those memories in solving the new challenge will help us understand the contents of the memories they made during the ecosystems challenge. We will also observe their interest in returning to the ecosystems challenge, and we will make the materials they used previously (software, books, their notes, etc.) available to them so that they can re-engage with it.

Interviews: We will follow up this activity with interviews of small groups of learners and individuals, each tailored to finding out more about the particular memories they made, their retrospective analysis of what made those experiences salient, and how they used those memories to address the new challenge.

Continued case analysis: We will focus analysis that addresses our three issues in two ways: towards enriching the reconstructions of reminding, memory representations, and emotion evocations that we expected and towards explaining unexpected results of the memory probe. Unexpected results will include rich memories we were not expecting learners to have and lack of rich memories when we were expecting richness. We will use a micro-genetic approach to this analysis but will not go as deep or be as detailed as a real micro-genetic analysis would be.

Addressing our issues: We'll address our issues by comparing and contrasting across the case studies we've developed. We hope to be able to describe the range of emotions we see; to propose conditions that elicit those emotions; to propose conditions under which learners develop rich memories, to describe what it looks like when learners want to return to a completed challenge, and to propose conditions under which they have that desire.

Intellectual Merit:

In general, virtual worlds for education are designed to allow exploration or to allow solving a particular problem or achieve a particular challenge. Or, a virtual world is designed and then the same designers or someone else designs a curriculum unit to go around it. The idea here is to begin to learn (i) how to design virtual worlds that support learning some particular content and/or achieving some particular challenge so that the same virtual world can also be used as secondary resources in other units, (ii) how to co-design project-based curriculum units and virtual worlds for achieving disciplinary and unit-specific goals and also achieving cross-disciplinary and cross-cutting goals, and (iii) how affect while solving problems affects backward and forward sense making and connections and how to elicit such affect.

There is reason to believe that the emotionally rich experience of achieving a personally-meaningful challenge holds affordances for rich knowledge integration across the content of challenges, across the content of disciplines, and within the content of disciplines that project-based education does not yet take advantage of. But to know how to best frame project challenges, design the figured worlds in which they are carried out for such knowledge integration, and identify best pedagogical practices for achieving such knowledge integration, there is more we need to know about the conditions under which learners will tend to richly interpret their experiences and build rich and useful mental representations.

Broader Impacts:

We foresee an educational future where infrastructure is in place so that learners excitedly engage collaboratively in project-based or mission-directed curriculum that encourages active and mindful engagement over sustained time periods and that supports deep understanding of phenomena and processes and mastery of a wide variety of disciplinary, collaboration, communication, and project skills. This project aims to move us closer to that future.

Dissemination:

We will neither be building technological products nor running well-controlled experiments as part of the proposed project. We will, however, be systematizing hypotheses and gathering evidence for conditions under which learners engage intensely and the interpretations and representations they form as a result. Our dissemination, therefore, will be of ideas, and will be done through posters and short presentations at learning sciences, educational technology, and cognitive science conferences, and short briefs in learning sciences and cognitive science journals.

Project Team:

The PI and co-PI are Janet Kolodner and Amy Pallant of The Concord Consortium. Janet Kolodner is a long-time expert in how people (and computers) learn from experience and how to foster learning from experience. Amy Pallant has managed, written curriculum and conducted researcher on several Earth Systems models and curriculum efforts at Concord. Kolodner and Pallant will observe in classrooms and meet regularly to interpret data; they will be helped by another member of the Concord Consortium staff and will advise Harvard undergrads who will work on transcribing recordings.

Another major player on our team will be Tina Grotzer, from Harvard School of Education, and a principal on the Eco-Muve team. Grotzer's expertise is in … … micro-genetic methodology. She will give up to 10 days of advisory time to the project, helping Kolodner and Pallant identify Eco-Muve classrooms and teachers to involve, advising about the use of Go-Pro cameras, and most importantly, making sure Kolodner and Pallant have appropriate methodological rigor to their data collection and analysis and serving as a confidant in discussions of the data.

The advisory team will also include Dan Schwartz, of Stanford, expert in preparation for future learning, Joanne Labato, from UCS??, expert on agent-based transfer, and ????. We expect to have three extended video meetings with the advisory team: one towards the beginning of our project to advise us on the conditions they think we should be looking out for in our observations, once after analyzing that data to advise about setting up our probes, and once after the data analysis is complete to advise about lessons learned and next steps. We will also call on them with questions as needed. <<also Jody Asbell-Clark>>

Prior Research:

In her previously funded NSF research, Kolodner explored ins and outs of learning from experience and case-based reasoning, both in computers and in people. The results of that work are best represented in her book *Case-Based Reasoning* (Kolodner, 1993). During the 1990's and 2000's, Kolodner and her team used the cognitive model implied by case-based reasoning to propose a new approach to project-based pedagogy in middle school classrooms. The result was the approach called Learning by Design (Kolodner et al., 2003a, b), and its principles form the backbone of *Project-Based Inquiry Science*, a three-year middle school science curriculum published by It's About Time, Inc. with units derived from Kolodner's Learning by Design units and the LETUS Institute's Project-Based Science units. The published curriculum has been adopted by school systems across the US, and it is currently being refined to better match the NGSS. The Learning by Design approach has informed approaches to design-based, problem-based, and project-based curriculum worldwide.

Pallant has worked on many NSF funded projects. Her most recent work the ***High-Adventure Science: Earth's Systems and Sustainability (HAS:ESS)*** (DRL-1220756. 10/1/12 – 1/31/16. $2.3M, PI: Pallant, Co-PIs: Lee and Larson) project is applying design knowledge gained from the curriculum and assessment development and validation from the ***High-Adventure Science (HAS)*** (DRL-0929774. 9/15/09 – 8/31/12. $695,075. PI: Pallant) project to a broad range of environmental science topics. The result of these projects are six modules for secondary school students related to climate change, fresh water availability, land management, energy resources, air pollution and the search for life space. We created and validated an assessment framework that measures students' formulation of uncertainty-infused scientific arguments with professionally collected data and modeling. We are also in the process of testing several protocols to assess students' systems thinking focused on system dynamics items related to stock and flow and time delay. **Intellectual Merit:** The goal of HAS:ESS is to gain and validate curriculum design knowledge that can promote understanding of how Earth's systems work and how human interactions might impact Earth's systems while also situating this understanding in important science practices of scientific argumentation through modeling. **Broader Impacts:** At the completion of HAS:ESS, the will be freely available to teachers through the National Geographic Society (NGS) and the Concord Consortium websites. Additionally, Pallant, has been project manager and researcher on several Molecular Workbench projects. She has been developing curriculum and contributing to research studies at the Concord Consortium for the last fifteen years.

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