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Abstract

This paper reports on a study of primary contextualization processes during science immersion trips and the resultant student learning. Four High School Ecology classes (n=67) and teachers participated. Through a pre/post assessment of science concept knowledge (Pathfinder Network Modeling) and follow-up interviews with students, it was determined that (1) significant learning was associated with these immersion experiences, though overcontextualization was problematic for some, (2) there was a positive interaction between degree of contextualization (primary vs. secondary) and degree of learning, and (3) key primary contextualization processes included the situating of knowledge in time and place as well as the collection of personalized visual or embodied evidence for science concepts. The study contributes to our understanding of contextualization in the learning process and has the potential to inform field, classroom, and virtual learning environments.

Contextualizing Science Learning Through Immersion in Content-Rich Settings

In science education we find a common call for the need for deeper, more conceptually rooted knowledge that students can relate to and apply to real world problems (Braund & Reiss, 2006; Bulte, Westbroek, de Jong, & Pilot, 2006; Gilbert, 2006; NRC, 2012). However, didactic classroom pedagogies do not tend to foster schematic, applicable knowledge for the majority of students (Greeno, Collins, & Resnick, 1996). Secondary science education often results in the development of what Whitehead (1929) called “inert knowledge,” information that is de-contextualized from the real world. This is problematic if science education is to engage students, help them to understand contextualized interconnections of STEM disciplines, and apply that understanding outside of school.

If we are to help students contextualize their understanding of STEM concepts then we need to better understand the role of contextualization in the learning process. In this study I examined the contextualization of high school students’ knowledge as a function of their interactions with the learning environment during four multi-day science immersion trips. Two questions guided the study:

1. Do students contextualize their understanding of science concepts when immersed in an authentic, content-rich learning environment?
2. If so, what processes do students use to contextualize their knowledge?

Contextualization

Context is approached here as the interactive everything in which learning is situated for an individual learner or a group, with parts that cannot be meaningfully separated (Finkelstein, 2005). Contextualization occurs not only as a result of the planned curriculum but through every other aspect of the learner’s experience. Four assumptions on context undergird this study: (1)

contextualization requires there to be something that is contextualized, there is a direct connection between context and concepts (Rivet & Krajcik, 2008). (2) We are “condemned to context” in that it is inherently connected to our learning (Tessmer & Richey, 1997) and we must consider the contexts educators intentionally or inadvertently scaffold for students. (3) Context varies based on the intensity, details, and individualized interaction with each learner (Tessmer & Richey, 1997), as does the relationship between context and knowledge (Schwartz & Lederman, 2008). (4) Without context any knowledge is of limited use and incomplete (Spiro, 1988).

The term *contextualization* is used here to describe the process of drawing specific connections between content knowledge being taught and an authentic environment in which the content can be relevantly applied or illustrated. This environment includes the cultural backdrop, other actors, the physical environment, and a scenario in which the concept is inherently related and applicable. Contextualized experiences and environments stand in contrast to *decontextualized* experiences and environments, wherein the context is often scholastic, abstracted away from actual events and from the content knowledge as it is typically used in practice (Rivet & Krajcik, 2008). Contextualization also requires that the students understand, can relate to, and have some experience with the context used (Rivet & Krajcik, 2008). Because contextualization is a learner-centered process, framing a concept within a hypothetical context that the learner is not familiar with only adds another layer of abstraction rather than truly contextualizing the concept.

Contextualization in the science education literature spans a range from text-based scenarios to full immersion experiences in real-world settings. This spectrum can be dichotomized into learning *with* context or learning *in* context. Learning *with* context, can be labeled *secondary contextualization* as it relies on a provided, second-hand source of context. This may include a case study, in which a narrative is built around a concept, or a laboratory exercise in which a scenario fictitiously positions students as scientists running an experiment. In secondary contextualization the context is layered onto the content to develop relevance and is limited to what is explicitly provided by the curriculum or teacher. Learning *in* context, or *Primary contextualization,* refers to first-hand, direct experience within contexts in which the content can be readily detected and applied in an authentic manner. Internships and field studies are likely environments where this might occur. This dichotomy examines context from the perspective of the learner's experience and thereby distinguishes it from previous frameworks (e.g. Gilbert, 2006) that use a curriculum lens. The two approaches could be complimentary and provide a more complete view of a given learning environment.

There is ample evidence that contextualization writ large betters students' perceptions of the relevance of the science content they are learning as well as their interest in it (King & Ritchie, 2012). Research into the relationship between conceptual understanding and contextualization has produced more variable results with some investigators finding positive associations (CTGV, 1990; Gerber, Cavallo, & Marek, 2001), others showing mixed or inconclusive results (Bennett & Lubben, 2006; Rivet & Krajcik, 2008), and some showing contextualization as detrimental to conceptual understanding (Lave, 1988; Son & Goldstone, 2009). In past work exploring the relationship between conceptual science learning and contextualization, most studies have relied on secondary contextualization, such as problem-based learning (Strobel & van Barneveld, 2009), and project-based learning (Rivet & Krajcik, 2004). Outcomes are variable and debated (Hmelo-Silver, Duncan, & Chinn, 2007; Sweller, Kirschner, & Clark, 2007) perhaps owing to the requisite assumptions of students' previous experiences and interest. A number of studies have shown that immersion in contextualized learning environments can foster science learning (Ballantyne & Packer, 2010; Falk & Balling, 1982; Orion & Hofstein, 1994; Nashon & Anderson, 2013; Charney et al., 2007) and while there is an underlying assumption that primary contextualization contributes, it is unclear how or why. As Dillon (2003) points out, “assuming that because the body is in the field that the mind is there too might be naive” (p. 219). Without an understanding of the primary contextualization *process* we cannot know if or how it contributes to learning, how to improve associated pedagogies, nor if the associated expenses are justified.

As we move forward in developing future science education opportunities we need to find a balance between student understanding of abstract science concepts and grounding those concepts in a contextualized world where they have relevance, meaning, and maintain the sense of wonder that often leads students into STEM careers. While there can be no perfect learning environment or curriculum for all students, efforts to move toward that goal are hindered by a limited understanding of *how* contextualization impacts science learning.

Situated Cognition

A situated perspective of learning forms the foundation of the study as this theory fundamentally describes the relationship between the learner and her environment (Greeno et al., 1996). Knowing and learning from this perspective are processes, rather than outcomes, situated within and influenced by specific environments (Fenwick, 2000). Useful within this framework, Perkins (1993) introduced the *person-plus* as a unit of analysis. It represents the individual learner along with the external tools, practices, and other individuals that allow for a given cognitive process. Thus, the cognitive process as well as any memory or “cognitive residue” is distributed throughout the learning environment, such that the learner *off-loads* some memory into notebooks, other people, etc. (Brown, Collins, & Duguid, 1989; Perkins, 1993). This perspective should not be seen as person-solo cognition occurring independently within a larger social vessel but rather as an entity with specific roles within the larger person-plus system. These roles include perception, indexing, the assignation of meaning, and transfer of knowledge to new settings. In this way, the cognitive elements of constructivism are joined with the situated elements of learning in a manner that reflects actual learning in authentic environments (Dillon, 2003). As a theoretical foundation this perspective accounts for both the interactional complexity of authentic learning environments as well as the importance of individual manifestations of knowledge. Experience is the process that unites the individual learner with the person-plus, the interactions in the physical world with the cognitive constructions of the mind. With this perspective an individual's learning experience can become a lens into the person-plus system and the relationship between context and knowledge can be examined.

Method

Participants and Setting

High school administrators in the Western U.S. were asked to nominate highly qualified teachers with upcoming plans for extended field science classes for their students. Each selected class was part of the standard curriculum at different schools and either included or was conducted entirely through an immersive field science experience. This study tracked the learning of 67 students enrolled in four different high school ecology classes in the western United States. Students lived and learned in highly contextualized environments for an extended period (between 3 and 8 days). The courses were designed and conducted by each teacher independent of this study.

Two of the courses (Cases 1 and 2) were part of residential high school programs in which the students learned principles of winter ecology while living in mountain settings adjacent to wilderness. The students regularly traveled on skis into wilderness settings as a part of their studies. The primary learning objectives involved understanding the relationship between evolutionary adaptations and extremes of the physical environment. In Case 3, the students spent three days at a migration stopover for sandhill cranes. They studied the relationships between critical crane habitat, migration, and human use of the landscape. Case 4 travelled to Florida for eight days to canoe and hike through the Everglades ecosystem and learn about regionally unique ecological characteristics, focusing on evolutionary adaptations to microenvironments. For each of these courses the location was selected to highlight or contextualize the learning goals. While the instructional patterns varied from case to case, they all included (1) students and teachers living and learning in the field; (2) some pre-planned lessons, lectures, readings, and itineraries; (3) impromptu lessons as 'teachable moments' arose; (4) time devoted to lessons and to free time in context; (5) specific field data collection assignments in groups; (6) conceptual connections to classroom lessons back at school; and (6) some student choice in topic foci and presentations of student learning. The student experience could be characterized as an extended journey through a novel ecosystem in which they were receiving teacher- or curriculum-sourced information in pulses, making individual observations throughout, participating in a learning community in which the ecosystem was always a part of the discourse, and consistently reflecting on their learning. Please see (Author, 2012) for more specific narrative details by case.

Within each case eight students were selected for interviews with the goal of a representative sample across age, gender, and ability level (as indicated by teachers). The students ranged from 9th to 12th grade (age 14-18). With the exception of Case 1, most of the students were white and of middle to upper socio-economic status (SES). The students of Case 1 were highly diverse, largely from inner city neighborhoods, of low SES, and enrolled in a school for students who had not been successful in their previous school experiences.

Procedures

Measuring learning. A pretest/posttest design was used in conjunction with Pathfinder Analysis (Schvaneveldt, Dearholdt, & Durso, 1988) to assess students' conceptual knowledge structures before and after their science immersion experiences. Pathfinder is a graph-theoretic algorithm that generates network graphs (*PFnets*, see Figure 1 for an example) of salient structural knowledge based on *relatedness* values between a series of ideas (Schvaneveldt et al., 1988). On the pre- and post-assessments students were asked to rate the *relatedness* of pairs of ecology concepts, *targeted science concepts (TSCs)*, pre-chosen by their teacher as relevant to the learning goals of the course. Students were free to interpret what it meant to be related, an important aspect of the Pathfinder process (Dearholt & Schvaneveldt, 1990).

[Insert Figure 1 about here]

Based on the relatedness ratings of between 15 and 20 concepts, each paired with every other, PFnets were generated and compared using Pathfinder software (*Pathfinder*, 2007). The program produces network graphs such that (a) every link (relationship) between two nodes is assigned a comprehensive weight that reflects how closely related the two nodes were judged to be; (b) the sum of the weights of the edges that must be passed through to move from one node to another is the *path weight* and therefore the lower the path weight, the closer the connection between two nodes; and (c) any edges are removed if the path weight between the two nodes is less when following an alternate route through the graph (Dearholt & Schvaneveldt, 1990). The resulting graph shows the most salient relationships and an overall view of the student's domain-specific structural knowledge (Dearholt & Schvaneveldt, 1990). Pathfinder was used to catch subtleties of students' learning in an open environment that would have been difficult to capture with a traditional assessment. Also, the relatedness judgments are not affected by contextual discrepancies between the learning process and the assessment.

Each student's pre-trip and post-trip PFnet was quantitatively compared to an expert referent, resulting in a value representing the similarity between the student and the referent, corrected for chance (*csim*, see Schvaneveldt, Durso, & Dearholdt, 1989), a process that has been validated against more traditional assessments (Acton, Johnson, & Goldsmith, 1994). Referents were generated by averaging the relatedness values of the class teacher and two ecologists on the assessment (Acton et al., 1994). The Pathfinder results were validated for the purposes of this study through the interview process described below. All students used language in their relatedness descriptions that was consistent with the relationships depicted in their PFnets. In two cases students were first shown an unidentified PFnet belonging to another student and they immediately indicated that the graph did not seem to agree with their understanding of the TSCs.

Contextualization. Using each student's PFnets as elicitation tools, six to eight students in each of the four cases (n=28) participated in semi-structured, 30-minute interviews immediately following the trip. Students were first asked to explain their understanding of the concepts or relationships between concepts for which important changes were represented by that student's PFnets. This allowed for interviews that were focused on concepts for which substantial change in knowledge did occur. Students were then asked to describe what led to each highlighted change in their understanding if they agreed that a change had occurred. Follow-up questions encouraged elaboration when necessary.

The interviews were transcribed from audio recordings. Using HyperRESEARCH qualitative data analysis software (*HyperResearch*, 2011) each transcript was divided into units of analysis labeled *concept descriptions*, which included a student's complete description of their current understanding of a TSC or a relationship between multiple TSCs as well as their description of how changes in their understanding manifested. Each description (n = 357) was coded to indicate the degree to which the described learning process involved contextualization. *Primary contextualization* required a description of learning the concept in conjunction with or directly attributed to a direct, personal experience of the concept. *Secondary contextualization* indicated a generalized or second-hand contextual association with the content. *No contextualization* coded descriptions in which students spoke of the concept in an abstract manner without any context.

Contextualization processes. Descriptive codes were added to each concept description to indicate aspects of the learning environment that students associated with their learning and the processes characterizing these interactions. Code definitions relevant to this paper are shown in Table 1. See Author (2012) for a description of the field observations used to validate the interview data through comparison to an outsider's perspective.

[Insert Table 1 about here]

Analysis. Descriptive and inferential statistics were used to analyze change in knowledge structures (PFnets), students' contextualization of their knowledge, and the relationship between them. These analyses were used in conjunction with the qualitative data described above for cross-case analysis using *pattern matching logic* (Yin, 2009). An attempt is made in the results to provide greater confidence in these inferential judgments and to mitigate the single coder limitation through description of the results in sufficient detail and the use of direct quotes of the informants.

Results

Student Learning

Overall, the students' structural knowledge showed a significant change in the quantitative similarity (*csim*) of their PFnets to the expert referents as determined by a Wilcoxon Matched Pairs test ($Z = 4.24$, $p < .001$). Some test results were not included due to low measures of coherence in the post-test PFnets, an indication that these students may have randomly selected responses (Dearholt & Schvaneveldt, 1990).

[Insert Table 2 about here]

Acton et al. (1994) found that the experts in their study of Pathfinder referents tended to show *csim equivalent*[1] values of .15 between experts. In this study, between-expert values averaged .18. In another study, college undergraduates showed a change of .04 *csim* equivalent (Goldsmith & Johnson, 1990) over a full semester. Though future work is needed in this area to further explore levels of mastery and learning, these existing studies provide some guidance on interpreting the results presented here. Based on these numbers, a Δ *csim* value of about .04 should be expected for a full semester course and this was also the change found in this study (mean = .046), despite the shorter duration and lower academic level of these high school immersion experiences. As indicated by the standard deviation (Table 2), there was a wide spectrum in the degree of change in students' knowledge structures during their immersion experiences. Surprisingly, 13% of students in Case 2 and 40% in Case 3 showed an overall

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[1] Acton et al (1994) and Goldsmith and Johnson (1990) used Pathfinder similarity values that were not corrected for chance as in this study. Similarity values corrected for chance tend to be about 50% less than uncorrected values. The values presented here are approximated for comparison to the data of this study.

negative change from pretest to posttest, suggesting that their ecology knowledge organization became less similar to the experts' over the course of their experience. Of this subgroup, all but two students started with pretest scores much higher than case averages, suggesting they began with conceptually sophisticated knowledge structures and reorganized their knowledge following these experiences into less expert ways of knowing. The role of contextualization in both the positive and negative results is discussed in the next section.

Contextualization

The interviewed students contextualized the TSCs in 68% of their concept descriptions, suggesting that it played a role in their learning and recall. When analyzed at the level of individual concept learning, one-way ANOVA demonstrated significant differences in the degrees of learning between contextualization levels (primary, secondary, none) following the immersion experiences, $F(2, 357)=6.9$, $p=.001$, $\eta^2=.061$ (a medium effect), but not before the experiences, $F(2, 357)=2.5$, $p=.080$. No statistically significant interaction was found between overall change in students' knowledge structures and the degree to which students contextualized their knowledge. These analyses suggest that while the students' overall knowledge structures were not predictably affected by a given student's tendency to contextualize her learning, the learning of individual concepts was noticeably improved when contextualized and primary contextualization was more influential than secondary contextualization. The absence of a statistically significant difference at the pretest supports the explanation that the contextualization impacted the learning rather than the possibility that previous knowledge positioned the students for greater contextualization.

Previous knowledge, however, was related to students who showed overall declines in their domain knowledge. Qualitative analysis of the PFnets and transcripts provides a possible explanation for these students. All of the students with high pretest scores but low posttest scores reflected an imbalance in their posttest PFnets when novel concepts were given undue importance. Although these students, like all others, showed positive changes with some individual concepts, they also seemed to ascribe importance to topics that were situationally relevant within their immersive learning experience but are less significant within the larger domain of ecology, thus rendering their posttest PFnets less like the experts', including the teachers. For example, students in Case 2 who dropped in overall *csim* values made more and higher relational value links to the TSC 'orographic precipitation' in the posttest than did the expert ecologists. Orographic precipitation played a central role in the ecosystem Case 2 students studied, though not in ecology writ large. It is likely that the same contextualization that led to learning gains for most students also fostered an undue importance for novel concepts and positioned those concepts as more significant than previously acquired knowledge that is more central to the domain. In short, some of the knowledge acquired through immersion may have been overcontextualized. For Case 3 students, the group that began with the greatest background knowledge, this was particularly problematic.

Processes of Primary Contextualization

Cross-case analysis of the student interviews identified two dominant themes describing the processes the students used to directly contextualize their learning. (1) They used context to generate a geo-temporally situated understanding of the TSCs and (2) They built understanding through direct, personal experience with the environment. Table 3 shows the associated codes and the degree to which each student relied on these identified contextualization processes in their learning of the TSCs. The percentages shown represent the starting point for analysis rather than quantitative measures of finite constructs. Although these themes suggest some common patterns across the cases, there are also important differences and variance in how individual students relied on combinations of these processes. For example, finding personally meaningful evidence for a TSC in the environment was the most consistently cited contextualization mechanism for students, but for some students (e.g. 215 and 224), there were other mechanisms that were much more important for their learning (Table 3).

[Insert Table 3 about here]

Table 4 lists examples of students' descriptions of their learning processes and the associated contextualization process codes that were assigned to the excerpts. These examples represent only 5% of the concept descriptions analyzed and represented in Table 3. They were selected for the efficiency of illustrating multiple themes and to highlight the interrelatedness and complexity of these learning processes.

[Insert Table 4 about here]

Geo-temporally situated contextualization. All but one student described some learning of the TSCs as situated within a specific place and/or time. When asked about a TSC, students would often discuss the place in which they learned it (22% of concept descriptions) and would also link the learning events together in a storyline of connected events (23%). These code frequencies and examples are represented in Tables 3 and 4, respectively. Their knowledge seemed to be contextualized within a narrative that included time and place, providing a memory stamp that helped students access and communicate the idea (Table 4: 101, 102, 105, 201, 204, 215, 301, 305, 401-1, 401-2, 408). It was a tool they used to help index their knowledge, if inadvertently, such that when asked to recall a TSC, the concept was recalled within a context that gave it meaning rather than abstraction. Robert (Student 215) described his experience with this learning and recall process:

> I would have understood it (TSC) if we hadn't been outside, but definitely not as well, and it definitely helped me remember and fully understand it… I don't go back to where we were in the woods but it helped me understand it really well. It cemented the ideas rather than drew me back to a place where I could… "Oh this is where I was, it must be that". It is hidden back in my mind somewhere.

Rather, the opposite seemed to be true; when prompted with a concept, the place or time came as a supporting association to the concept. These geo-temporal memory stamps were often associated with novel settings in the field and in such a way that one place was associated with one idea for a given student (Table 4: 101, 105, 201, 305, 401-2, 408). In some of these instances the teachers reported intentionally highlighting the TSC at those locations (Table 4: 102, 105, 108, 401-1) while for others the locations were not predictable or obvious illustrations of the TSC but became meaningful or memorable for individual students (Table 4: 101, 201, 305, 401-2, 408).

Moving through a landscape or moving from one place to another also seemed to support student learning by providing contextual contrast between places that emphasized different aspects of a concept and by linking geographic with temporal elements to form a narrative (Table 4: 101, 102, 305, 401-2, 408). In excerpt 101 (Table 4), Katie describes identifying a tree partially by juxtaposing her campus with another location. Had Katie learned about the trees exclusively at a single site, the important relationship between elevation and species distribution may not have been apparent to her. The environment on her school grounds became a baseline context with which to compare other environments.

Temporally situated contextualization was also associated with student learning beyond contrasting geographical places. Some students seemed to be situating their learning processes as well as their understanding within a narrative storyline of connected events (Table 4: 101, 102, 204, 215, 301, 305, 401-2, 408). Rachel (Table 4: 204) explains how the TSC *thermal conductivity* became a part of her daily narrative while immersed in the context, a thread that connected different events through a scientific concept. The narrative thread led to a learning trajectory of deeper understanding. This trajectory is also illustrated by excerpt 401-2 (Table 4) in which Jake describes his learning of *niche* as a trajectory from a general but disconnected knowledge to a contextualized understanding, connected through the narrative of his trip. In using these narrative links students commonly used the threads to connect what they had done in the classroom to a learning event in the field (Table 4: 102, 204, 207, 215, 301, 305, 401-2). As can be seen in these excerpts, students tended to connect a generalized class experience with a specific field experience. It is possible that the narrative quality of students' knowledge, as they described it, was an artifact of the interview format in that students were asked to recall their learning process. It would be natural for them to present this in a narrative form. However, 29% of students' TSC descriptions did not include any contextualization (Table 3), indicating that students were comfortable describing their knowledge in an abstract manner and therefore without any narrative component when they conceptualized it in that way.

The geo-temporally situated nature of the learning was important for most students (Table 3), who described it with up to 63% of TSCs, while three students did not identify the process in their learning much or at all (Table 3: students 240, 207, 404), and a few students relied heavily on either the geographical or the narrative linking process but not the other (Table 3: 104, 240). Student 240's learning did not seem to be situated in time or place at all (Table 3). Rather, she relied almost exclusively on seeing visual examples of the TSCs in the learning environment to contextualize her learning (Table 3). Each student took advantage of a unique combination of contextualization processes, suggesting that access to multiple processes was valuable to address the diversity of learners present.

Experiential contextualization. All students described pivotal information that they individually gained through observation of or embodied experience with the environments they were immersed in. The observational information became associated with an average 37% of students' concept descriptions and up to 75% for one student (Table 3). This was the most significant mechanism for students' contextualization as indicated by the frequency with which it was cited and the importance that students ascribed to it (Table 4: 101, 102, 105, 108, 201, 207, 215, 301, 305, 401-1, 403-1, 408). Students expressed through explanations of their learning processes that seeing an actual event, object, animal, etc., was more powerful than seeing a recorded image and it was more likely to help them develop a more complete conceptual understanding. In Vern's (Student 107) words, "going out and seeing what it would look like, it kind of implants a memory into your head a lot easier." Jared (Table 4: 305) ascribed the value of this personalized visual evidence to his ability to make connections between the abstract and the real. Students of Case 4 described having difficulty with visualizing the role of human impact on the Everglades early in the immersion experience but an ability to do so eventually through the collection of individualized, visual evidence. Jake, for example, came to connect *human impact* to the *niche* and *invasive species* TSCs, though it took a series of observations throughout the ecosystem to develop those connections (Table 4: 401-2). He had learned about these concepts in class but seeing them in context helped him make the connections.

Students trusted and developed a sense of ownership of their own observations, which in turn were held as more meaningful, accessible, or trustworthy than provided images, videos, or other evidence (Table 4: 102, 105, 207, 215, 301, 305, 403-1). Student 207 (Table 4), for example, describes his skepticism regarding the veracity of the teacher's lesson until the student's own observations in the field provided the support to believe the teacher's information. In some cases students seemed to be compartmentalizing the abstract knowledge they were learning as acceptable but somehow different than reality until they were able to contextualize it through observations during their immersion experiences (Table 4: 215, 401-2). Despite this trust in personal, contextualized observation, students did not seem to use their observations in opposition to the more abstract information they were receiving, as is often the case with folk knowledge (Lave, 1988). Rather, they seemed comfortable fitting their observations into the conceptual frameworks they learned from teachers or fitting explanations into their observations (Table 4: 102, 105, 207, 215, 301, 305, 408). It should be noted that the interview protocol focused only on concepts for which learning was demonstrated by the student and therefore may not have captured misconceptions that students could have developed as they constructed their understanding of the environment.

The difference between words or pictures and personally seeing a phenomenon was not entirely a function of the type or details of the information but the perspective that came along with it (Table 4: 101, 108, 301, 401-1, 401-2, 408). Students developed a sense of a bigger picture or systemic understanding through the detection of relationships between TSCs when observed directly in the contextualized environments, often observing how a given TSC played a role within an actual, complex ecosystem (101, 401-1, 401-2, 408). In all of the cases students stated or implied that seeing examples of the TSCs in context helped them to develop an ecosystem-level understanding and use that level of understanding to infer ecosystem relationships that were not specifically taught to them.

Four students described events when their personal discoveries provided the final piece of evidence that helped them fully understand a developing concept. The evidence led to a conceptual breakthrough for a student or a barrier to understanding was lifted. I labeled these occurrences *keystone events* as one event would complete and hold together a concept much like a keystone in a stone arch holds the structure in place. In one such event (Table 4: 408) Mei was primed with the information from the required reading about mangroves along with the teacher's explanation but her individually observed evidence in context provided the pivotal information to understand a phenomenon and the relationship between concepts. As in this example and as with their geo-temporal understanding, the observations that students described were personalized such that they were not likely to be obvious "teachable moments" to the educators and required a synergy of timing and placement. Time in the field seemed to present situations in which students were thinking about a TSC at the correct place and time, though those times and places were different for each student.

In addition to these visual experiences, all students in Cases 1, 2, and 4 also described learning concepts in a personally embodied way such that they physically experienced a TSC in an authentic context (Table 3). These embodied experiences, associated with 27% of the TSCs students described, represented more than lessons with kinesthetic elements. Rather, they were personal experiences in which the student experienced the TSC in a corporeal way (Table 4: 108, 204, 224, 403-2). The students in Case 3, the crane migration class, did not report any embodied experiences, accurately reflecting the more passive, observational experience they had as compared to the other cases.

The physical embodiment of the TSC *thermal conductivity* was reported by students in Cases 1 and 2. Kelly (Case 1) described the embodiment of the concept simply as "you are one of the animals" to explain how she came to understand how to minimize thermal conductivity while out in the cold by mimicking evolutionary adaptations. Tara (Case 2) explained how a simple, embodied activity helped her to grasp the idea of applied thermal conductivity (Table 4: 224). Tara surely had other experiences of being cold but the contextualization of the lesson directly related to the concept being taught helped her solidify her understanding. The teacher provided much of the information but physically experiencing the concept helped students put everything together. The immersion aspect of these experiences seemed to be particularly important as it provided opportunities for the application of lessons learned not just when students were participating in facilitated activities but at any point (Table 4:101, 204).

Experiencing tidal changes was cited by half of the students in Case 4 as an example of physical interaction that helped them grasp the enormity of the phenomenon. While paddling the canoes through tidal sloughs the students were at times paddling with the tidal current and at times against it, resulting in dramatic differences in the progress they made. These students did not indicate that the physical experience led to a complete understanding of the forces behind tides but it did give them the perspective to understand the power of the forces involved (Table 4: 403-2). It also helped them understand that tidal changes were regular but were not simply water moving up and down. In a later, formal lesson on the gravitational causes of tides, students applied their experience to the new information. Eventually students were making their daily travel plans by applying their understanding of tidal currents in relation to channel width and timing (Table 4: 403-2).

Discussion

Helping students contextualize their science learning is critical if they are to move beyond inert knowledge to an integrated, applicable understanding that will serve them beyond the immediate classroom walls. The experiences of the students in this study suggest that learning science within an authentic context can increase conceptual understanding. Contextualization contributes to that learning. Further, the level of contextualization that students utilized directly impacted the degree of learning achieved. This was influenced by identifiable processes of interaction with the learning environment. Primary contextualization did much more than help students see how a concept could be applied in the real world, it helped the students understand the concepts and develop knowledge structures that were closer to the way experts organized their knowledge. These findings add to a small body of evidence that immersion or field experiences can be an effective pedagogical tool for developing science content knowledge (e.g. Ballantyne, Fien, & Packer, 2001; Orion & Hofstein, 1994).

Contextualization helped the students to see how the various concepts were interrelated in the real world and gave the students a personalized, first-hand perspective that they valued. Their learning became situated within a referential narrative of time and place. For students there was something categorically different about direct experience with the physical environment that allowed them to understand the concepts in ways that they could not when the information was entirely abstract. Contextualized experience helped them develop deeper understanding that positioned them to better comprehend the abstract idea, and see how it manifested in actual contexts. This *"you had to be there" effect* was described as important by most of the students in the study as they listed the many ways in which they felt that direct experience provided some level of information that was different than what they could access through other means. This effect might have something to do with trusting one's own senses more than secondary information, even if implicitly, and the ability to judge scale and complexity in a way that cannot be done well through description or recorded media.

By situating the study in a real context, the enacted curriculum rather than the intended curriculum was examined from the perspective of the learner, the nucleus of contextualization. Within this frame students did learn through both primary and secondary contextualization as well as without any contextualization. As students had access to all of these learning opportunities over the course of their immersion experiences and variably keyed in to each, it seems likely that they were all important. Although conceptual learning was greater when associated with primary contextualization, it would be premature to assume that learning with secondary contextualization or without contextualization are consistently less effective. It seems more likely that there are also differences between individual students, differences in developmental levels, and differences in the content itself that would render a given contextualization level more or less effective in a given scenario. While this deserves further study, the data presented here suggest that there is value in making multiple levels of contextualization available to students, particularly the rarely utilized primary contextualization experiences.

The lack of a consistent pattern in how each student proportionally used the identified contextualization mechanisms, suggests that they are variably important within a group of students. Most students contextualized through multiple mechanisms but for a few, removing opportunities for embodied learning or unique geographical situating may have resulted in students who did not contextualize as readily or at least not through their preferred mechanism. Use of multiple contextualization processes may also reflect the situated and distributed nature of knowledge and learning (Brown et al., 1989). Students' descriptions of their learning indicated that understanding was inextricably tied to multiple elements of the environment. Their knowledge was not simply an abstract notion but a collection of interrelated ideas that were completely described only when referenced against times and places or visual and physical experiences. Students' knowledge was distributed across multiple aspects of the real environment through multiple mechanisms. The situated nature of the knowledge is what gave it meaning and utility. Situated learning theory has been difficult to apply in schools and had its genesis in other educational systems (e.g. Lave & Wenger, 1991; Lave, 1988). This study represents a test of and a support of the theory in schools, albeit when the classroom is extended into the field. This suggests that the environment may contribute more than is traditionally credited.

The generation of relevance has been shown to be a common outcome of contextualized learning, particularly for curricula that utilize secondary contextualization (King & Ritchie, 2012). As with all of the primary contextualization processes identified here, it is difficult to distinguish experiences that generate relevance for a given student and those that do not. It could be argued that observing real world contexts automatically does so. For this reason, relevance did not emerge as a useful distinction in these analyses. However, relevance may have played a significant role for the students whose knowledge structures became less expert. Those students tended to score highly on the pretest but then overemphasize the importance of concepts highlighted during their in situ experiences on the posttest. They saw these novel concepts as more relevant than would an expert considering the full domain of ecological knowledge. The outsized sense of relevance caused the students to overcontextualize the information. It is unclear if this phenomenon was a function of the test timing or if this effect would attenuate over time. This effect may account for the mixed results of contextualized learning in the education research literature (Bennett & Lubben, 2006; Gerber et al., 2001; Son & Goldstone, 2009).

The data suggest a clear relationship between contextualization and development of science knowledge but the spectrum of required conditions for this remains unclear. All of these cases represent deep immersion into natural, outdoor settings with experienced teachers and students in small classes who were familiar with and had chosen experiential learning opportunities. The findings presented here represent themes that were robust across the cases despite some important differences in SES and grade level but a much wider sample is warranted before broad conclusions can be made. In all of the cases there was a very clear connection between the ecology being taught and the natural environments where the learning occurred. It is unclear how closely aligned the content and context need to be to achieve the results presented here. Another limitation of the study is that it relied largely on self-report of student learning experiences. Although the assessment-driven interviews helped students to recall learning events, it is unrealistic to assume that their meta-cognitive processes would recognize all aspects of learning. I can be more confident in reporting what overtly contributed to learning in these cases than in ruling out elements that did not or that were not apparent to the students. The reliance on sticking close to students' own accounts of their experiences was used to increase the trustworthiness of the account but it also adds this inherent limitation.

Implications

As the science education community works toward incorporating greater relevance and applicability into science curricula and instruction (Braund & Reiss, 2006; Bulte et al., 2006; Gilbert, 2006) immersion experiences in authentic, contextualized learning environments present one avenue for doing so. Providing students with strategic opportunities to learn science content in contexts where that content can also be applied and observed may help students to develop more robust and nuanced understanding of the intended science content. It is clear that the extended immersion in context provided students with experiences in which the content could be contextualized through individually meaningful synergies of time, place, and experience that would not be as available in more limited immersion. However, this was not enough. Students also needed content to contextualize; they rarely discovered it entirely on their own.

The students who began the study with high pretest scores and overcontextualized their understanding of ecology indicate the need for careful facilitation and formative assessment by teachers. More support might be required to help students understand the relative value of novel information. This phenomenon needs further study as it is unclear if the effect attenuates over time or if the contextualized aspects of the students' ecological knowledge is indefinitely held as more important than appropriate. This phenomenon, once better understood, might also suggest that the timing of the contextualization experience is important. Students who experienced these contextualized learning environments as more novice ecologists developed more positive learning trajectories. The use of these experiences as capstones rather than introductions might need to be rethought.

In discussions of primary contextualization there is a logical call for simplification so that the process might be brought into the classroom (e.g. Son & Goldstone, 2009) but we must ask what is lost in doing so. Students struggle with applying the clean, "compliant knowledge" (McCaslin & Good, 1992) of the classroom with the unruly and messy applications of the real world (Choi & Hannafin, 1995). Brown (1989) asserts: "In the creation of classroom tasks, apparently peripheral features of authentic tasks- like the extra-linguistic supports involved in the interpretation of communication- are often dismissed as 'noise' from which salient features can be abstracted for the purpose of teaching" (p.34). The analyses I present here support the notion that the noise has value for learning as well, value that is not easily replaced through the abstract.

Secondary contextualization is often used to simplify connections to the real world and while this approach has value, these data suggest that it is not an equivalent of primary contextualization. We need to better understand this distinction along with the advantages and limitations of each. Further research should help elucidate this distinction and thereby identify what, if any, aspects of primary contextualization can be imported into the classroom.

It may be possible to use these findings to enhance contextualized learning in classrooms, free-choice, and virtual learning environments even if this is not through primary contextualization. As science educators work toward contextualizing their teaching, the lessons of this study suggest that authentic contexts in which students can collect context cues at times, places, and perspectives unanticipated by the educators can enhance levels of knowledge gained through other means. Although the physical environment may be underutilized or avoided in most classrooms, it seems conceivable to create curricula that use the built environment as a context or to create a laboratory context within a teaching lab that more closely approximates a real world setting. The latter would be strengthened through student-scientist partnerships to enhance the authenticity. Internships, schoolyard ecosystem studies, and service learning opportunities all hold potential for authentic contextualization and deserve a critical look from a contextualization perspective. We are currently seeing a surge in virtual world and gaming approaches to science education. The patterns that emerged from this study could be tested and potentially used to enhance those virtual environments. For example, providing many different ‘geographical’ spaces, and opportunities for students to make their own discoveries and observations could potentially enhance the contextualization of their content knowledge. The narrative thread is already a part of these approaches and it seems worthwhile to intentionally design the narrative to facilitate distributed cognition. Learners would value personal discovery of complex relationships or non-obvious examples of concepts. Overall, these data suggest that such systems need to be open to multiple pathways for learners to contextualize the content.

Based on the experiences of the students across these four cases, science immersion experiences do have the potential to add learning value when used in conjunction with more traditional pedagogies. Adding context, particularly primary contextualization, to science instruction does more than increasing engagement or relevance, it can fundamentally change student understanding.

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Table 1

Descriptive codes indicating contextualization processes.

Category	Code	Definition
Geographic/ Temporal	Connection to specific place	Refers to specific, geographic place as associated with learning
	Linking across events	Ascribes learning to multiple, connected events or conceptually connects multiple events
Experiential	Visual evidence of concept	Saw an example of a TSC within the environment
	Visual of process in action	Saw a process associated with TSC take place within the environment
	Illustrated relationships	Saw an example of the relationship between TSCs within the environment
	Personal discovery	Learning related to TSC through un-facilitated observation or realization
	Embodied experience	Refers to physical interaction with environment associated with learning

[*] TSC = Targeted Science Concept

Table 2

Wilcoxon matched pairs test: Results of pre to post assessment csim values

n	min pre/post	max pre/post	Median[2] pre/post	SD pre/post	*W*	*Z*	*p*
55	-.01/.02	.36/.31	.10/.15	.07/.06	1012	4.24	***< .001***

[1] *csim* = similarity to the referent, corrected for chance.

[2] Wilcoxon test uses assigned ranks and median rather than mean.

Table 3.

Contextualization code frequencies by percentage of each student's concept descriptions

		Geo-temporally situated contextualization		Experiential contextualization			
	Student	Connection to specific place	Narrative Linking	Personalized* Evidence	Embodied experiences	Personal discovery	Not contextualized
Case 1- Winter Ecology	101	18	18	55	36	18	33
	102	33	8	50	50	0	20
	103	0	30	40	20	0	44
	104	8	0	15	23	0	66
	105	0	11	67	11	11	13
	106	33	27	53	33	7	22
	107	25	50	75	50	0	0
	108	30	10	50	40	0	13
	Mean	**18**	**19**	**51**	**33**	**4**	**29**
Case 2- Winter Environmental Science	201	20	50	60	20	20	0
	204	0	31	8	15	0	42
	207	6	0	50	22	6	40
	211	8	31	31	8	0	25
	215	17	33	8	25	0	55
	224	0	8	8	25	8	63
	230	29	7	36	7	0	25
	240	0	0	25	6	6	60
	Mean	**10**	**20**	**28**	**16**	**5**	**39**
Case 3- Sandhill Crane Trip	301	13	27	13	0	7	29
	302	7	29	29	0	0	46
	304	36	18	18	0	9	43
	305	25	63	63	0	13	13
	309	36	36	27	0	9	60
	310	31	31	38	0	0	20
	Mean	**25**	**34**	**31**	**0**	**6**	**36**
Case 4- Everglades Immersion	401	40	40	60	40	33	9
	402	17	8	42	58	8	0
	403	44	33	33	44	22	0
	404	0	8	8	8	0	44
	405	50	8	33	33	8	36
	406	36	9	45	18	0	0
	407	40	0	30	70	0	0
	408	36	36	45	27	9	0

	Mean	**33**	**18**	**37**	**37**	**10**	**14**
	Overall Mean	**22**	**23**	**37**	**22**	**6**	**29**

As multiple codes were applied to concept descriptions, total percentages do not = 100.
*Includes the codes for *visual evidence of concept, visual of process in action,* and *illustrated relationships*.

Table 4

Student interview excerpts illustrating contextualization processes

Student Excerpt	Contextualization Processes	Quote
101 Katie	Geographic[1] Narrative Link[2] Pers.Evidence[3]	I was skiing and I was just thinking to myself and I was looking at the trees because we were trying to figure out which tree was which and I was thinking "well it can't be this tree because this tree wouldn't survive in this environment." Because we were high in the park (elevation) and there is- I don't remember what tree it was but that tree is at (school) so it's on campus there but I was thinking it's not going to be able to survive that high in the park because its' branches won't be able to hold up the snow.
102 Daniel	Geographic Narrative Link Pers.Evidence	That's kind of what I thought was so cool about it. We would hear about an example of an adaption of a tree, we would have a reading on it and then we would go up to the park and actually see it doing it. And it's like "whoa, I know what that is. We learned about that". I just think that's one of the coolest parts of the class is actually going to watch it instead of just hearing about it which is boring.
105 Ashley	Geographic Pers.Evidence	(Teacher) gave a pretty good explanation about black and white (mangroves). And then the day we stopped on Turtle Key, we actually got to see those really close, the black and white mangroves. So that kind of imprinted it in my mind.
108 Joseph	Pers.Evidence Embodied[4]	We dug a pit of snow and touched it all the way to the ground. That was pretty deep and the ground was a lot warmer. And I guess that's how we realized that animals… some animals can adapt by being under the ground because it traps in the earth's heat, which is something I never knew.
201 Nick	Geographic Pers.Evidence Pers.Disc.[5]	I thought it was interesting to see when we went out on our tracking lab, the way that animals did interact with man-made elements. There's snowmobile trails and Nordic skiing trails just out there and there would be birds that walked across the groomed trail. There was a snowshoe hare that had gone on the snowmobile trail. I thought it was interesting that an animal might make use of human elements.
204 Rachel	Narrative Link Embodied	I definitely started thinking about the concepts that we learned in class a lot outside of class. Just living here I guess, I'm not used to this climate and this environment. I think it's really cool, but we learned a lot about taking care of yourself here properly and so I think it really registered learning about thermal conductivity and then thinking about the layers that I had on. We had ski week and I had to think a lot about if I was going to wear cotton then I would get wet and if it was a cloudy day how I should protect myself that way. I think what I learned in class, a lot applied to what I was doing every single day here.
207 Mitch	Pers.Evidence	The idea of when snow crystals facet they're actual small pyramids- I thought it was more of an abstract idea where it's not really like that but when we looked at the snow layers we had some really huge clear facets and it was actually really amazing to see. In class when we talked about it, it was drawn on the board. I guess I didn't really.... I thought they were more solid and instead when we looked at them they were hollow in the middle, which was kind of a cool thing... like a little cup.
215 Robert	Narrative Link Pers.Evidence	So we sort of learned the theoretical aspect of it in class: "and this happened because of this", "how the Sun affects the snow". Then by going outside and really experiencing it, it just proved to all of us that this really does happen and here's the proof right in front of us.

Table 4 Continued

Student Excerpt	Contextualization Processes	Quote
224 Tara	Embodied	One time we took one shoe off and that was to talk about insulation… we went out onto the porch with one shoe on. (Teacher) doesn't mind the cold, which is weird, but everyone else does. So then you're like, "so now your foot is freezing and the other one's not, why?" So it's different than "*if* you went outside your foot *would* be cold". Things can make more sense if you're experiencing them and you can talk about them more accurately without hypothesizing about what it would be like. You *know* exactly what it's actually like.
301 Heather	Narrative Link Pers.Evidence	When I first learned they (sandhill cranes) mate for life, it was kind of cool. But then once I went and I could see all the cranes… it was mostly at sunset… just all the calls between the cranes, it just all tied together like a big group and if they didn't have their mates then it wouldn't be like that and it just kind of impacted me how meaningful, how really important their mates are.
305 Jared	Geographic Narrative Link Pers.Evidence	The first night we were on the trip, we were in the blind and we were watching the cranes and the sun was setting and all those facts that Jennifer (teacher) had told us were starting to just come together and make sense. And then I was able to visualize, put a face to all of those facts that she gave us. So that was kind of cool. So the lesson… I don't think the lesson would have been important if I hadn't ended up seeing that. And I don't think the blind experience would have been quite as helpful if I hadn't learned all that. So those kind of come together and I think learning and then visualizing was good.
401-1 Jake	Geographic Pers.Evidence	That transitional phase between the sawgrass and the forest- that was one of the biggest moments because we kind of saw it up close. You saw the woods and then the prairie and then we kind of dove into the woods a little bit and there were some branches and then we kind of just went right to the spot where it changed and there were a couple of like inches of change going up and then it just kind of transitioned to the woods after that.
401-2 Jake	Narrative Link	We are introducing invasive species and making some species go extinct so it's really connected. Niche and invasive species I connected because invasive species are taking over niches and driving other organisms out of their specific niche. I never really had known all of how these things have their own niche and how they kind of affected everything and have their own place in it… Little by little during the trip I think I just understood it more and more because I think when I did niche in school it was kind of a basic understanding of it.
403-1 Thomas	Pers.Evidence	What gave me that connection was seeing it (an epiphyte) attached to those plants in person and seeing its connection to the environment, like seeing the strap fern or the vanilla orchid, those that were attached to the actual trees themselves rather than just having this concept.
403-2 Thomas	Embodied	It's very important to consider tides when traveling on the water because paddling against high tide is extremely difficult but having the high tide on your side behind you is very, very beneficial. So if you are going against the tide you want to make sure that you are going during low tide and if you are going with the tide you want to make sure that it's during high tide.
408 Mei	Geographic Narrative Link Pers.Evidence Pers. Disc.	I read my research, I realized tides are related to pneumatophores, but not until when (teacher) explained this and really pointed that out for us. That visual… really The day when we were at the Pavilion Keys, we had the day off, I was laying right next to that red mangrove...actually a white mangrove… I was writing in my journal and I was watching the tide, the high tides just coming in on my right and I saw the high tides like slowly covered the pneumatophores. I think that was the moment of like, "yeah, this is how it works. It just all makes sense suddenly".

[1]Included a description of a specific geographic place; [2]links the concept through multiple events; [3]describes visual evidence of concept, process, or relationship; [4]describes physical experience of the concept; [5]indicates a sense of personal, non-facilitated discovery.

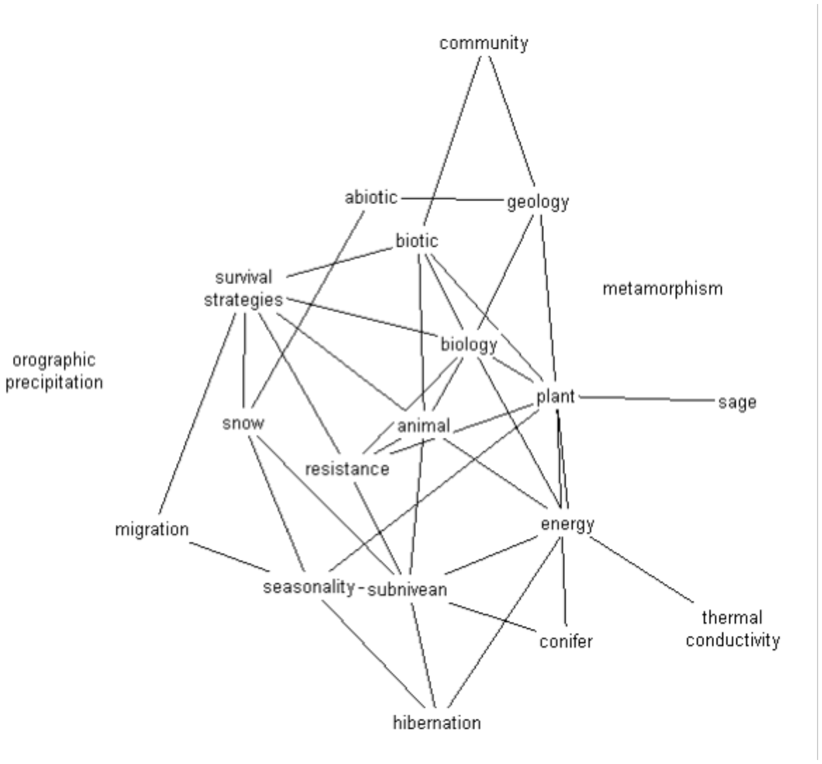

Figure 1. PFnet example from Case 2