Journal of the Scholarship of Teaching and Learning, Vol. 24, No. 1, March 2024, pp.58-75.
doi: 10.14434/josotl.v24i1.35170

Deconstructing a Geology Field Trip to Reconstruct Around a Pedagogical Framework: A Case Study on the Integration of Cognitive Learning Theories and Learning Progressions

Erin P. Argyilan
Indiana University Northwest

Kristin T. Huysken
Indiana University Northwest

Robert Votaw
Indiana University Northwest

Abstract: Field-based education is an integral component of undergraduate geoscience curricula and provides educational and social benefits associated with enhanced learning. But field excursions can too often end up as simple show-and-tell events and fall short of implementing effective teaching practices and achieving desired student learning gains. Moreover, logistical and economic pressures tend to discourage or create obstacles for the inclusion of field-based activities in undergraduate geoscience programs, especially in commuter-based colleges and universities. This case study shares how a one-day field trip offered at a commuter-based undergraduate campus of Indiana University was deconstructed to identify content-specific learning outcomes, and then reconstructed to a unit-based learning progression. The site-specific geologic content focused on describing and correlating outcrops of Paleozoic sedimentary strata in the Starved Rock area of Illinois. Shifting from a single-day field trip to a multi-session learning progression focused on instructional scaffolding and emphasized formative assessments that integrate cognitive learning theories including retrieval practice, elaboration, spaced practice and dual coding. Common practices of field geologists such as creating sketches of outcrops (dual-coding) were purposefully integrated as meaningful activities with opportunities for peer mentoring and reflection. Restructuring to a three-week unit included pre- and post-trip assessments to enable instructors to identify and address knowledge gaps and facilitate self-driven learning opportunities for students.

Keywords: Learning progression, field-based education, undergraduate, scaffolding, cognitive learning

Introduction

The National Association of State Boards of Geology (ASBOG) reviewed geoscience curricula from 62 universities and reported that 79% of those programs required a course in Field Methods or Field Geology to achieve a BA/BS degree in geology (AGI, 2019). These results underscore the fact that courses in geologic field methods are considered integral components of undergraduate geoscience curricula. In their research on Sense of Place (SOP), Shepphard et al. (2010) effectively notes that field-based pedagogy has long been recognized in the literature as effective, transformative, hands-on active learning that fosters comprehension and retention of content (e.g., McKenzie et al., 1986). Field courses and experiences enhance learning of fundamental geologic concepts, increase student interest and motivation, and better prepare students for professional careers and/or graduate studies (Huysken et al., 2016; Kelso and Brown 2009, Elkins and Elkins, 2007). Additionally, students may reap the social benefits of field-based work that can include enhanced communication, self-reliance and motivation, and increased confidence (McConnell, 1979, McNamara and Fowler, 1975), skills

that Boyle et al. (2007) argued are transferable beyond a single course. Moreover, field-based education has the potential to engage students with recognizable disparities in their individual learning styles: sensory/intuitive perception of information, visual/verbal sensory of information, preference for inductive/deductive organization of information, tendency to actively/reflectively process information, and progress toward understanding through sequential/global steps (Felder, 1993).

The design and implementation of field courses and field experiences inevitably vary widely in undergraduate curricula depending on factors that include faculty/student time availability or allocation, functional and financial resources, geographic setting of the institution, role of distance education, and institution type (e.g., 2-yr versus 4-yr, residential versus commuter) (Thomas and Roberts, 2009). Huysken et al. (2016) argued that while there are many ways to incorporate field geology education into undergraduate curricula (e.g., field trips, individual field-based projects, complete field-based courses), too often field work can end up as simple "show-and-tell" experiences; and it becomes difficult for educators and students to fully assess and appreciate student learning gains beyond basic increased student interest or enthusiasm. Weinstein et al., (2018) suggests that instructors in evidence-based disciplines overwhelmingly spend their time on learning content and practicing skills, leaving them unable to focus on best strategies in teaching practice and the science of learning. Meanwhile, from the perspective of administrators, field-based education might be considered inefficient in terms of scheduling challenges (Thomas and Roberts, 2009), logistical expense, and low student–instructor ratio (Salter, 2001; Sheppard et al., 2010).

As undergraduate institutions and programs intensify their focus on assessment, high impact practices, and student retention, it becomes essential for geoscience educators to purposefully integrate cognitive learning theories into the content and assessment of field-based courses and to fold high impact teaching practices into course design. The purpose of this contribution is to demonstrate how a one-day undergraduate field trip was deconstructed to identify critical content components and redesigned into a three week learning progression to deliberately draw ties between best teaching practices, cognitive learning theories, and assessment tools. Instruction adopts the premise of the TILT model (Transparency in Learning and Teaching) by Winkelmes (2013) that builds on research in metacognition which demonstrates students learn more and retain that learning longer when they have an awareness of how they are learning (e.g., Cohen, 1980; Dunlosky and Metcalfe, 2009; Nelson and Dunlosky, 1991). As the unit progresses, students engage in low-stakes formative assessments specifically designed to reinforce essential skills for field geologists that construct components of a larger summative report on the geologic history of a study site in the Starved Rock State Park in north-central Illinois.

The one-day field experience visits multiple outcrops of Paleozoic sedimentary rocks in the area of Starved Rock State Park near Utica, Illinois and asks students to construct and assemble site-specific stratigraphic columns into a cross section and interpret the geologic history of the area (Huysken et al, 2016). Today the Starved Rock area lies in the central craton of the North American continent within the Illinois Basin. Outbursts of glacial meltwater from moraine-dammed lakes during the Quaternary deepened the Illinois River valley through tills, exposing Paleozoic bedrock along bluffs and in tributaries. The Paleozoic stratigraphy records successive marine transgressions and regressions of an epeiric sea across a shallow marine platform. A major unconformity exists between Ordovician and Pennsylvanian strata. The largest and most prominent structural feature in the Starved Rock area is the Peru Monocline, an asymmetric north–south-trending antiformal feature. Deformation is most pronounced in Ordovician-aged rocks that make up the western limb of the monocline, striking approximately 34 degrees and dipping to the north-northwest, and can be observed in two outcrops included in the field trip; Matthiessen State Park and along the I&M Canal.

Fieldwork focuses on rock and outcrop descriptions, generating site-specific stratigraphic columns, constructing a local cross section, and interpreting the sequence of events and geologic history of the area. Instructors unfamiliar with the area (e.g., traveling from outside the Midwestern states) can readily reproduce the learning objectives as these are broadly applicable to undergraduate geoscience curricula and the pedagogical approach could be easily adapted to local field projects elsewhere. The unit learning objectives are presented as:

"By the end of this unit students should be able to:
1. identify and describe sedimentary rocks with appropriate terminology and methods in hand sample and at outcrop scale
2. apply the principles of relative and absolute dating to relate individual rock units to a published stratigraphic column and identify unconformities in the rock record
3. locate field sites on geologic maps (topographic and surficial geology) and interpret landscape features
4. correlate individual rock units across multiple outcrops, identify contacts and/or unconformities, and interpret underlying geologic structures
5. reconstruct the geologic history of the study area by interpreting transitions in depositional environments and unconformities in the rock record"

Institutional and Curriculum Background

Indiana University (IU) Northwest is a public non-residential regional campus of the IU system founded in 1948 and serving a seven-county region in northwest Indiana and bordering Illinois. Enrollment in the 2019-2020 academic year was ~3,500 (Indiana University Office of Institutional Effectiveness and Research). The Department of Geosciences is within the College of Arts and Sciences which reported a 2019-2020 student population that is a majority female (~68%), with African-American (~15%) and Hispanic (~25%) populations reflective of the communities it serves (Indiana University Office of Institutional Effectiveness and Research). In 2020, the institution was designated as a Hispanic Serving Institution (HSI) by the U.S. Department of Education, reflecting demographic shifts in the region. The Department of Geosciences consists of three full-time tenured professors holding Ph.D.s and typically maintains between 20 and 30 full-time undergraduate majors. The department currently provides B.A./B.S. degrees in Geology and an Interdepartmental Major in Environmental Science. Graduates typically pursue graduate school, gain employment in geology, environmentally related, or other STEM fields, or enter earth science education. While a semester-long field and laboratory methods course is required for all majors, undergraduate students pursuing a B.S. in Geology are further required to attend a field camp through an accredited college or university.

Laboratory and Field Methods in Geosciences (GEOL 317) is a 4-credit lecture/laboratory course available to students that have completed an introductory course in geosciences (equivalent courses at other institutions may include Earth Science, Geology, Physical Geography or Environmental Science), and also serves to partially fulfill the College's Intensive Writing requirement. The course is offered on a two-year rotation so undergraduate geoscience majors enroll when it fits their schedule, producing a class that can be populated by sophomores to seniors with a wide range of content knowledge, field/laboratory experience, confidence, and motivation. Occasionally an enrolled geoscience major will have already completed their required field camp experience. More often, the course attracts non-majors and potential majors enticed by the idea of field trips. Initially the field methods course was scheduled as an extended face-to-face session (minimum of four hours) once a week for a 16-week fall semester. Each week was initially structured

as a self-contained unit, focused on creating unique hands-on experiences that exposed students to wide range of geologic topics that contained field components, rather than on connecting learning from across individual geoscience courses in the undergraduate curriculum.

The Rationale for Course Redesign

The Starved Rock correlation project consisted of a single day in the field. Students were asked to complete formative assessment tasks in the field that included outcrop descriptions with detailed field notes, construction of individual site-specific stratigraphic columns with appropriate geologic symbols and labels, and a regional cross section correlating Paleozoic rock units, and highlighting unconformities (Figure 1). Stratigraphic columns for outcrops or quarries not accessible to students were provided as a guide. The summative assessment required students to generate a time series drawing that illustrated the series of geologic events that produced the stratigraphy and structures observed in the field. Students should arrive at specific conclusions, denoting evidence for multiple Paleozoic marine transgressions and regressions, the timing of regional tectonic activity, and geologic evidence for an underlying regional bedrock structure minimally identified as an anticline or monocline (Figure 2). Instruction for the summative assignment relied on an instructor-led detailed group discussion.

While students were consistently enthusiastic about the trip and reported increased confidence and enthusiasm for fieldwork, the one-day field trip and assessments failed to adequately promote self-driven learning, provided little opportunity to evaluate individual student learning gains, and lacked a clear alignment between content and course learning objectives. In general, advanced students moved quickly and confidently in the field and demonstrated higher order thinking skills in the context of Bloom's Taxonomy of Cognitive Development (Bloom, 1956). They demonstrated competency by (1) describing and identifying rock units in the field and relating them to the published stratigraphic column, (2) correlating rock units across individual outcrops, (3) recognizing unconformities versus contacts, (4) describing connections between rock type and depositional environments, (5) interpreting an underlying monocline structure, (6) identifying the timing of regional folding between Ordovician and Pennsylvanian strata, and (7) generally describing how transitions in sedimentary rock types would represent Paleozoic transgressional/regressional events in a shallow marine environment. Less experienced students demonstrated competency at lower levels of Bloom's Taxonomy. Collectively students consistently reported feeling rushed for time and uncertain of how to connect information across individual outcrops. While students generally arrived at a basic understanding of the series of geologic events during the Paleozoic, they struggled to connect depositional environments to a broader interpretation of geologic history and paleogeography. Moreover, there was a missed opportunity to connect the modern landscape to exposures of Paleozoic stratigraphy and to ask the broader question of "Why are these Paleozoic sedimentary rocks exposed as they are today?"

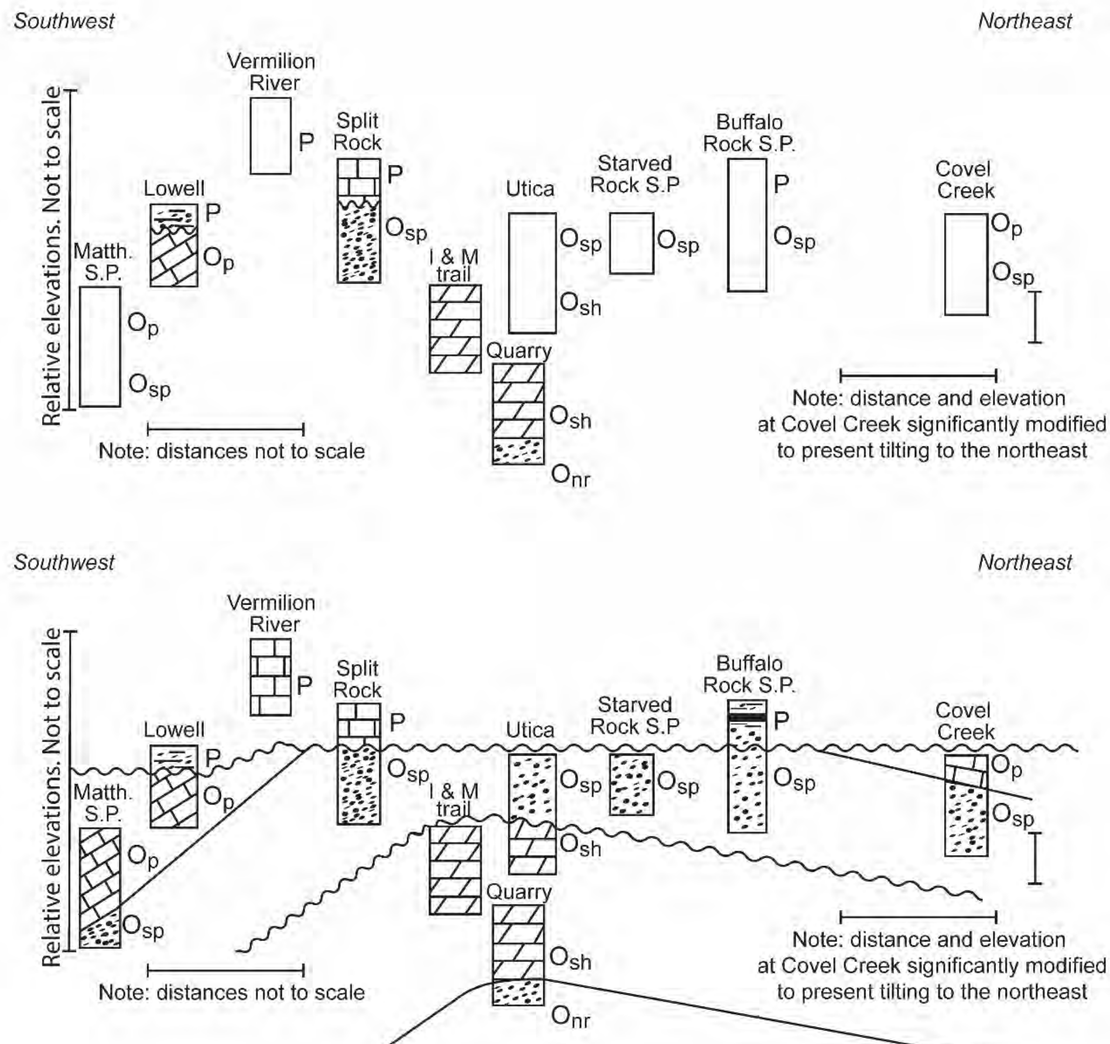

Figure 1. Fence diagram illustrating stratigraphy at individual outcrops in the Starved Rock study area. Student handout with information provided for inaccessible outcrops (A) and instructor guide illustrating rock units, contacts and unconformities, strata symbology and labels (B).

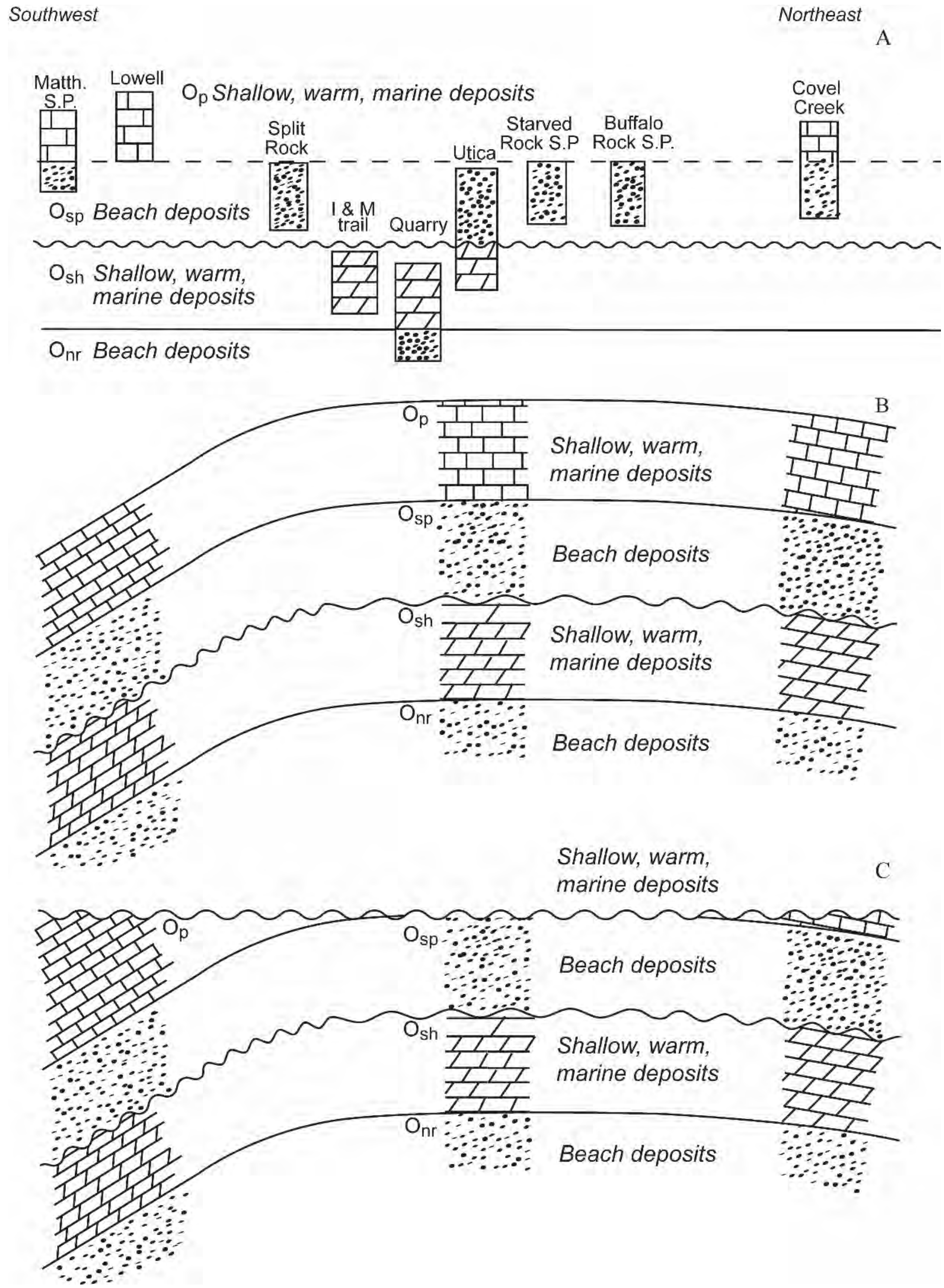

Figure 2. Geologist's sketch of the series of geologic events and changes in depositional environment that led to the stratigraphy and bedrock structure observed in outcrops of the Starved Rock area. Ordovician transgressional/regressional sequences (A), folding in response to basin development (B), and erosion of Ordovician strata prior to deposition of Pennsylvanian sedimentary strata (C).

Course Deconstruction to Critical Component Concepts

The one-day scheduling model provided the long blocks of time necessary for hands-on field trips and the field-based problem inherently provides a complex real-world problem, a tenant of critical thinking. But the scheduling failed to provide time for instructional strategies that are recognized to develop critical thinking including guided discussions, self-reflection on formative tasks, instructor/peer feedback, and an impactful summative assessment that measures individual student learning gains. In 2019 the schedule was revised to a three week unit that meets twice a week for a short face-to-face session (maximum of one hour) early in the week and an extended session late in the week (minimum of three hours) to accommodate field/laboratory work. This scheduling model provides time for pre-fieldwork preparation, post-fieldwork reflection, and data analyses. Core geologic concepts were identified and partitioned into a three-week unit focused on (1) building foundational geologic knowledge, (2) field preparation and experiences, (3) data synthesis including analysis, interpretation, and communication (Table 1).

Integrated Cognitive Learning Theories

The modified course schedule creates time and opportunity to build formative assessments that intentionally integrate cognitive learning theories. Weinstein et al. (2018) suggests that instructors and researchers outside the field of educational psychology often struggle to integrate the science of learning into evidence-based teaching. A purpose of this contribution is to demonstrate that field-based instruction in the geosciences inherently incorporates or can be easily adapted to integrate multiple cognitive learning theories, although it may be unknowingly and unintentional. While geologists have long accepted the importance of annotated "geologist's sketches" in our field books, rarely is it acknowledged that this practice is a demonstration of dual coding cognitive learning theory (Paivo, 1971, 1986, 1990; Clark & Paivio, 1991). Consequently, with intentional redesign of field course instruction and assessments, instructors and students can reap the benefits that effective cognitive learning strategies can provide.

Throughout the learning progression outlined in Table 1, each topic contains a paired assessment that integrates cognitive learning theories recognized to promote effective teaching and enhance student learning (Pashler et al., 2007; Weinstein et al., 2018), specifically retrieval practice, elaboration, spaced practice and dual coding. Retrieval practice is the cognitive learning strategy of accessing learned information (e.g., Collins and Quillian, 1969, Thomson and Tulving, 1970; Salatas and Flavell, 1976, Shrunk 2016, Weinstein et al., 2018). While testing and quizzing are one form of retrieval practice, asking students to apply learned information to higher-order questions is another. Elaboration theory requires students to connect new information to preexisting knowledge (e.g., Postman, 1976; Anderson 1983; Shrunk, 2016; Weinstein et al. 2018). Spaced practice or distributed practice theory recognizes that practice with information that is spaced over time produces superior long-term learning as opposed to cramming or mass repetitions (Ebbinghaus, 1885, 1913; Roediger, 1985; Kang 2016). And finally, dual coding theory emphasizes improved memory when imagery is presented with text. Weinstein et al. (2018) further emphasizes that research indicates the physical act of drawing imparts an additional "motor code" that enhances learning and memory (Engelkamp and Zimmer, 1984; Wammes, Meade, and Fernandes, 2016). An explanation of how individual assessments are paired with learning theory in the revised field unit is presented below.

Incorporating High Impact Teaching Practices

The expanded schedule provides opportunity to focus on integrating high impact teaching practices with content delivery and assessment. During course redesign the trip was deconstructed to identify critical geologic concepts and to develop assessments that align with course learning objectives following the principles of backward design (Wiggins and McTighe, 1998; 2011). Course re-development through backward design theory moves through three stages: (1) identifying desired results or learning objectives in terms of what students should know and be able to do, (2) determining assessment evidence that would indicate that students have learned and can apply the new knowledge, and (3) planning instruction and activities that will allow students to perform effectively and achieve desired results. After applying backward design theory, the field trip was reconstructed into a well-defined learning progression (Table 1) (e.g., National Research Council [NRC], 2005, 2007; Duncan 1993; Duncan and Hmelo-Silver, 2009). Popham (2007) summarized a learning progression as a "powerful analytic tool" whereby instructors present students with subskills and bodies of enabling knowledge as the building blocks that students must accomplish en route to mastery of critical concepts.

Engaging in an explicit conversation that frames the field trip within the context of a learning progression and ties formative assessments with course learning objectives invites students into a deeper understanding of metacognition and the importance of applying knowledge acquired across other geology courses. Increasing the transparency of course design can be an important step toward helping students develop metacognitive skills and establish self-motivation toward learning. Research on transparency in teaching and learning by Winkelmes (2013) has demonstrated that students' learning outcomes improved when they understood how and why instructors had structured their learning experiences. A fundamental goal of undergraduate instruction is to move students from being instructor-centered learners to self-directed learners. Yet the knowledge gaps that inevitably exist amongst students enrolled in this field course present obstacles to individual student motivation and learning. Creating a social collaborative learning environment can allow students to identify and address learning gaps through constructive rather than punitive methods. Instructional scaffolding is a teaching approach based on Vygotsky's (1978) concept of the Zone of Proximal Development that suggests that learners advance toward understanding complex problems by working socially alongside a knowledgeable instructor or more capable peers. As the name implies, instructional scaffolding aims to tailor instruction to support students as they move from familiar tasks they can easily master to those that challenge their abilities and knowledge (Simons and Klein, 2007; Bruning et al., 2004; Puntambekar & Hübscher, 2005). Redesigning the course as a learning progression aims to move students toward mastery of fundamental geologic concepts and skills by implementing high-impact teaching practices that emphasize scaffolding of instruction and transparency in teaching to promote metacognition, self-directed, active and collaborative learning**.**

Week One - Building Foundational Knowledge with Fundamental Geologic Concepts

The project introduction begins by building a sense of purpose and place. Photographs of the Starved Rock area highlight the dramatic vertical bluffs, canyons, dells and waterfalls within the Ordovician St. Peter Sandstone along the Illinois River. Images of past students examining outcrops with hand lenses and Brunton compasses illustrate the expectations for hands-on fieldwork. Examples of figures and notes from field notebooks of previous classes further elucidate expectations and course standards (Figure 3). This brief introduction to the study area can be delivered face-to-face or online depending on an instructor's scheduling needs.

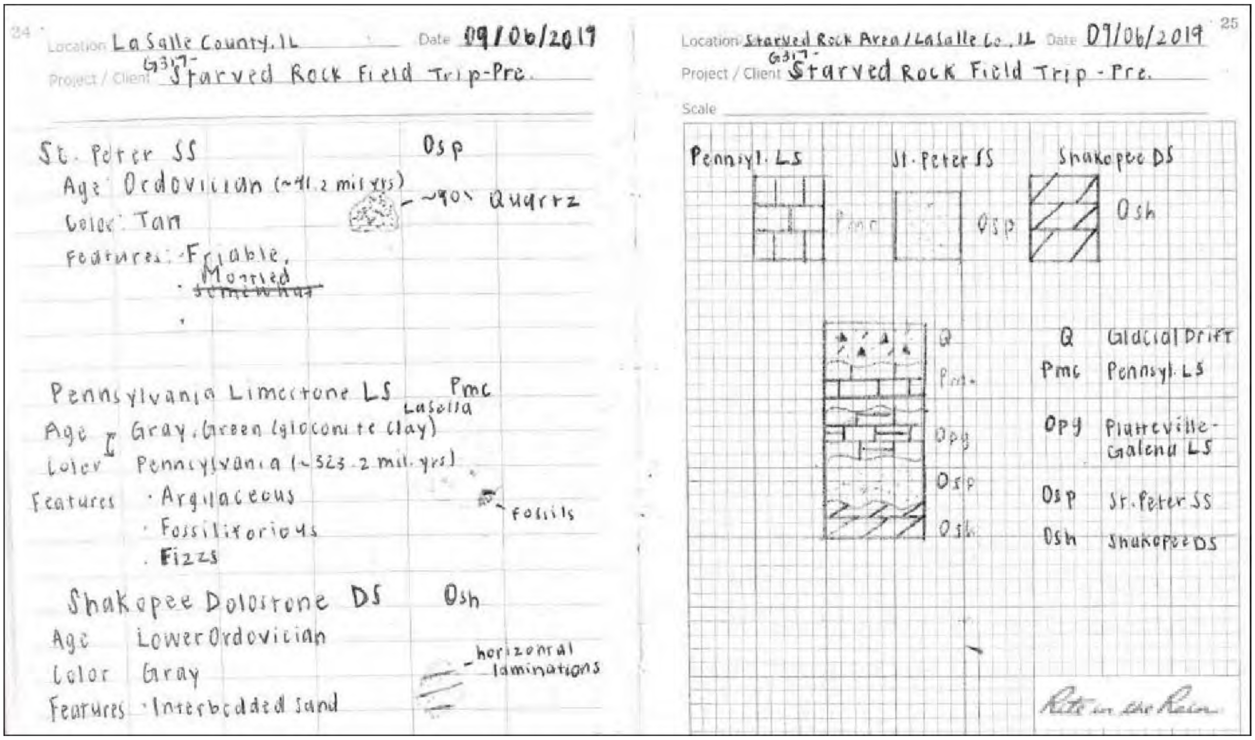

Figure 3. Sample of student field notes that can serve as an instructional example for current students.

Past experience shows that students struggle with defining the objectives of a field study and instructors can move students into a conversation about required knowledge and tasks if they provide a concise statement of purpose. An explicit conversation about course learning objectives, the development of the learning progression, and the formative assessments that students will synthesize into a summative assessment (e.g., paper, virtual field trip, StoryMap) creates transparency and establishes expectations for self-driven learning. A quick exercise through which the class brainstorms and maps out the geologic skills and knowledge required to meet the goal of each week, provides an opportunity for students to self-identify where they perceive individual knowledge gaps or strengths and develops a visual model of how instructional scaffolding will help construct knowledge (Figure 4).

Constructing foundational content knowledge and identifying knowledge gaps through formative assessment begins by directing students to concepts from their introductory geoscience course(s) that will be relevant and applied in this field study (Table 1). A basic exercise that asks students to review and apply principles of relative dating can be administered in a traditional class or online. The review requires students to engage in retrieval practice (e.g., Collins and Quillian, 1969, Thomson and Tulving, 1970; Salatas and Flavell, 1976, Shrunk, 2016, Weinstein et al., 2019). Baddeley (1998) argues that retrieval occurs best when retrieval cues match those present during initial learning. This suggests that the review ought to adhere to teaching methods of introductory geoscience courses and might focus on simply defining terms and applying concepts rather than demonstrating proficiency. The review addresses fundamental concepts that include: an understanding of the rock cycle, describing and identifying different rock types, relating rock types to depositional environment, applying principles of relative dating, and using the geologic timescale (Figure 4).

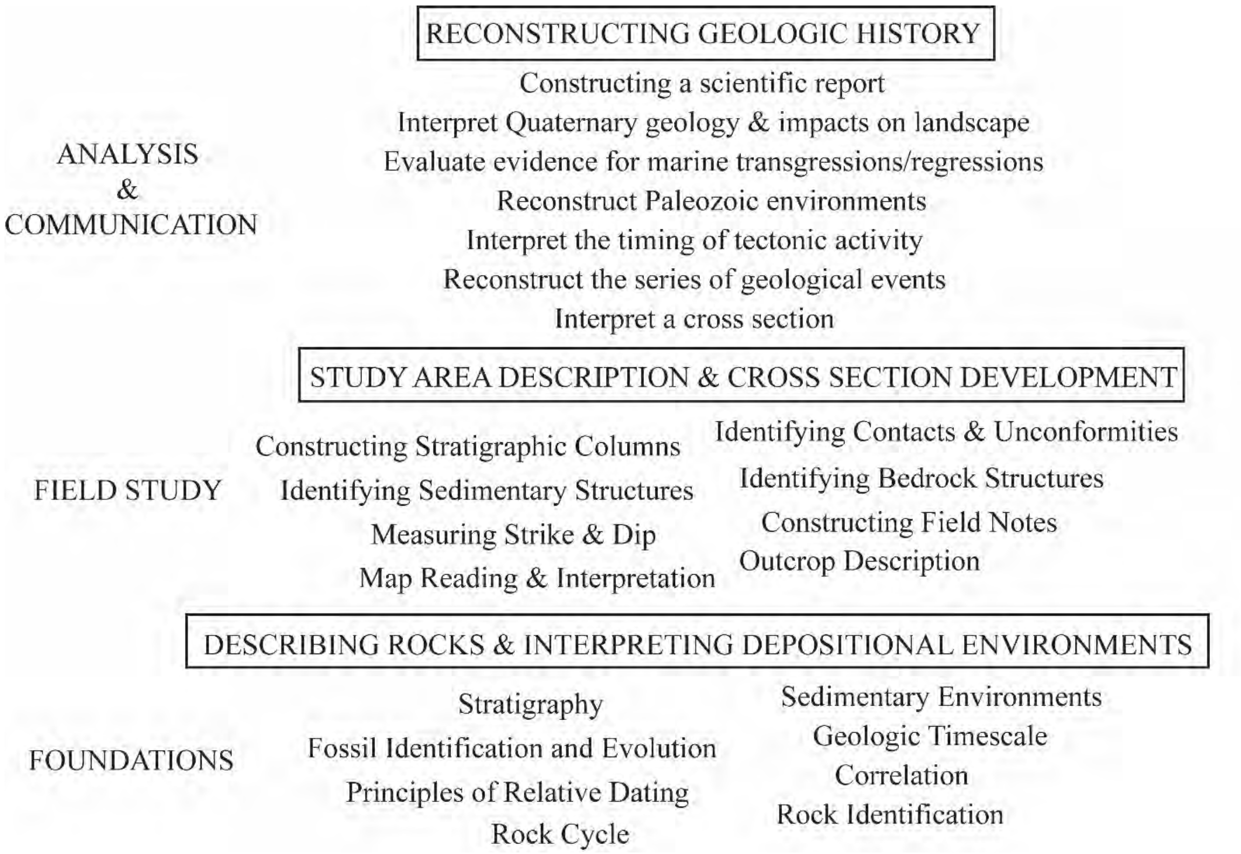

Figure 4. Conceptual model of content contained in the learning progression. Instructors ought to prepare to scaffold instruction to address gaps in background knowledge.

TABLE 1. The revised unit schedule introduces content as a learning progression of formative assessments that build to a summative assessment that interprets the geologic history of the study area.

	Week	Focus	Delivery Format	Critical Concepts & Skills
FORMATIVE ASSESSMENT	1	**Foundations:** Describe Rocks and Interpret Depositional Environments	Monday: Lecture/Lab Friday: Lab	• Rock Cycle & Rock Types (review) --- • Rock descriptions of hand samples • Photograph and label hand samples • Read & create stratigraphic columns • Interpret depositional environments
FORMATIVE ASSESSMENT	2	**Field Study:** Describe and Correlate Outcrops in the Field (Formative)	Monday: Lecture/Lab Friday: Field Trip	• Locate stops and interpret a surficial geology map --- • Describe rocks at outcrop scale • Identify contacts and unconformities between strata • Create site-specific stratigraphic columns

SUMMATIVE ASSESSMENT	3	**Synthesis:** Reconstruct the Geologic History of the Starved Rock Area, Illinois	Monday: Lecture/Lab Friday: Computer Lab	• Complete regional correlation/cross section • Reconstruct geologic events, transitions in depositional environments, and paleogeographic context -- • Interpret regional geologic history: written report with figures; GIS StoryMap; Virtual Field Trip

The initial extended laboratory session of the unit is its own learning progression that requires students to examine hand samples, construct written rock descriptions, identify each sample by name, and relate it to the stratigraphic column of the Starved Rock area of Illinois published in (Nelson et al, 1996). These low stakes formative assessments aim to familiarize students with the rocks they will see in the field. Unlabeled hand samples include sedimentary rocks that will be observed in the field: Ordovician St. Peter Sandstone, Ordovician Shakopee Dolostone, Ordovician Platteville-Galena Limestone, Pennsylvanian LaSalle Limestone. (Figure 5). Initial rock descriptions vary in detail depending on student background and provide an opportunity to assess student knowledge and confidence with basic rock identification (Figure 5). One-on-one interaction between the instructor and student can be followed immediately by a think-pair-share (TPS) collaborative learning opportunity that partners upper-level with lower-level geoscience students to discuss their descriptions. While students ought to identify basic rock type with relative ease (sandstone, dolostone, limestone), further instructional support can direct them to add new information and expand beyond rock type (e.g. structures, fossil type, grain size), an application of elaboration learning theory (e.g., Postman, 1976; Anderson 1983; Hirshman, 2001; Shrunk, 2016; Weinstein et al., 2018). Once hand samples are identified, instructional support emphasizes elaboration by asking students to photograph hand samples with a scale bar and create individual figures with figure captions to be used in the summative unit project.

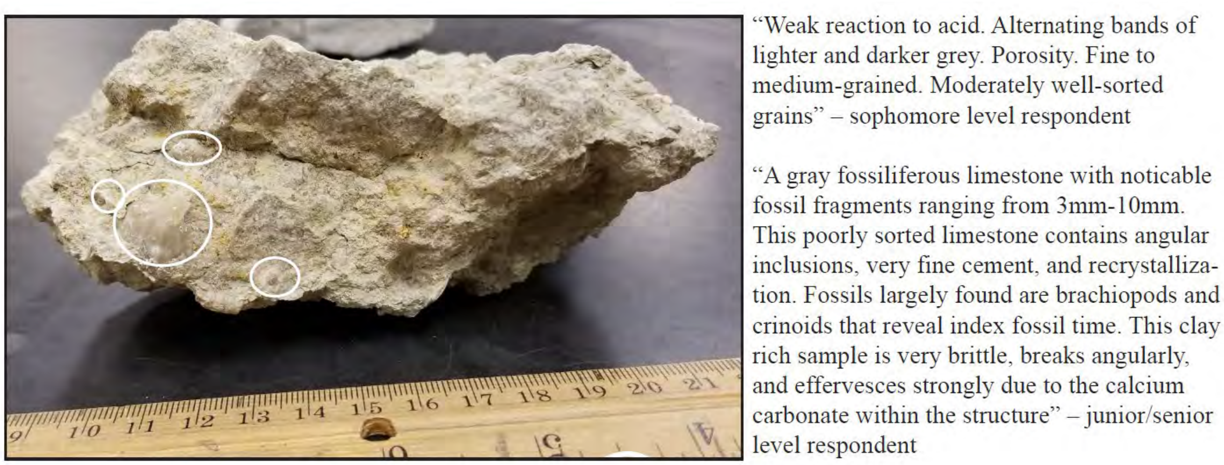

Figure 5. Example of a hand sample of Pennsylvanian limestone of the McLeansboro Group with samples of student rock descriptions.

Students then relate the rocks to the published stratigraphic column of the Starved Rock area to identify geologic age within the Paleozoic (e.g. middle Ordovician, lower Pennsylvanian). Students prepare for the field exercise by constructing a stratigraphic column with appropriate rock symbols, notation, and representation of contacts versus unconformities. The session ends with a discussion

of possible depositional environments for the individual rock types and brainstorming about the paleogeography and tectonic setting of Illinois during the Paleozoic. Collectively the formative activities associate learned information (rock types and principles of relative dating) with new information needed to identify specific rock units in the field, helping students move toward deeper meaning that will facilitate the interpretation of depositional environments and geologic history. By the end of this unit, students have constructed figures and written descriptions of each Paleozoic rock type that they will observe in the field. They are prepared to analyze these rocks at outcrop scale, to identify contacts and/or unconformities between rock units, and to prepare site-specific stratigraphic columns.

Week 2 - Moving from Classroom into the Field

Once students are familiar with the individual rock they will observe in the field, the schedule redesign allows for a full session where students can explore topographic and surficial geology maps to orient themselves to where rocks are exposed in the study area. Students transfer outcrop locations from a sketch map of the trip route to the relevant topographic and surficial geology maps of the Starved Rock, Utica, IL area (Figure 6). Students are assigned the task of developing a written description of the study area prior to entering the field using data from relevant topographic and surficial geology maps along with online tools like Google Earth.

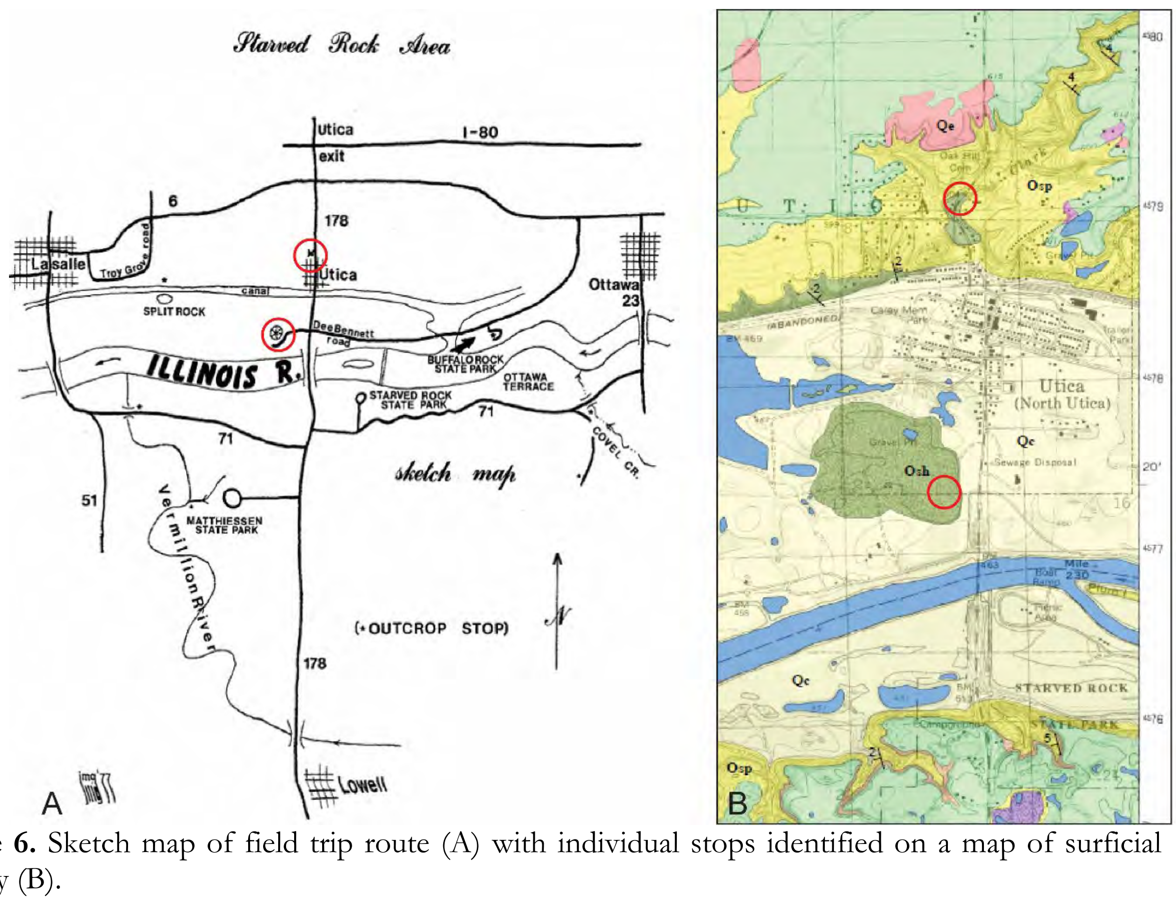

Figure 6. Sketch map of field trip route (A) with individual stops identified on a map of surficial geology (B).

Constructing the site description facilitates the broader questions of *why* Paleozoic sedimentary rocks are exposed today and what evidence exists for the major unconformity between

Paleozoic rocks and Quaternary tills. Collaborative discussion asks students to apply their map reading skills to note the contrast between the flat topography of north central Illinois composed of Quaternary ground and end moraines versus the steep canyons or "dells" that expose Paleozoic sedimentary rocks along the Illinois and Vermilion Rivers and their tributaries. Apparent age inversions are evident as Quaternary alluvium occurs within the river channels formed of Paleozoic rocks. This collaborative low stakes learning activity leads to a discussion of the Quaternary processes that produced moraine-dammed lakes and the outburst flooding that incised the Illinois River to expose the Paleozoic rock sequences observed in the field. The study site session strives for self-driven discovery while the instructor trains students in methods for analyzing a field site prior to field work. By the end of this session, students have constructed the "study site" section suitable for the summative project paper or project.

Field work focuses on conducting outcrop descriptions at six locations including three roadside exposures and sites within Starved Rock, Matthiessen, and Buffalo Rock State Parks (Figure 1). A thorough description of the geologic setting and field trip route is available in Huysken et al. (2016). Students are already familiar with the individual rock units from hand sample and quickly engage in retrieval practice to identify rock units in the field, relate them to the stratigraphic column, identify contacts and unconformities, and construct the site-specific stratigraphic columns. Instruction applies elaboration theory by having students describe rocks at outcrop scale (e.g. thickness, orientation of strike and dip, weathering patterns, fossil assemblages, sedimentary structures, contacts etc.) and create detailed and annotated drawings in field notebooks, another application of the dual coding learning theory. Rather than asking students to arrive at an interpretation of the geologic history of the area, the day of field work now ends by asking students to correlate individual rock units and unconformities to construct a geologic cross section across the Starved Rock area, again relying on dual coding theory (Figure 1). By the end of the field day, students are prepared to analyze the geologic cross section. Before the next meeting they are required to establish a sequence of geologic events that would produce the stratigraphy and structure observed in the field and to justify their reasoning (Figure 2).

Week 3 - Analysis and Summative Assessment of Field Data; Focusing on Science Communication

Asking students to prepare a sequence of geologic events is the first step toward arriving at a broader interpretation of the geologic history and paleogeography of the Starved Rock area. The final lecture session emphasizes metacognition by engaging students in collaborative discussion to examine the geologic evidence and reasoning for their interpretations. Instruction can utilize elaboration theory by asking students to relate rock types and stratigraphy to depositional environments and transitions between depositional environments. More advanced students should describe transgressional/regressional sequence stratigraphy and explain to peers how it relates to the stratigraphy of Paleozoic sedimentary rocks of the Starved Rock area with limited instructional support. Instruction can focus on clarification of misconceptions and aligning claims, reasoning, and evidence.

Through discussion that emphasizes retrieval and elaboration, all students should arrive at the understanding that the stratigraphic sequence is indicative of a shallow marine platform that experienced multiple transgressive/regressive events during the Paleozoic. Beyond an explanation of depositional setting, the interpretation of geologic history must include the timing of folding and erosion between Ordovician and Pennsylvanian sedimentary strata and the major unconformity between Paleozoic and Quaternary deposits. Paleogeographic maps (www.PaleoMap.org) can provide visual tools to reinforce the interpretation and can facilitate discussion of how geologists

generate these maps. While this session emphasizes collaborative learning, individuals are required to revisit topographic and surficial geology maps and edit their site descriptions to add new knowledge from the field experience. By the end of this session students will have prepared a written explanation of the geologic history of the Starved Rock area from early Ordovician to present that directly relates interpretations to geologic evidence.

The final extended laboratory day is devoted to assembling and revising formative assessments (text and figures) and constructing the summative report. The site description, methods and results have largely been constructed in formative assessments and students should focus on developing text. Instructional support focuses on helping students to align their interpretations of depositional environments with the evidence. For example, students must use the lithology of the St. Peter sandstone (well rounded, well sorted, frosted, fine to medium grained quartz sand) and observations of sedimentary structures from the field (low-angle cross bedding) to justify interpretation of a nearshore environment. Think-pair-share and small collaborative reading groups should be utilized to help students progress through each section of the scientific report (Introduction, Methods, Results, Discussion/Conclusions). The summative assessment is a full scientific report in which figures and figure captions are aligned with text. Students are required to conduct peer reviews using the project rubric and to complete revisions of their own work. This process fulfills the course's intensive writing component. Geology programs that have scientific writing embedded into other courses might ask students to design a virtual field trip or ArcGIS StoryMap as an alternative summative assessment.

Discussion

Field trips and field-based education is an integral component of undergraduate geoscience curricula. While field trips unarguably represent important place-based and hands-on experiences, field excursions often lack the pedagogical framework and intentional design of classroom activities. Moreover, field trips are increasingly being cut from smaller undergraduate geology and environmental programs due to logistical and economic obstacles. To truly understand and articulate the educational "value added" of a field trip, this project deconstructed a favorite local one-day field trip to the Starved Rock area of Illinois to reconstruct the content as a multi-week project with a pedagogical framework developed as a learning progression with intentional integration of cognitive learning theories.

The one-day field trip experience was rich with geologic information and included project-based design, but highlighted knowledge gaps amongst undergraduates and failed to provide time for students to reflect, assess and address those gaps to achieve maximum learning gains. Revision occurred over - three sequential offerings of the field course and because enrollments in upper-level geology courses are low ($n<15$), and because student content knowledge varies significantly within and across courses sessions, the assessment of the impact of the redesign is based mainly on the instructor's evaluation of learning gains demonstrated by the detail and sophistication of student responses to short answer questions.

Because this course is offered on a two-year rotation, the students enrolled typically span a range of background knowledge with some having only completed 100- and 200- level courses, while others have completed 300- and 400- level courses and some level of independent research. During course revision, a pre-field trip lab session was created in which students were asked to apply foundational geologic knowledge and skills (rock identification and description, map reading and site description, reading stratigraphic columns), and allowed the instructor to conduct a quick assessment of knowledge gaps for students at all levels of experience in a low stakes environment. While upper-level students excelled at detailed rock descriptions, the activity creates an opportunity

for peer mentoring and collaborative learning. Interestingly, all students struggled to understand how to connect claims, evidence, and reasoning in terms of identifying an unconformity using the published stratigraphic column of the Starved Rock area. Similarly, all students struggled to construct a written site description using observations of topographic and surficial geology maps, which created an opportunity to for instructor-centered instruction to clarify key details about the study site and map reading.

During the actual field excursion in session two of the unit, students were challenged to collect geologic data to validate their site descriptions using a different set of skills and techniques. As a result of working with maps and describing hand samples of the specific rock units, students were better prepared for fieldwork and exhibited higher confidence when asked to approach outcrops and identify individual rock units, contacts between rock units, and relate the information back to a stratigraphic column. Rather than spending time on foundational skills, students moved immediately into applying field-based skills that included constructing detailed outcrop measurements and descriptions and recording data in their field books. Most notably complaints about students feeling “rushed” at outcrops declined. Discussion in the field moved beyond rock type and age to evaluating sedimentary features, noting transitions between rock types, detecting contacts and unconformities, observing and measuring bed thickness and orientation, and taking field measurements including strike and dip. Undergraduates at all levels of experience reported an increase in their confidence and skill in conducting fieldwork.

Week three of the unit focused on data analysis, interpretation and communication by asking students to use their own notes, observations, and stratigraphic columns to interpret the series of geologic events from Paleozoic to present time. The result was a self-driven classroom discussion as opposed to an instructor-dominated discussion in the field with a group of students anxious to end the long field day. The revised analysis session is focused on assisting students to connect interpretations (claims) with the geologic data (evidence) collected in the field to develop the reasoning component for a written explanation of the geologic history of the Starved Rock area for a final lab report (communication).

Interestingly, while the course revision focused on many low-stakes formative activities and collaborative learning opportunities, students expressed a desire for more quizzing and individual assessment. Their request indicates that students perceive learning gains from quiz preparation and possess a desire to directly assess their individual knowledge of geologic content by traditional metrics. Dunlosky (2013) provides perspective on the benefits of quizzing and testing as a tool to develop students’ study habits and future course offerings will incorporate traditional quizzes as opportunities for retrieval practice and spaced practice. Development of low-stakes formative assessments that utilize cognitive learning theories (e.g. retrieval practice, elaboration, spaced practice, dual-coding theory) and are paired with key geologic concepts prepare students for field work and allow instructors to identify and address knowledge gaps. The formative assessments should be aligned with course learning objectives to increase course transparency and enhance metacognition. And high impact teaching practices focused on instructional scaffolding and collaborative learning help undergraduate students transition to self-directed learning and move along the spectrum of content knowledge toward mastery. As a result of these considerations, the next offering of the course will include pre- and post- assessments disseminated during the first and third sessions of the unit.

Conclusions

Field-based education represents a fundamental and critical component of undergraduate geoscience curricula. It engages students in learning strategies shown to promote higher level thinking skills like

active-learning, project-based learning, problem solving, and place-based learning. Field-based education allows undergraduates to apply knowledge, develop skills, and “hone their field credentials” (Whitmeyer et al., 2009). But to reap the potential educational benefits of field-based education, geoscience instructors must actively marry principles of learning theory and high-impact teaching practices in their course design. Like traditional lecture and laboratory-based geoscience courses, field geology courses must provide a pedagogical framework that moves students toward mastery of core geologic concepts while consistently working to develop written and oral communication skills, quantitative and computing skills, and problem solving and critical thinking skills (Kelso and Brown, 2009). Revising a favorite field trip to a learning progression and purposefully integrating cognitive learning strategies and high impact teaching strategies can be achieved with minor adjustments to an instructor’s current practice building from core learning objectives and assessing the desired field skills we aim to develop. The biggest change and challenge will be time and the fear of sacrificing content. But online or hybrid approaches might facilitate additional interaction if additional in-person contact is impractical. This case study presented how a one-day field trip can be deconstructed and reconstructed around a solid pedagogical framework.

References

American Geophysical Institute. 2019. *Does your department have a Licensure Qualifying Program?* Factsheet 2019-002; October 28, 2019.

Anderson, J. R. (1983). A spreading activation theory of memory. Journal of Verbal Learning and Verbal Behavior, 22, 261–295. DOI: 10.1016/S0022-5371(83)90201-3

Baddeley 1998. Recent Developments in Working Memory. Current Opinion in Neurobiology.8, 2, 234-238. DOI: 10.1016/S0959-4388(98)80145-1

Bloom, Benjamin S. Taxonomy of Educational Objectives: The Classification of Educational Goals. New York: Longmans, Green, 1956. Print.

Boyle, A., Maguire, S., Martin, A., Milsom, C., Nash, R., Rawlinson, S., Turner, A., Wurthmann, S., Conchie, S. 2007. Fieldwork is Good: the Student Perception and the Affective Domain. Journal of Geography in Higher Education, 31 (2). 299–317. DOI: 10.1080/03098260601063628

Bruning, R., Schraw, G., Norby, M., & Ronning, R. (2004). Cognitive psychology and instruction. Upper Saddle River, NJ: Prentice Hall.

Clark, J.M., Paivio, A. 1991. Dual Coding Theory and Education. Educational Psychology Review, 3 (3): 149-209. DOI: 10.1077BF01320076

Cohen, P. A. 1980. Effectiveness of Student-Rating Feedback for Improving College Instruction: A Meta-Analysis of Findings. *Research in Higher Education* 13 (4): 321–41. DOI: 10.1007/BF00976252

Duncan and Hmelo-Silver, 2009. Learning Progressions: Aligning Curriculum, Instruction, and Assessment. Journal of Research in Science Teaching, 46 (6) 606-609. DOI: 10.1002/tea.20316

Dunlosky, J. (2013). Strengthening the student toolbox: study strategies to boost learning. American Educator, 37(3), 12–21.

Dunlosky, J., and J. Metcalfe. 2009. *Metacognition.* Thousand Oaks, CA: SAGE Publications.

Ebbinghaus, H. (1885). Memory: A contribution to experimental psychology. (HA Ruger & CE Bussenius, Trans.1913). Reprinted with permission (2013). Annals of Neuroscience 20: 155-156. DOI: 10.5214/ans.0972.7531.200408

Elkins, J.T, Elkins, N.M.L. (2007) Teaching Geology in the Field: Significant Geoscience Concept Gains in Entirely Field-based Introductory Geology Courses, Journal of Geoscience Education, 55:2, 126-132, DOI: 10.5408/1089-9995-55.2.126

Engelkamp, J., & Zimmer, H. D. (1984). Motor programme information as a separable memory unit. Psychological Research, 46, 283–299. DOI: 10.1007/bf0030888

Felder, R.M., 1993. Reaching the Second Tier: Learning and Teaching Styles in College Science Education. J. College Science Teaching, 23(5), 286-290.

Huysken, Kristin, Argyilan, Erin, and Votaw, Robert, 2016, Project-based Field Trips to the Starved Rock Area for Geoscience Educators, Northern Illinois, In Lasemi, Z. and S. Elrick eds., 2016, 1967-2016 – Celebrating 50 Years of Geoscience in the Mid-Continent: Guidebook for the 50th Annual Meeting of the Geological Society of America – North Central Section, April 18- 19, 2016, Illinois State Geological Survey, Guidebook 43, p. 125-140

Kang, S. H. (2016). Spaced repetition promotes efficient and effective learning policy implications for instruction. Policy Insights from the Behavioral and Brain Sciences, 3, 12–19. DOI: 10.1177/2372732215624708

Field Geology Education: Historical Perspectives and Modern Approaches: Geological Society of America Special Paper 461, p. 57–64, DOI: https://doi.org/10.1130/SPE461

Knowles, M. S. (1990). The Adult Learner: A Neglected Species. Houston, TX: Gulf Publishing Co.

McConnell, R.J. (1979). The geography teacher and outdoor education. *New Zealand Journal of Geography, 66*, 9–12. DOI: 10.1111/j.0028-8292.1979.tb00630.x

McKenzie, G.D., Utgard, R.O., & Lisowski, M. (1986). The importance of field trips: A geological example. *Journal of College Science Teaching, 16*(1), 17–20.

McNamara, E.S., & Fowler, H.S. (1975). Out-of-doors earth science: One reason why. *School Science and Mathematics, 75*, 413–418.

National Research Council (NRC). (2005). Systems for state science assessments. In M.R. Wilson & M.W. Bertenthal (Eds.), Committee on testing design on K-12 science achievement. Washington, DC: The National Academy Press. DOI: 10.17226/11312

National Research Council (NRC). (2007). Taking science to school: Learning and teaching science in grade K-8. In R.A. Duschl, H.A. Schweingruber, & A.W. Shouse (Eds.), Committee on science learning, kindergarten through eighth grade. Washington, DC: The National Academy Press. DOI: 10.17226/11625

Nelson, T. O., and J. Dunlosky. 1991. When People's Judgments of Learning Are Extremely Accurate at Predicting Subsequent Recall: The Delayed JOL Effect. *Psychological Science* 2 (4): 267–70. DOI: 10.1080/09658211.2017.1406523

Nelson RS, Malone DH, Jacobson RJ, Frankie WT (1996) Guide to the geology of Buffalo Rock and Matthiessen state parks area, La Salle County, Illinois: Field Trip Guidebook 1996C, Illinois State Geological Survey, 62 p.

Pashler, H., Bain, P. M., Bottge, B. A., Graesser, A., Koedinger, K., McDaniel, M., and Metcalfe, J. (2007). Organizing instruction and study to improve student learning. IES practice guide. NCER 2007–2004. National Center for Education Research.

Popham, J.W., 2007, The lowdown on learning progressions: Educational Leadership, v. 64, no. 7, p. 83–84.

Postman, L. (1976). Methodology of human learning. In W. K. Estes (Ed.), Handbook of learning and cognitive processes (Vol. 3). Hillsdale: Erlbaum.

Puntambekar, S., Hübscher, R. 2010. Tools for scaffolding students in a complex learning environment: What have we gained and what have we missed? Educational Psychologist. 40 (1). 1-12. DOI: 10.1207/s15326985ep4001_1

Roediger, H. L. (1985). Remembering Ebbinghaus. [Retrospective review of the book On Memory, by H. Ebbinghaus]. Contemporary Psychology, 30, 519–523. DOI: 10.1037/023895

Rosenshine, B. & Meister, C. (1992). The use of scaffolds for teaching higher level cognitive strategies. Educational Leadership. April. 26-33.

Salatas, H. and Flavell, J.H. 1976. Retrieval of Recently Learned Information: Development of Strategies and Control Skills. *Child Development,* 47 (4), 941-948. DOI: 10.2307/1128429

Salter, C.L. (2001). No bad landscape. *The Geographical Review, 91*, 105–112. DOI: 10.1111/j.1931-0846.2001.tb00463.x

Scotese, C.R., 2002, http://www.scotese.com, (PALEOMAP website).

Shepphard, P., Donaldson, B.A., Huckleberry, G. 2010. Quantitative assessment of a field-based course on integrative geology, ecology and cultural history. International Research in Geographical and Environmental Education, 19 (4), 295-313. DOI: 10.1080/10382046.2010.519150

Simons, K.D., Klein, J.D. 2007.The Impact of Scaffolding and Student Achievement Levels in a Problem-based Learning Environment. Instructional Science. 35:41–72. DOI: 10.1007/s11251-006-9002-5.

Stokes, A., and Boyle, A.P., 2009, The undergraduate geoscience fieldwork experience: Influencing factors and implications for learning, in Whitmyer, S.J., Mogk, D.W., and Pyle, E.J., eds., Field Geology Education: Historical Perspectives and Modem Approaches: Geological Society of America Special Paper 461, p. 291-311, doi: 10.113012009.2461 (23).

Schunk, Dale H. *Learning Theories: An Educational Perspective.* , 2016. Print.

Thomas, R.C., and Roberts, S., 2009, Experience One: Teaching the geoscience curriculum in the fi eld using experiential immersion learning, in Whitmeyer, S.J., Mogk, D.W., and Pyle, E.J., eds., Field Geology Education: Historical Perspectives and Modern Approaches: Geological Society of America Special Paper 461, p. 65–76, doi: 10.1130/2009.2461(07)

Thomson, D. M., & Tulving, E. Associative encoding and retrieval: Weak and strong cues. Journal of Experimental Psychology, 1970, 86, 255-262. DOI: 10.1037/h0029997

Vygotsky, L. (1978). *Mind in society.* Cambridge, MA: Harvard University Press. 159pp.

Walberg, H. 1991. Improving School Science in Advanced and Developing Countries. Review of Educational Research. 61(1) 25-69. DOI: 10.3102/00346543061001025

Wammes, J. D., Meade, M. E., Fernandes, M. A. (2016). The drawing effect: evidence for reliable and robust memory benefits in free recall. Quarterly Journal of Experimental Psychology, 69, 1752–1776. DOI: 10.1080/17470218.2015.1094494

Weinstein, Y., Gilmore, A. W., Szpunar, K. K., McDermott, K. B. (2014). The role of test expectancy in the build-up of proactive interference in long-term memory. Journal of Experimental Psychology: Learning, Memory, and Cognition, 40, 1039–1048. doi: 10.1037/a003616

Whitmeyer, S.J., Mogk, D.W., and Pyle, E.J., 2009, An introduction to historical perspectives on and modern approaches to fi eld geology education, in Whitmeyer, S.J., Mogk, D.W., and Pyle, E.J., eds., Field Geology Education: Historical Perspectives and Modern Approaches: Geological Society of America Special Paper 461, p. vii–ix, doi: 10.1130/2009.2461(00).

Wiggins, Grant, and McTighe, Jay. (1998). Backward Design. In *Understanding by Design* (pp. 13-34). ASCD.

Wiggins, G., & McTighe, J. (2011). The Understanding by Design guide to creating high-quality units. Alexandria, VA: ASCD

Winkelmes, MA. (2013) Transparency in Teaching: Faculty Share Data and Improve Students' Learning. *Liberal Education* 99, 2.