JOURNAL OF GEOSCIENCE EDUCATION **64**, 215–230 (2016)

Building an Outdoor Classroom for Field Geology: The Geoscience Garden

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ABSTRACT

Many geoscience educators have noted the difficulty that students experience in transferring their classroom knowledge to the field environment. The Geoscience Garden, on the University of Alberta North Campus, provides a simulated field environment in which Earth Science students can develop field observation skills, interpret features of Earth's crust in three dimensions, and discover Earth history. The garden consists of large (1–5 m) boulders and rock slabs arranged in a landscaped layout that represents the geology of western and northern Canada. The project adds a unique capability for teaching basic field skills to students in a local environment and prepares them for field courses at more remote locations. Students work in the garden in a second-year introductory structural geology class that precedes a field school. Student perceptions of the effectiveness of the installation were evaluated using surveys of students returning from field school. Initial responses were positive; students returning from field school after the introduction of the garden reported significantly greater satisfaction with their ability to collect field data. *© 2016 National Association of Geoscience Teachers.* [DOI: 10.5408/15-133.1]

Key words: Outdoor classroom, fieldwork

INTRODUCTION

The Geoscience Garden is an installation at the University of Alberta designed to assist in the education of geoscience students in field data collection and interpretation and to ease the transition from the classroom to the field. Though primarily designed for students learning geologic mapping in the second to fourth year of geoscience programs, it is also visited by a range of students in introductory classes and in other programs and has an outreach function, acting as an extension to indoor museums housed nearby and thus reaching a diverse public. The Geoscience Garden is installed close to the classrooms in which most geoscience teaching occurs. It provides an environment in which geoscience students can learn basic techniques of field observation, measurement, and mapping, without facing some nongeologic challenges that emerge on the first day at field school.

In the following, we first summarize the challenges uniquely faced by Earth Science educators and students involved in field education. We then describe the physical context of the University of Alberta campus and the role of field school and related classes in geology and other programs. We then describe the construction of the Geoscience Garden and the role it has played in these courses and other activities on campus. We present the results of surveys to determine student perceptions of the extent to which their in-classroom courses prepared them for field school, conducted among students who completed field school without prior exposure to the Geoscience Garden, and contrast the results with those from students who completed field school after the installation of the garden and its incorporation in the teaching program. We conclude with some retrospective comments aimed at others contemplating similar installations.

FIELD TEACHING IN EARTH SCIENCE

Importance of Field Education

Earth Science is distinguished by its dependence on field data. Even in laboratory-based analytical studies, proper documentation of the field location and geologic context are vital for the correct interpretation of the analytical data. Hence, in the education of geology students, providing field experience is of paramount importance. This has been recognized since the early days of geology. Petrologist H.H. Read (1957) famously observed that "the best geologist is he who has seen the most rocks." Read's words reflect the times in which he wrote: most of the geologists taught during his distinguished career at Imperial College, London, would have been men and would have entered geology expecting to see rocks while working outdoors on rugged landscapes, often in arduous conditions, for much of their careers.

More recent analyses (e.g., Orion et al., 1997; King, 2008) have noted particular spatial abilities acquired by geoscience students. These include understanding how three-dimensional (3D), but concealed, rock bodies interact with the more visible 3D surface of Earth and how those complex relationships change over geologic time. Mogk and Goodwin (2012) emphasize the immersive nature of the field environment, in which the observer is situated within the objects and structures being observed.

The demographics of typical Earth Science classes have also changed since the time of Read. Instructors can no longer assume that beginning students have experience hiking or working outdoors, and most introductory classes must engage a student population that has a range of

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Received 16 November 2015; revised 25 April 2016 and 11 June 2016; accepted 13 June 2016; published online 19 August 2016.

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fitness and physical agility more representative of the population as a whole (Wilson, 2014). The level of risk while working outdoors that is acceptable to teachers, students, and university administrators has declined (Fisher, 2001). Nonetheless, most teachers and professionals are in agreement that aspects of geologic practice and understanding can only be learned in the course of field mapping (Trifonov, 1984; Orion et al., 1997; Petcovic et al., 2014). As a result, organizations that define standards for the registration of geoscientists typically insist on field experience as a prerequisite for professional status (e.g., Geoscientists Canada, 2008; Boyle et al., 2009).

Challenges of Field Education

Providing field education in the geosciences involves unique logistical and pedagogical challenges, which vary from institution to institution, as noted by Huntoon (2012). Fieldwork is expensive, and the expense of providing fieldwork education depends on a number of factors. For example, some universities are fortunately located close to classic geologic sites or can access a variety of geologic features close to the classroom, whereas others are placed in areas with few outcrops or where the geology displays little of the variety that students require for their education. Travel to more remote locations that have suitable geology entails higher transportation costs, and there may be legal limitations to access on private land and environmental limitations in public areas. Natural and artificial hazards particular to fieldwork areas can include extremes of heat and cold, steep topography, landslide and avalanche hazards, dangerous wildlife, drowning hazards, roads, railways, industrial and mining operations, and even, in some jurisdictions, unfamiliar or unwelcoming human residents. Most field schools require accommodation; remote areas may lack permanent lodgings, whereas popular tourist areas may have abundant accommodation but at prices unaffordable for groups of students. Student populations have different degrees of familiarity with work outdoors and different levels of tolerance for discomfort, physical exertion, and perceived risk. University administrations may require a much higher ratio of instructors to students than is usual in classroom-based courses because of these risk factors (Fisher, 2001; Boyle et al., 2007). Thus, the pedagogical design of field schools typically involves compromises imposed by logistics (Mogk and Goodwin, 2012).

Students embarking on their first field course may be more apprehensive than those entering a typical classroom course. Orion and Hofstein (1994) describe the combination of new experiences as the "novelty space" of the fieldwork and emphasize the benefits for learning outcomes of preparing students for this novelty space. Stokes and Boyle (2009) and Wirth et al. (2011) suggest that in addition to strictly geologic skills, students beginning fieldwork may be challenged by many aspects of the novelty space, including the following:

- Collaborating in small peer groups
- Physical agility in rough or steep terrain
- Recording data by hand without a desk or a computer
- Dressing for and coping with weather conditions, including extremes of cold, wet, or heat
- Dealing with perceived risk from wildlife, livestock, or other factors
- Interacting with one another in a group residential social setting

Despite these challenges, most of the students surveyed by Stokes and Boyle (2009) came away with strongly positive perceptions of the value of their field experience. Nonetheless, for those teaching basic field techniques such as compass-clinometer use, the abundance of distractions on the first few days of field teaching can make the task considerably more difficult.

Evaluating Field Education

Despite the common assumption that "fieldwork is good" (Boyle et al., 2007), direct measurement of the educational outcomes of fieldwork is difficult, for several reasons. First, dividing a single student population into two groups, one of which is given more field experience than the other, may be perceived as putting one group at an unacceptable educational disadvantage. Second, year-to-year comparisons of assignment scores and grades are unreliable because of changing logistical factors like weather, variations in the student population, changing instructional staff, and the tendency of instructors to make allowance for these factors in the evaluation of student work. Good field learning projects involve synthesizing a range of observations and theoretical knowledge into complex working hypotheses (Mogk and Goodwin, 2012); those results are presented in writing and illustrated by diagrams, maps, and cross-sections. There may be more than one "right answer" in a given geologic mapping exercise (Ernst, 2006). Objective evaluation of such work, in a form that allows comparison between student populations, is difficult. As a result, Huntoon (2012) noted a shortage of unassailable data on the learning outcomes of field-based teaching. Boyle et al. (2007) noted only two attempts to objectively demonstrate the benefits of fieldwork. In one, Kern and Carpenter (1986) were able to divide a class into field-based and classroom-based groups and showed that the field-based group performed better in a final learning assessment. In the other, Fuller et al. (2003) reported the impact of a reduction in fieldwork enforced by an outbreak of cattle disease in the United Kingdom; they found no impact on grades but interpreted this as a result of instructor compensation for any negative impact on students' learning. Because of these challenges, most studies of the benefits of fieldwork have focused on the affective domain (Boyle et al., 2007) and have been based on experimental results showing that students' perceptions of a learning situation have a major influence on their cognitive performance (e.g., Entwistle and Smith, 2002). For example, Stokes and Boyle (2009) concluded that the students in their study came away from field studies not only with attitudes and behaviors in the affective domain that would benefit their future professional practice but also with parallel improvements in their cognitive skills.

Because of these challenges, our approach to evaluating the Geoscience Garden, reported in more detail here, was "metacognitive" (Mogk and Goodwin, 2012) in the sense that it examined students' perceptions of their cognitive gains; our survey asked the students how well their

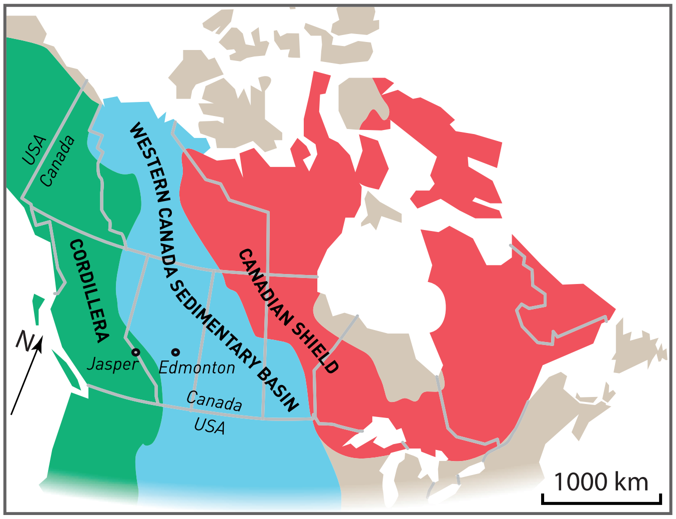


FIGURE 1: Map of Canada showing the location of Edmonton (location of the University of Alberta) and Jasper (location of the second-year EAS 234 Geology Field School).

experience in a university-based course supported learning in a second, field-based course.

OBJECTIVES: THE CONTEXT OF THE GEOSCIENCE GARDEN

Physical Environment at the University of Alberta

The University of Alberta is located in the Western Canada Sedimentary Basin (Fig. 1) on near-horizontal Cretaceous and Quaternary strata cut by incised river valleys and ravines that provide local topographic relief of less than 100 m. Although these provide excellent field examples of landforms and glacial and periglacial deposits, there are few exposures of bedrock and no bedrock that has been deformed or metamorphosed. Thus, from the point of view of a bedrock geologist, the level of variety in local landscapes and geology is limited. These conditions prevail for at least 250 km in all directions, with the result that there are no opportunities for half- or one-day field trips to see significant geologic structures. Hence, off-campus residential field schools form an important part of the learning experience.

Course Structure at the University of Alberta

Programs at the University of Alberta follow a typical North American structure in which the school year for full-time students is divided into two terms; in each term, the program of a full-time student is divided into five courses, and students in most disciplines have a wide choice of courses. Earth Science is introduced to a large number of students (~600 annually) via two first-year Earth and Atmospheric Sciences (EAS) courses (currently EAS 100 Planet Earth and EAS 105 The Dynamic Earth Through Time) each of which comprises ~40 h of classroom teaching and ~30 h of laboratory work. One 3-h lab session is devoted to a field trip through the valley of the North Saskatchewan River, providing students with a brief opportunity to see Quaternary landforms and deposits and small exposures of late Cretaceous sandstone and coal. These courses are delivered to a range of students, including many who do not pursue Earth Science further.

Of the students who take first-year geoscience courses, about a quarter (~150 annually) choose to continue to take Earth Science courses in their second year at university, in many cases working toward bachelor's degrees in Geology, Environmental Earth Science, Paleontology, Geophysics, or Atmospheric Science or toward other science degree programs that allow a minor area of study in Earth and Atmospheric Science (EAS). About 125 students annually choose, or are required as part of their program, to take the classroom course EAS 233 Geologic Structures, and between 40 and 80 students follow this with EAS 234 Geology Field School. Although we have not collected detailed demographic data, most of these students are Canadians of European ancestry. The proportion of visible minorities is about 20%, mainly students of East Asian, aboriginal North American, and African ancestry. Most students in the class entered university directly from high school and are between 19 and 25 years of age. In recent years, about 70% of the class has been male and 30% has been female.

Higher-level courses in the geology program also involve both fieldwork and structural geology. A second field school (EAS 333 Advanced Geology Field School) takes place in the third year of the geology program. It is nominally followed by a second structural geology course (EAS 421 Structural Geology and Tectonics), taught in the fall term from September to December. However, because of both personal factors and program considerations (e.g., financial constraints and conflicts with summer employment and other courses), a proportion of students takes these two courses in reverse order (EAS 421 Structural Geology and Tectonics before EAS 333 Advanced Geology Field School). The student population in EAS 421 Structural Geology and Tectonics therefore has variable field experience.

Translating the Classroom Experience to the Field

EAS 233 Geologic Structures is a classroom-based course, taught from January to April, that is a prerequisite for EAS 234 Geology Field School. Originally named Geologic Maps and Cross Sections, this course introduces basic concepts of 3D geometry and geologic map interpretation. Before 2008, this course was taught primarily as a practical lab course focusing on solving map problems using structure contours on purely planar surfaces, techniques popularized by texts such as those of Bennison et al. (2011). The concepts of 3D orientation (strike and dip of planes and trend and plunge of lines) were introduced primarily using these map techniques, and the process of geologic mapping was introduced by means of paper map exercises, in which boundaries were to be drawn between scattered outcrops that were described in words; geologic histories could then be deduced from the map patterns. From 2009 onward, EAS 233 was progressively revised and renamed, becoming Geologic Structures and Maps and eventually just Geologic Structures, incorporating additional material on the description and significance of geologic structures from a discontinued third-year course. Also introduced into the course were practical sessions with hand samples, some of which involved measuring orientations with the compass clinometer. As the Geoscience Garden became available, some of these activities were undertaken outdoors.

EAS 234 Geology Field School is a residential course that takes place in late April and early May, typically near Jasper (Fig. 1), a location in the Canadian Rocky Mountains ~370 km from the university campus. Transportation to and from the locations of study is provided by bus. Students are accommodated in three-person cabins, where they are typically responsible for preparing their own meals. Fieldwork undertaken by the students includes a series of 1-day exercises that focus on the measurement and interpretation of stratigraphic sections and a 4- to 5-day mapping exercise in which students prepare a geologic map of an area of ~10 km^2.

The experience of instructors in EAS 234 Geology Field School has been that students have traditionally had difficulty transferring concepts learned in EAS 233 Geologic Structures to the field environment. We attribute this to distinctive aspects of geologic fieldwork noted by Mogk and Goodwin (2012): In the field, the structures being studied occur at scales of meters to tens of kilometers and are perceived from an internal spatial position; students are literally immersed in the field experience. This contrasts with typical laboratory study in which students are typically in an external position with respect to samples that are at most tens of centimeters across. The first author's early experiences teaching EAS 234 Geology Field School, before 2008, showed that learning to measure and record the orientation (strike and dip) of a bedding surface occupied a significant part of the first day's work at field school and needed consistent reinforcement thereafter. In some years, poor weather on the first few days compounded the difficulty, because students were unused to manipulating the compass clinometer and recording data under the near-freezing conditions that sometimes prevailed. In addition, the mapping area near Jasper is dominated by folded strata on a kilometer scale, and students who attempted to apply the structure-contour techniques learned in EAS 233 Geologic Structures to the mapping area typically had limited success.

A principal aim of the Geoscience Garden is to bridge the gap between the theoretical, classroom-based understanding achieved by students in EAS 233 Geologic Structures and the practical demands placed on them in the more immersive environment at EAS 234 Geology Field School. As the Geoscience Garden was constructed, concomitant changes in EAS 233 Geologic Structures were introduced to make it more relevant to field school and to give students experience in field measurement of simple structures, before their exposure to the more complex geology at field school. A second aim of the installation was to provide some outdoor instruction in a refresher exercise for students who are unable to take a second field school in the summer before they take the higher-level structural geology course EAS 421 Structural Geology and Tectonics. Third, the Geoscience Garden was planned to provide an outreach capability complementary to the more traditional, indoor mineralogy/petrology and paleontology museums operated by the Department of Earth and Atmospheric Sciences, the target audience for which includes members of the public and numerous primary and secondary school students who visit campus in the course of each year, in addition to university students.

Outdoor Geologic Installations for Education and Outreach

A number of other institutions, in Canada and elsewhere, have installed outdoor exhibits and facilities involving large rocks placed in outdoor arrangements. One of the first to be developed was the Peter Russell Rock Garden at the University of Waterloo, Ontario (Russell and Hebert, 1998; University of Waterloo, 2014). This facility opened in 1982 and currently includes a large collection of ~65 boulders drawn from the geology of Ontario and adjacent areas. It functions as an outdoor exhibit, illustrating various rock types closely spaced in a landscaped area, and is used in both teaching and outreach by the department. Although the garden contains several groups of related samples, it functions primarily as an outdoor exhibit rather than a mapping area per se. Rockwalk Park at Haileybury School of Mines, currently operated by Ontario Trails (Ontario Trails, 2015), also functions as an outdoor exhibit of distinctively labeled rock boulders but does not incorporate a mapping component. Elsewhere in Ontario, the Geologic Rock Garden at the University of Western Ontario (Dillon et al., 2000) comprises a large number (>70) of large samples in a small area—many rocks are contiguous—that simulates a geologic map. Neither Rockwalk Park nor the Geologic Rock Garden attempts to simulate the natural appearance of outcrops by embedding boulders in the landscape, though both can be used to teach students identification of rocks and measurement of rock structures. The Rock Garden at Mount Royal University in Calgary simulates a geologic map within a relatively small area, using contiguous boulders embedded in the campus landscape to indicate superposed stratigraphic units and other relationships.

Outside Canada, we are aware of installed boulder gardens at a number of institutions. The Keweenaw Boulder Garden at Michigan Technological University incorporates glacial erratic boulders in an educational and artistic installation (Rose, 2011), while the Fred Webb Jr. Outdoor Geology Laboratory at Appalachian State University, North Carolina, features 31 boulders from the local geology, arranged on either side of a trail within the university campus (Appalachian State University, 2015). The Prof. Charles B. Creager Kansas Rock Garden is an extension of the geology museum at Emporia State University (Aber, 2001). The Assembling California Garden (UC Davis Geology, 2010) is planned to illustrate the work of McPhee (1993). None of these installations includes a geologic map component. However, the Ohio Department of Natural Resources (2015) provides a large geologic map surrounded by boulders that illustrates the geology of the state, and at Glendale Community College, Arizona, the relationship of outcrops to geologic maps is highlighted by a large map made of colored gravel that underlies an array of boulders (Calderone et al., 2003). In Australia, the National Rock Garden (Pillans, 2014) is planned to incorporate large boulders representing the geology of Australia, arranged in stratigraphic order, in an area of ~6 hectares; its educational component is targeted toward primary and secondary school students (Simpkin, 2014). However, probably the earliest and best documented endeavor was that undertaken at Central Michigan University, beginning in the 1960s, when groups of glacial erratics began to be installed on campus. Subsequent

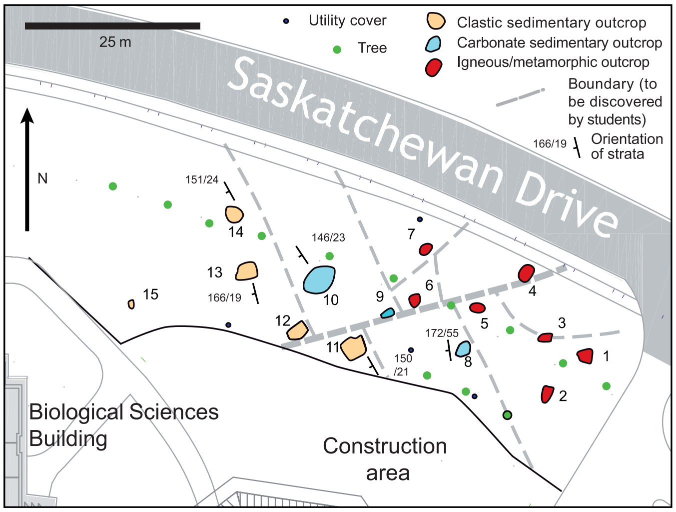


FIGURE 2: Plan of Phase 1 of the Geoscience Garden as installed from 2008 to 2010; its location on the University of Alberta campus is shown in Fig. 4.

efforts, described by Benison (2005) and Matty (2006), led to the arrangement of boulders in a configuration that simulates a geologic map and to the installation of rocks in the landscape so as to simulate natural outcrops, similar to those in the University of Alberta Geoscience Garden.

BUILDING THE GEOSCIENCE GARDEN

Design

The initial conception of the Geoscience Garden occurred independent of the prior initiatives just described, during 2006 and 2007 while the first author was teaching EAS 233 Geologic Structures and 234 Geology Field School and in response to a search for new teaching support initiatives at the University of Alberta. Applications for funding for the project were made in 2007 and 2008 to the Faculty of Science Teaching and Learning Fund and the University Teaching and Learning Enhancement Fund.

To provide students with an understanding of the mapping process, and to provide an immersive experience lacking indoor classroom work, the layout of samples was critical. It was decided from the start that the design would involve groups of related samples that would be oriented but spatially separated so that students would have to use their own observations (e.g., strike and dip of bedding) to infer the relationships between simulated outcrops and to group them into mappable units. In this respect, the design is different from that of most other installations in Canada and elsewhere, where either no map relationship is implied (Russell and Hebert, 1998; Rose, 2011) or the proximity and labeling of outcrops make their relationships obvious (Dillon et al., 2000; Calderone et al., 2003). An objective of the Geoscience Garden was to give the students experience in deducing less obvious relationships between noncontiguous outcrops, a type of problem-solving that we regard as fundamental to the mapping process.

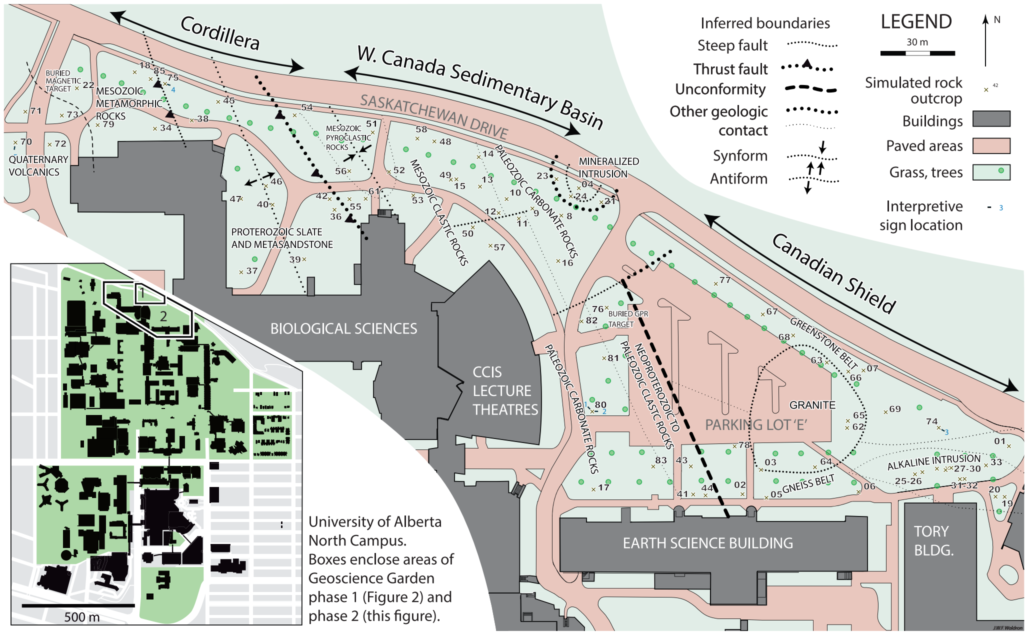
The initial layout of the Geoscience Garden focused on a limited group of samples, comprising bedded clastic sedimentary rocks from the Triassic Spray River Group of Alberta, more massive carbonate rocks from the underlying Mississippian Mount Head Formation, and a selection of plutonic and high-grade metamorphic rocks collected from glacial erratic boulders available in the Edmonton region. These were installed in what came to be known as Phase 1 of the Geoscience Garden (Fig. 2). Initial calls to landscaping companies elicited only one response from a company willing to participate in the meticulous type of installation work envisaged; this company became our principal landscaper, and we developed a useful rapport over the course of the project. To illustrate the type of installation required (embedding rocks in a landscape to simulate the appearance of natural outcrops), the first author prepared a mockup using photo-editing software (Fig. 3[a]). The sedimentary rocks were installed with approximately constant strike and dip (157/19 SW) so as to outline two outcrop bands, but these bands were offset by a simulated fault. A faulted block bearing a slickenside, with calcite slickenfibers, was placed at an appropriate location on the trace of the simulated fault. By making appropriate measurements and constructions, students would be able to calculate the net slip. Igneous and metamorphic rocks were placed to the east to simulate a basement on which the sedimentary strata rested unconformably.

Following the successful use of Phase 1 in 2008 and 2009, a more ambitious Phase 2 (Fig. 4) was planned to incorporate a wider variety of rocks and structures. The basement igneous and metamorphic rocks of Phase 1 were moved eastward to incorporate a much larger range of sedimentary rocks representing the Western Canada Sedimentary Basin (Fig. 1), in which Edmonton is situated. Agreement was also obtained from the university to extend the garden westward, allowing us to simulate a region of allochthonous folded and thrust metamorphic rocks. In its current form, the Geoscience Garden includes ~80 simulated outcrops (Supplemental Materials Part A; available in the online journal and at <http://dx.doi.org/10.5408/15-133s1>), representative of geology that extends from the Canadian Shield, across the Western Canada Sedimentary Basin, and to the Canadian Cordillera in the west (Fig. 1). With support from colleagues teaching geophysics classes, we also were able to bury two hidden geophysical targets: a block of magnetite suitable for detection by magnetic surveying and a plastic-encapsulated stainless steel cylinder detectable with ground-penetrating radar. The garden occupies a region of ~450 m from east to west, with a variable north–south width of up to 150 m.

Sample Selection

In both phases of the garden's construction, repeated adjustments were made to details of the layout once the specific features of available rock samples became clear. Thus, a cycle developed in which a phase of planning was accompanied by the development of a wish list of samples. Efforts to secure samples corresponding to the wish list were variably successful; sometimes the samples we found contained different or additional features, such as unusual minerals or sedimentary structures. Once the samples were acquired, but before installation, adjustments were made to the plan so that the features could be used to the best advantage.

FIGURE 3: (a) Preinstallation mockup of the installed appearance. (b) Photograph of the installed sample with support. (c) Sample being moved into place by crane. (d) Students in the Geoscience Garden. (e) View of part of the Geoscience Garden with superimposed interpretation. The outcrop in the foreground includes the fault surface (pale). When extrapolated (broad dashed line), the fault offsets the stratigraphic boundary (narrow dashed line).



University of Alberta North Campus. Boxes enclose areas of Geoscience Garden phase 1 (Figure 2) and phase 2 (this figure).

FIGURE 4: Plan of Phase 2 of the Geoscience Garden as installed from 2010 to 2013. Inset shows the University of Alberta campus with the location of Geoscience Garden Phases 1 and 2.

Samples were obtained mainly from four types of sources:

- Quarries and open pit mines, with samples donated by operators
- Private farmland and public roadside locations, principally glacial erratics cleared during farming or development
- Parkland, particularly rocks excavated during highway construction through Banff National Park
- Samples sold for landscaping purposes by dealers

Criteria for sample selection included the following:

- Appropriateness of the sample for the planned use: samples needed to fit within the overall layout of the simulated geologic map
- Proximity to private or public roads: it was not possible to move samples weighing more than 1 ton from locations more than ~10 m from a road
- Size: the largest samples, weighing ~18 and 14 tons, presented significant challenges for installation because of the necessity of bringing large cranes onto a crowded site between mature trees
- Durability: friable lithologies and those subject to rapid weathering were avoided
- Owner access and permission: regulatory permission was required to move rocks from public roadways and from Banff National Park

Installation

Installation consumed the largest part of the available funds during the construction of the garden and presented a number of challenges. Samples arrived on campus in a sequence that was not ideal for placement, so a site was located for stockpiling samples for installation. A number of factors, not fully appreciated during the planning stages, affected the positioning of samples. The university required us to avoid placing rocks above numerous subsurface conduits for services such as water, electricity, and natural gas, some of which were not well located on plans. In addition, preservation of a stand of mature trees with shallow roots placed limits on the location and depth of excavations; the canopies of the same trees required delicate positioning of cranes when hoisting the larger samples.

In installing the rocks, it was hoped to achieve as natural an appearance as possible: these were to be simulated rock outcrops, embedded in the landscape. Few of the samples had flat surfaces on which they could be placed in the desired orientation. We therefore used a combination of built supports (Fig. 3[b]) and excavated pits to create the appearance of bedrock outcrops. When supports were built, they were constructed of smaller fragments of the same rock type as the sample. Pits, in which samples were partially buried, had to be dug initially to an approximate shape obtained by measuring the sample.

nce the supporting ground was prepared, a sample was lowered into a provisional position and its orientation was measured while still slung from the crane (Fig. 3[c]). Typically, the initial orientation needed to be adjusted; this was achieved by lifting the sample and inserting rock shims into the space below until the desired strike and dip were obtained. Wherever possible, the shims were placed so that they did not bear on the sling straps from which the sample was suspended, because these items needed to be retrieved for reuse by the crane operator. For samples with more than one fabric (e.g., bedding and cleavage), a rough placement was first made so as to achieve the required orientation of the more gently dipping plane; the sample was then raised and rotated, while suspended, and then lowered so as to give the line of intersection between the two fabrics the desired rake. In some cases, upward of a dozen trial-and-error adjustments were necessary to

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Siltstone
Spray River Group

Grès argileux
Groupe de Spray River

Kamenka Quarry near Canmore, Alberta
Provided by Kamenka Quarry Ltd.

GEOSCIENCE GARDEN

http://gg.eas.ualberta.ca/13

FIGURE 5: Example of the design for an informational plaque placed near a sample, including a digital QR code.

achieve a precision of within 5° of the target orientation, before the crane could be disconnected. These operations were learning experiences for all involved and required close onsite coordination among the designers, landscapers, and crane operators. We emphatically concur with the conclusion of Matty (2006) that, during installation, the presence of the designer geologists on site is essential.

Labeling, Signage, and Web Presence

The dual objectives of the Geoscience Garden necessitated care in the design of signage; it serves, on the one hand, as an outdoor classroom aimed at geoscience students and, on the other hand, as an outreach exhibit for teachers and members of the public. The initial design anticipated that each sample would be labeled with a plaque, identifying the rock type and giving basic information. Where rocks were provided by donors, the plaque would also identify the source of the donation. One of the questions most frequently asked by visitors to any geologic exhibit is "how old is this rock," so there was a desire to specify the age of the sample. However, this led to potential conflicts between instructional and outreach objectives; potential classroom uses would require students to use observations of the dip of strata, together with the principle of superposition, and to deduce a geologic history from their observations, not from the signage provided. This question was further complicated because not all rocks used were of known age, and in even where the age was known, in some cases the simulated geologic context of the sample in the garden was not the same as the real context of the rock where it was collected. Two solutions were tried for addressing these problems. In Phase 1, plastic covers were fabricated to cover informational signs during classes so that students would not have access to the information provided to outreach visitors. However, these proved time-consuming to place with the result that they were rarely used; because of this, students sometimes reported to instructors that they had deduced the relative age of the rocks from the plaques, not from the field evidence. Therefore, when the informational plaques were redesigned for Phase 2, age information was omitted from the plaque, but a digital quick response (QR) code (Fig. 5) was incorporated; for visitors with smartphones, this provides a link to a Web site providing additional information (listed in Supplemental Materials Part A, available in the online journal and at <http://dx.doi.org/10.5408/15-133s1>) that reveals both the actual age of the sample and the age simulated in the Geoscience Garden layout (if different). The Web site can be turned off if necessary for the duration of a lab exercise to prevent students from using information other than their own observations.

To supplement the plaques , larger signs were developed to provide general information about the garden, its purpose, and the geologic features simulated. Examples are shown in Fig. 6.

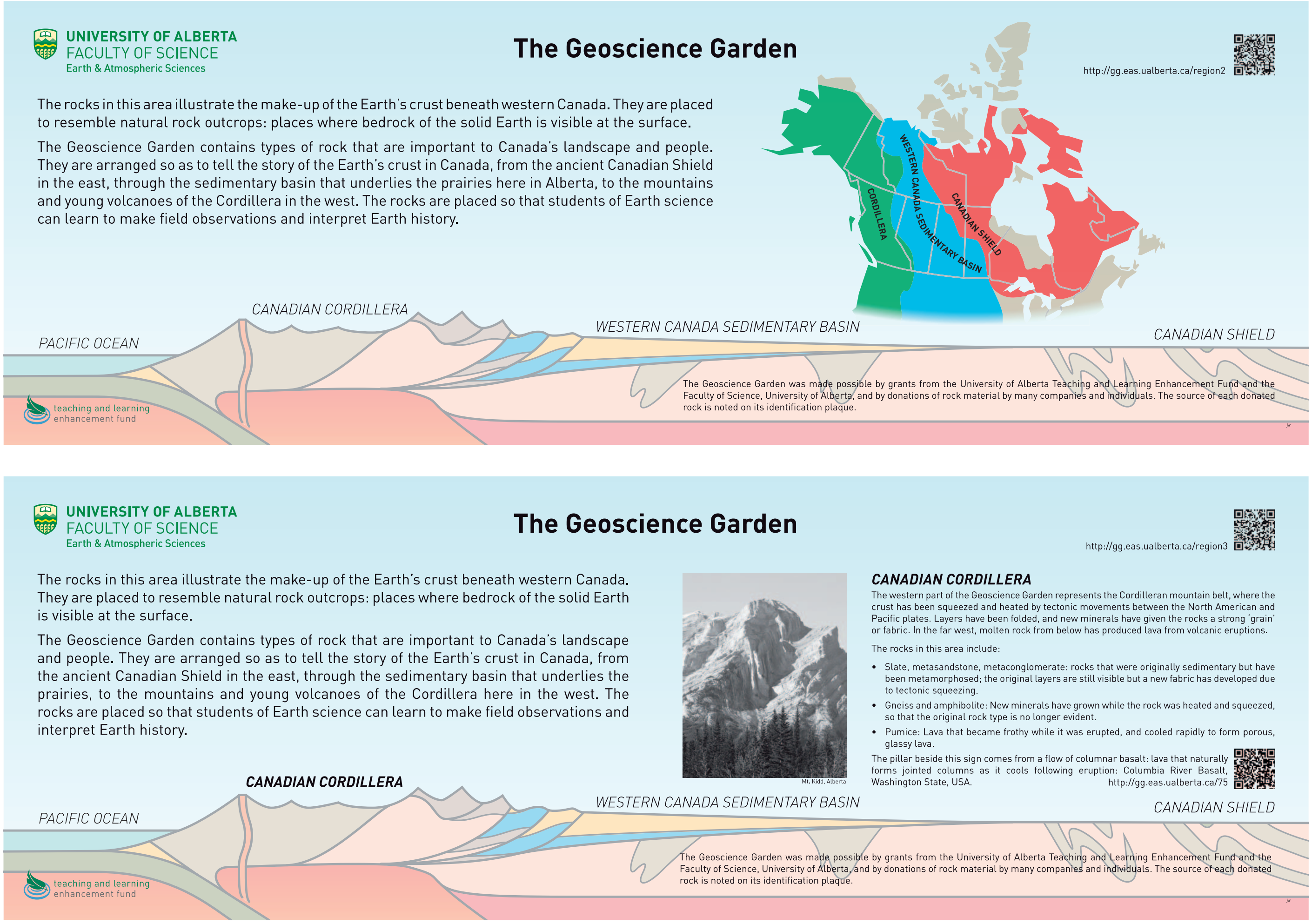
Uses of the Geoscience Garden

The garden provides opportunities to teach a range of skills. These include the following:

- Basic identification of a range of common sedimentary, igneous, and metamorphic rocks (See Supplemental Materials Part A, available in the online journal and at <http://dx.doi.org/10.5408/15-133s1>)
- Recognition of common rock-forming minerals
- Location and mapping of outcrops using both compass navigation and global positioning system (GPS)
- Recognition of certain fossils and biogenic structures in a field context (stromatolites, trace fossils, solitary and colonial corals, and ammonites)
- Recognition of sedimentary and tectonic structures, including graded bedding, lamination, cross-lamination and cross-bedding, folds, joints, veins, cleavage, schistosity, and gneissic foliation
- Measurement of the orientation of planar and linear structures using a compass clinometer
- Identification of mappable units among separated exposures of similar rock types
- Recognition, mapping, and interpretation of geologic contacts in discontinuous exposure
- Measurement of fault separation, determination of slip direction using slickenlines, and calculation of net slip on a fault
- Measurement, stereographic plotting, and interpretation of orientation data in an area of folded cleaved rocks
- Interpretation of shear zone kinematics from foliations in a shear zone

Before 2009, the classroom-based course EAS 233 Geologic Structures contained no outdoor components. The Geoscience Garden was first used in this course [Fig. 3(d)] starting in 2009, when the final lab exercise in the course was reconfigured to take place outdoors in Phase 1 of the Geoscience Garden. Subsequently, this work was expanded to include rocks installed in Phase 2 (Supplemental Materials Part B, available in the online journal and at <http://dx.doi.org/10.5408/15-133s2>). The Geoscience Garden has been used in each subsequent year and will continue to be used into the future. All students who attend second-year EAS 234 Geology Field School have now spent time in the Geoscience Garden.

Additional use has been made of the Geoscience Garden in a later course, EAS 421 Structural Geology and Tectonics. A group of low-grade metamorphic rocks,



UNIVERSITY OF ALBERTA
FACULTY OF SCIENCE
Earth & Atmospheric Sciences

The Geoscience Garden

http://gg.eas.ualberta.ca/region2

The rocks in this area illustrate the make-up of the Earth's crust beneath western Canada. They are placed to resemble natural rock outcrops: places where bedrock of the solid Earth is visible at the surface.

The Geoscience Garden contains types of rock that are important to Canada's landscape and people. They are arranged so as to tell the story of the Earth's crust in Canada, from the ancient Canadian Shield in the east, through the sedimentary basin that underlies the prairies here in Alberta, to the mountains and young volcanoes of the Cordillera in the west. The rocks are placed so that students of Earth science can learn to make field observations and interpret Earth history.

The Geoscience Garden was made possible by grants from the University of Alberta Teaching and Learning Enhancement Fund and the Faculty of Science, University of Alberta, and by donations of rock material by many companies and individuals. The source of each donated rock is noted on its identification plaque.

UNIVERSITY OF ALBERTA
FACULTY OF SCIENCE
Earth & Atmospheric Sciences

The Geoscience Garden

http://gg.eas.ualberta.ca/region3

The rocks in this area illustrate the make-up of the Earth's crust beneath western Canada. They are placed to resemble natural rock outcrops: places where bedrock of the solid Earth is visible at the surface.

The Geoscience Garden contains types of rock that are important to Canada's landscape and people. They are arranged so as to tell the story of the Earth's crust in Canada, from the ancient Canadian Shield in the east, through the sedimentary basin that underlies the prairies, to the mountains and young volcanoes of the Cordillera here in the west. The rocks are placed so that students of Earth science can learn to make field observations and interpret Earth history.

Mt. Kidd, Alberta

CANADIAN CORDILLERA

The western part of the Geoscience Garden represents the Cordilleran mountain belt, where the crust has been squeezed and heated by tectonic movements between the North American and Pacific plates. Layers have been folded, and new minerals have given the rocks a strong 'grain' or fabric. In the far west, molten rock from below has produced lava from volcanic eruptions.

The rocks in this area include:

- Slate, metasandstone, metaconglomerate: rocks that were originally sedimentary but have been metamorphosed; the original layers are still visible but a new fabric has developed due to tectonic squeezing.
- Gneiss and amphibolite: New minerals have grown while the rock was heated and squeezed, so that the original rock type is no longer evident.
- Pumice: Lava that became frothy while it was erupted, and cooled rapidly to form porous, glassy lava.

The pillar beside this sign comes from a flow of columnar basalt: lava that naturally forms jointed columns as it cools following eruption: Columbia River Basalt, Washington State, USA. http://gg.eas.ualberta.ca/75

The Geoscience Garden was made possible by grants from the University of Alberta Teaching and Learning Enhancement Fund and the Faculty of Science, University of Alberta, and by donations of rock material by many companies and individuals. The source of each donated rock is noted on its identification plaque.

FIGURE 6: Examples of informational signs placed near the boundaries of the Geoscience Garden.

obtained from the Neoproterozoic Windermere Supergroup in Banff National Park, is arranged to simulate a plunging anticline with axial-planar cleavage (Fig. 7). Students make measurements of both bedding and cleavage planes, together with fold hinges (visible in two samples) and bedding-cleavage intersection lineations, to deduce the overall structure of the fold. The samples are sufficient in number for students to be able to plot their measurements on stereographic projections and compare the statistically determined fold axis with the measured hinge and intersection lineation orientations (Fig. 7; text of assignment also included in Supplemental Materials Part B, available in the online journal and at <http://dx.doi.org/10.5408/15-133s2>).

In addition to these specific projects in teaching structural geology, the Geoscience Garden has been used by a number of other geoscience courses offered at the University of Alberta and by numerous visits from primary and secondary education groups (Supplemental Materials Part C, available in the online journal and at <http://dx.doi.org/10.5408/15-133s3>). During and following installation, we have become aware of number of unanticipated uses. In the summer, parts of the Geoscience Garden have become popular locations for lunches; several of the rocks make convenient seats. The University Faculty Club, located at the west end of the garden, is a popular location for wedding receptions, and many wedding photographers have used the rocks to pose groups for wedding photography. We do not discourage these types of use, because we consider increased awareness of rocks and their setting in the landscape to be beneficial both to geoscience programs at the university and, more broadly, to awareness of geologic heritage among the public. One problematic use involved the geocaching community, which placed a cache among the supporting rocks in one of the simulated outcrops. We would have liked to support this activity, but unfortunately, because of the limited precision of handheld GPS receivers, some geocaching enthusiasts started to displace support rocks from several nearby samples in efforts to locate the cache. We were able to contact the owner through the geocaching Web site to make him aware of this problem; he agreed to move the cache to another location. Subsequently, other GPS-based groups have made extensive use of the garden as a target area without detriment to the installation.

STUDENT EVALUATION OF THE GARDEN

Methods

A principal aim of the Geoscience Garden was to facilitate the transition from classroom-based learning to the field environment. We realized that directly comparing students' learning outcomes at field school from year to year would not be practical or ethical: the field school

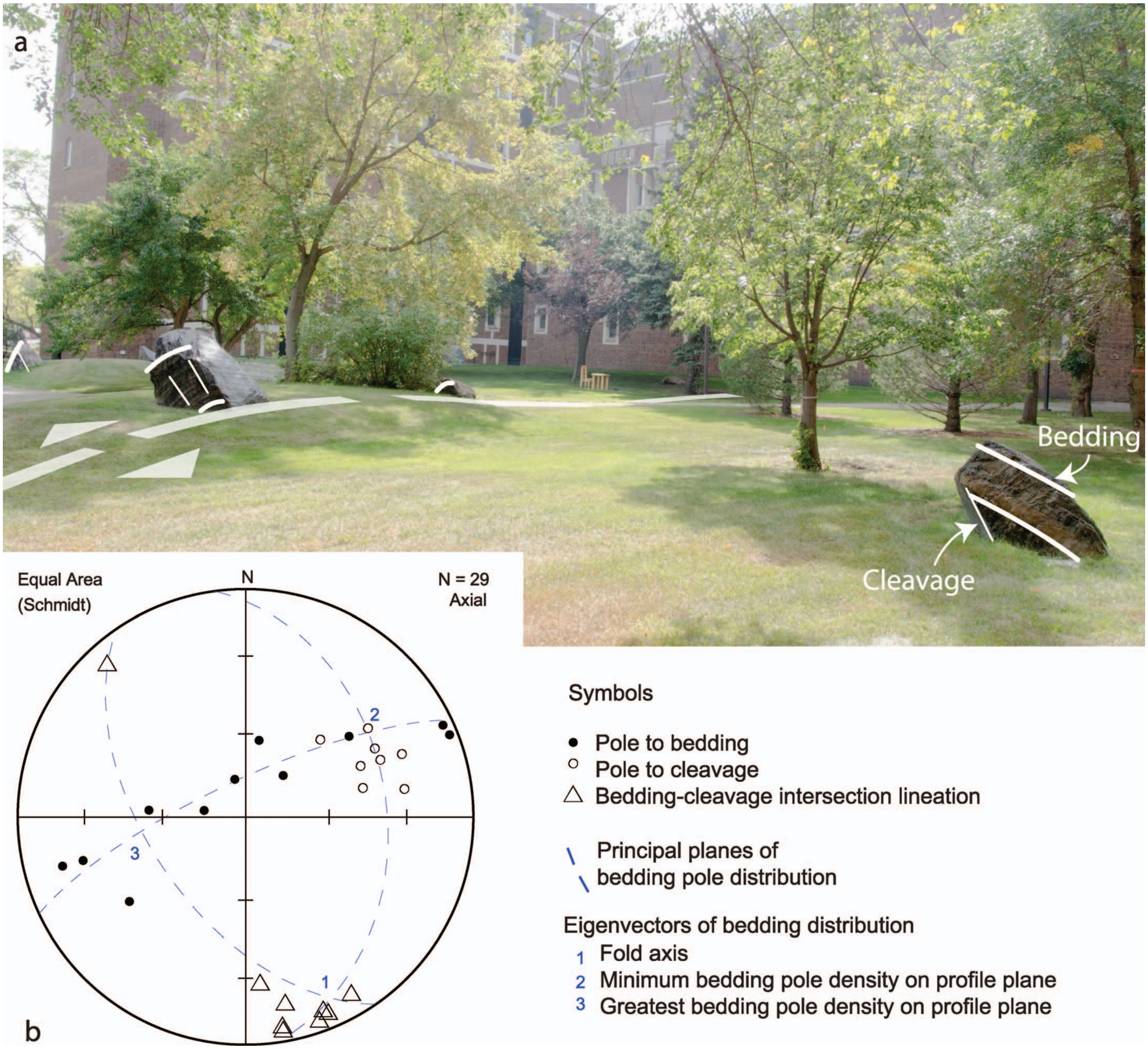
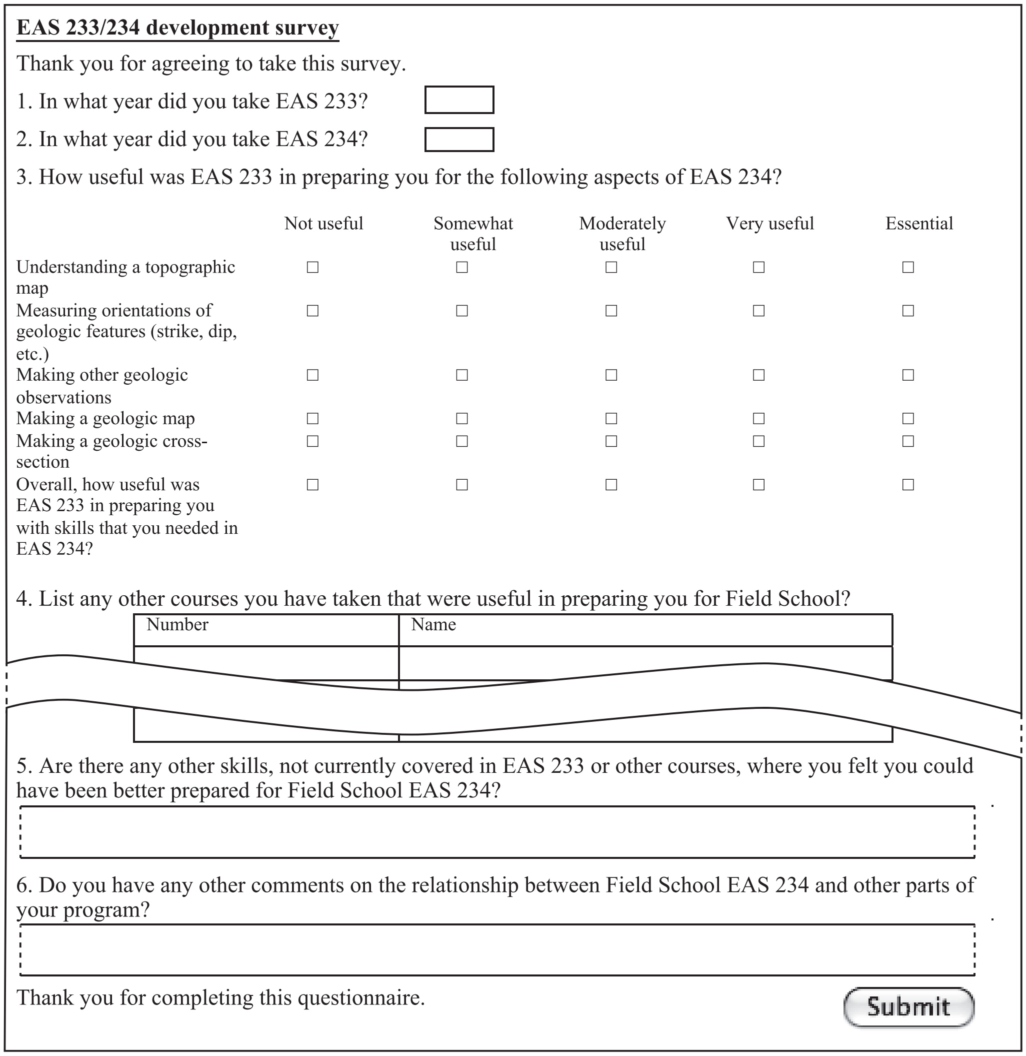


FIGURE 7: (a) View of the region of the Geoscience Garden that simulates a fold in metasandstone and slate with axial planar cleavage. The broad dashed line marks the trace of the simulated antiform. Lines on outcrops show typical traces of bedding (folded) and cleavage (∼constant orientation) across the area. (b) Stereographic equal-area projection of measurements in the area shown in (a) by a pair of students.

experience inevitably varies due to logistical factors, including weather and instructional staff, and evaluating student and instructor performance outside the regulated examination and course evaluation processes is prohibited by university regulation. To evaluate the achievement of our objective, we therefore followed most previous research in the area (e.g., Stokes and Boyle, 2009) by asking students their opinions of the experience. In particular, we adopted a metacognitive approach (Mogk and Goodwin, 2012), concentrating on students' perceptions of their learning experience. An online questionnaire (Supplemental Materials Part D, available in the online journal and at <http://dx.doi.org/10.5408/15-133s4>) was developed and approved by the University of Alberta Human Research Ethics Board. Most of the questions (Fig. 8) focused on the relationship between the classroom-based course EAS 233 Geologic Structures (and other classroom-based courses the students might have taken) and the field-based course EAS 234 Geology Field School. The survey contained both purely qualitative questions, in which students were asked to comment on the relationship between the courses, and more quantitative questions that invited evaluation of the utility of the classroom-based course on a 5-point scale between "not useful" and "essential" (Fig. 8).

Students taking the field course EAS 234 Geology Field School were surveyed after they had taken both EAS 233



EAS 233/234 development survey

Thank you for agreeing to take this survey.

1. In what year did you take EAS 233? ☐

2. In what year did you take EAS 234? ☐

3. How useful was EAS 233 in preparing you for the following aspects of EAS 234?

	Not useful	Somewhat useful	Moderately useful	Very useful	Essential
Understanding a topographic map	☐	☐	☐	☐	☐
Measuring orientations of geologic features (strike, dip, etc.)	☐	☐	☐	☐	☐
Making other geologic observations	☐	☐	☐	☐	☐
Making a geologic map	☐	☐	☐	☐	☐
Making a geologic cross-section	☐	☐	☐	☐	☐
Overall, how useful was EAS 233 in preparing you with skills that you needed in EAS 234?	☐	☐	☐	☐	☐

4. List any other courses you have taken that were useful in preparing you for Field School?

Number	Name

5. Are there any other skills, not currently covered in EAS 233 or other courses, where you felt you could have been better prepared for Field School EAS 234?

6. Do you have any other comments on the relationship between Field School EAS 234 and other parts of your program?

Thank you for completing this questionnaire.

FIGURE 8: Survey questionnaire, showing the main questions exploring the relationship between the classroom-based course EAS 233 Geologic Structures and the field course EAS 234 Geology Field School. Complete questionnaires are provided in Supplemental Materials Part D (available in the online journal and at <http://dx.doi.org/10.5408/15-133s2>).

Geologic Structures and EAS 234. (Students are not permitted to take EAS 234 without first taking EAS 233.) The same questionnaire was administered in 2008 before installation of the garden and in 2009 after installation of Phase 1 and modification of EAS 233 Geologic Structures to incorporate a wider range of activities, including work in the Geoscience Garden. The framing of the questionnaire clearly distinguished it from other course and instructor evaluation procedures in operation at the University of Alberta and contained elements to assure students of their anonymity and freedom from negative impacts should they choose not to answer (requirements for all research on human subjects at the University of Alberta). The answers to qualitative questions were analyzed using interpretive coding. The resulting categories and answers to quantitative questions were analyzed using descriptive statistics. The chi-square test was used to determine whether there were significant differences in responses between postinstallation and the preinstallation surveys. Full details of the survey are summarized in Supplemental Materials Part D (available in the online journal and at <http://dx.doi.org/10.5408/15-133s4>). Results are shown in Figs. 9 and 10 and Supplemental Materials Part E (available in the online journal and at <http://dx.doi.org/10.5408/15-133s5>).

Results

Out of 58 students who took the field course in the preinstallation year, 30 responses were received. In the answers to qualitative questions (Fig. 8, questions 5 and 6) a high number of participants in the preinstallation survey (13 of 30 respondents) evaluated field school positively, with comments such as "it was a good learning experience" and "useful." Some of the issues they specified were "I learned a lot of my skills that will help me in my future career," "it gave an appropriate introduction to field methods," and "it is super crucial to becoming a field geo." Four participants mentioned the relevance of the course with answers such as "it provides a student with real world examples and applications to the theory we learn in lectures."

Participants were asked about skills in which they felt they could have been better prepared for field school (Fig. 8, question 6). Of 30 participants, 16 identified such skills;

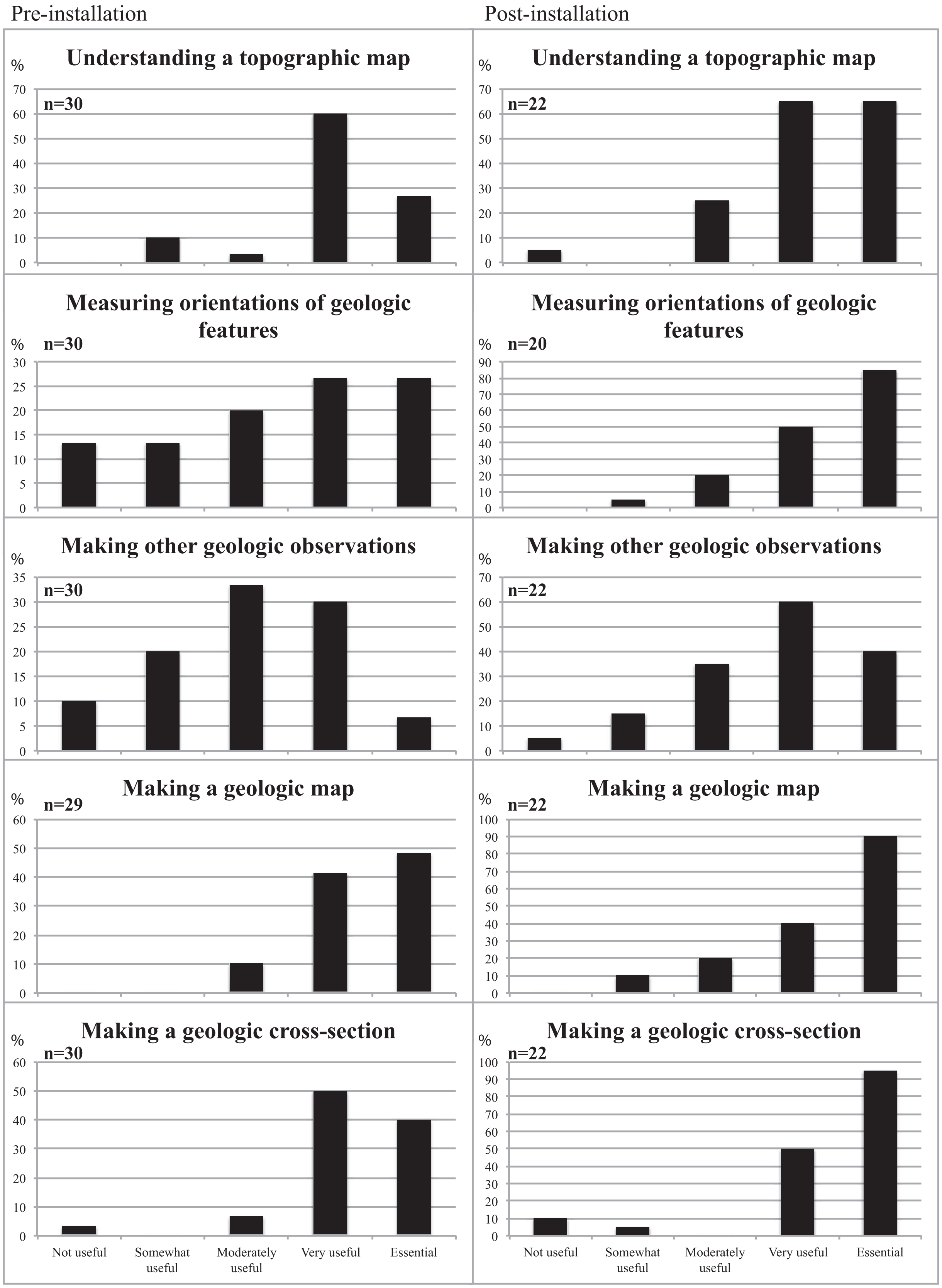


FIGURE 9: Comparison of survey results in 2008 and 2009 for questions 3.1 to 3.6, asking students how well the content of EAS 233 Geologic Structures prepared them for EAS 234 Geology Field School.

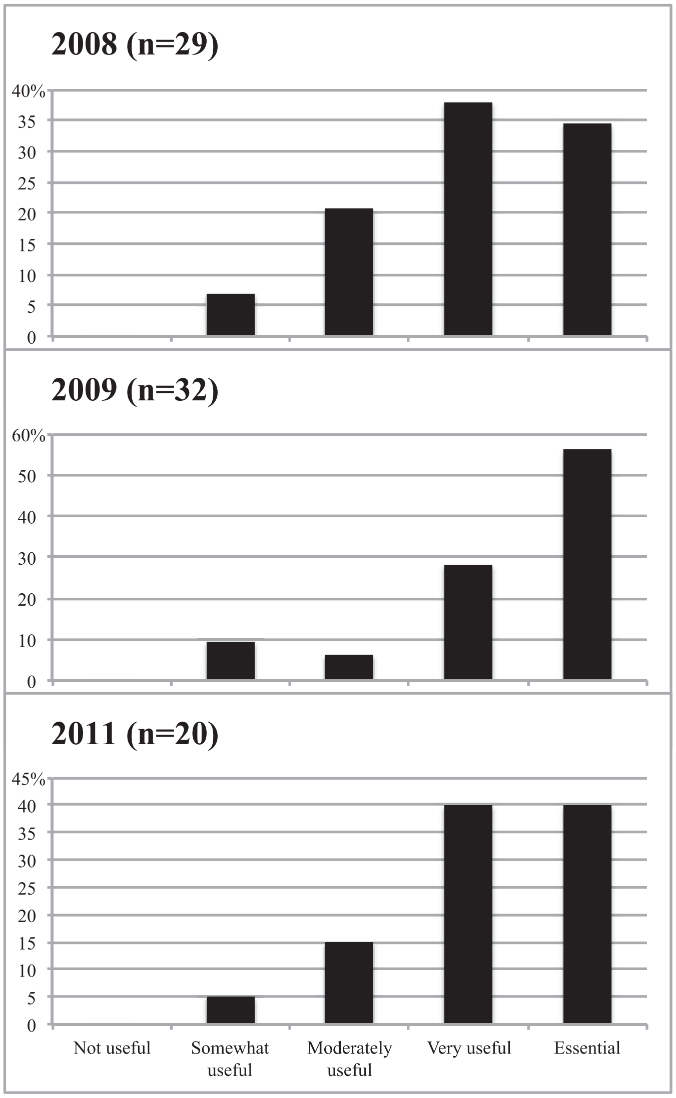


FIGURE 10: Comparison of survey results in 2008, 2009, and 2011 for question 3.6: "Overall, how useful was EAS 233 in preparing you with skills that you needed in EAS 234?" (Note: 2010 is omitted because EAS 233 was taught by a different instructor).

those most mentioned were measuring orientations of geologic features (9 participants); mapping skills (6 participants), and making a geologic cross-section (4 participants). A minority (3 participants) specified there were no skills for which they felt they could have been better prepared for field school, commenting "I felt very confident in the skill set that was required to complete the Field School" and "the prerequisite courses to the Field School covered the needed topic well." Of 30 respondents, 12 referred to reality (the field) being different from what is taught in theoretical classes or in the lab. They said that in class they are given "idealized theoretical examples" and in the lab they observe "samples" that are "ideal," "not real." Most of these participants (9) expressed how difficult it is to measure things even after being trained for it in previous courses. Some participants (4) highlighted the importance of meeting "real world examples" as geology students.

When respondents were asked to rate their classroom-based experience on a 5-point scale, most respondents (Fig. 9) rated the classroom-based course as "very useful" or "essential" in preparing them for six aspects of field school. The two aspects considered the most useful were understanding a topographic map (considered useful for 18 respondents and essential by 8 respondents) and measuring orientations of geologic features (considered useful and essential by 8 respondents each).

A second, postinstallation survey was completed in the following year by students returning from field school who took one lab session in the developing Geoscience Garden during the earlier course. Out of 71 students attending field school, 32 responses were received. As in the previous year, most evaluations of field school were positive. The largest number of responses (13) emphasized it was an enriching learning experience. Some of the comments made were "superb course and I learned so much from it," "extremely useful tool to help learn real world skills, and "it is an essential part of the program because it teaches you what geology is actually about."

In the questions that required a rating of the classroom-based course on a scale from "not useful" to "essential," a much higher proportion (56%, compared with 32% in the preinstallation survey) found EAS 233 Geologic Structures "essential" as a preparation for EAS 234 Geology Field School and a lower proportion (15% versus 28%) found it "moderately useful" to "not useful" (Fig. 10). This contrast extended to all subdisciplines for which the question was asked (Fig. 9).

In the qualitative questions, answers given by participants in the postinstallation survey were quite different from answers given by participants the previous year. Students felt better prepared for field school in measuring orientations of geologic features; a lower number of participants (3% versus 12%; $p = 0.014$) mentioned they felt they had weaknesses in this skill. However, in the postinstallation survey, a larger proportion (10% versus 5%) indicated they could have been more prepared in the skills of making a geologic cross-section. When referring to the skill of making other geologic observations, answers in both surveys were similar (full numerical results are shown in Supplemental Materials Part E, available in the online journal and at <http://dx.doi.org/10.5408/15-133s5>).

When talking about courses that helped them prepare for field school, many respondents in both years mentioned work done in EAS 233 Geologic Structures and made suggestions for improvements. These suggestions were made slightly less frequently in the postinstallation survey (4 versus 11 occurrences). The nature of the suggestions varied. In the first survey, many of these students would have liked more experience with basic observation techniques, such as measuring orientations. In the postinstallation survey, more of the comments sought more experience in the more advanced areas of map and cross-section construction using realistic field data.

Additional questions were asked in the postinstallation survey, after installation of Phase 1 of the Geoscience Garden. When asked what aspect of the Geoscience Garden was most useful in preparing students for field school, a high portion of respondents (21 of 32 respondents) answered it was the skill of measuring orientations of geologic features. They stated, for example, that the

Geoscience Garden "was very useful in learning how to take proper orientation measurements of the rocks," "like we would do in the field," and "it's good to see real examples rather than pictures." A smaller group of respondents (5) said the Geoscience Garden was useful in preparing students for "properly making geologic observations and describing an outcrop entirely." Another pair of respondents mentioned how useful it was in preparing students for making a geologic map "in real world situations." Some respondents (10) gave general answers to the question by saying that all the learning experience of the Geoscience Garden was helpful. Some of the comments made were: "the little rock garden was really cool and useful, I was not expecting to have such a privilege," it was "quite useful in applying aspects that would be used in field school such as mapping in a real world situation," "hands-on experience is priceless," and "it help you become a better geologist."

A second question asked what aspect of the garden was least useful. Some respondents (3) answered, "nothing, everything was helpful." Another group (3 respondents) said the low diversity of samples in the Geoscience Garden was not really useful and that "more variety like what we would see in the field would be helpful." Another group (3 respondents) said the exercise of mapping the Geoscience Garden was not useful. They complained about this exercise, saying for example that "the fact that you have to pace everything out was relatively annoying and in my opinion no [*sic*] particularly useful."

A final question asked for suggestions for improving the Geoscience Garden with future development. The most cited (by 8 respondents) was to have a higher diversity of rocks, "like what we would see in the field." Some of them specified it would be interesting to "add more rocks from different depositional environments," "have igneous and metamorphic rocks as well," and "more fosiliferous and rarer mineraled rocks." A related suggestion (5 respondents) was to add more rocks to the Geoscience Garden. Two students extended the answer by saying: "rocks at other locations around the university would better prepare students for Field School and for large scale mapping situations," and "if the garden is actually set up to connect together to form folds and there are difference types of rocks to simulate formations, that would have been extremely useful." A pair of respondents stated there were "no big suggestions, it's great!"

The results of these surveys were important in the development of the garden. First, they were included in our successful application for further funding to extend the garden beyond the limited area of Phase 1. Second, they provided some guidance for the types of rocks and their arrangement in the extended garden.

Additional surveys were undertaken in 2010 and 2011, though response rates were lower, perhaps reflecting the increasing prevalence of Web surveys in student life. In 2010, the first author took sabbatical leave and EAS 233 Geologic Structures was taught by a different instructor, making comparison with the earlier data inappropriate. Results from the 2011 survey, though less striking than those in 2009, show the Geoscience Garden continued to add value to both courses in comparison with the preinstallation data (Fig. 10).

DISCUSSION

We believe the Geoscience Garden project has benefited us as teachers, our students, and our outreach community. There are inevitably a number of areas in which hindsight allows us to identify things we could have done differently and, following Matty (2006), to offer useful suggestions to others contemplating a similar installation.

Interactions with university administrators, construction personnel, and landscapers brought home to us the different ways in which landscape features are perceived by geologists and nongeologists. Most of those without geologic training did not immediately perceive a difference between bedrock outcrops, in which in-situ rock protrudes through the landscape from below, and glacial erratics (common in the Edmonton area) that sit upon the landscape and are not connected to bedrock. In this respect, the initial mockups in Photoshop (Fig. 3[a]) were extremely useful in conveying the appearance we wanted to achieve. The act of explaining this difference to our landscapers increased our own awareness of a skill not normally explicitly taught to trainee geoscientists in the classroom but nonetheless acquired by most geoscientists during field training: the ability to use cues in the landscape to distinguish "outcrop" from "float." Despite our efforts, not all samples look convincingly like outcrops to the professional geoscientist; in some areas, the protection of mature tree root systems prevented us from creating as natural an appearance as we would have liked, and some of our "outcrops" have a resemblance to glacial erratics or standing stones.

Late in the project, we encountered unexpected resistance to our aspirations to erect signs to explain the garden to outreach users. The Office of the University Architect had developed new rules restricting the size and format of signs on campus that limited us to four signs and prevented us from attaching signs to two basalt columns that we had hoped to use in this way. Visitors approaching from some directions do not see an explanation for the puzzling presence of large rocks in the campus landscape.

The climate of Edmonton, in combination with the timing of university terms, restricts our use of the garden to the first half of the fall term (September to October) and the last three weeks of the winter term (late March and April). From November to February, the temperature is normally below 0°C and the rocks are frequently snow covered. During the spring melt, the greater heat absorption of the darker rocks helps to melt the snow around them, and some are temporarily surrounded by ice-cold puddles. Despite the relatively benign environment compared to field school, we still have to caution students to bring appropriate clothing and footwear for the labs that take place in the Geoscience Garden.

Our systematic evaluation of the garden has so far been limited to students who receive formal instruction in the garden as part of their geoscience program, the initial target population. We are happy to see widespread use by other groups, but these aspects are more difficult to quantify. There is no bounding barrier or fence around the garden and no formal admission process; members of the public can pass through freely, and instructors of other classes may use the garden on an ad hoc basis, without formality. We are limited in our ability to survey these users, both by these practical concerns and by university regulations guarding the privacy of students and instructors not involved in the design of the garden. If sufficient resources are available, we envisage counts of users on representative, randomly selected days during and outside university term, supplemented by brief interviews of visitors, to determine their level of awareness about the facility and the aspects of Earth Science that it displays. We also plan to place a counter to record visits to the Geoscience Garden Web site.

Finally, we reiterate that a careful balance between teaching and outreach objectives is necessary in any facility of this type. The outdoor installations reviewed previously adopt different positions in the spectrum between "outdoor laboratory" and "outdoor museum." Our primary objective, to encourage students to make discoveries and interpretations from their own observations, meant that didactic material posted on signs around the site was necessarily limited, even before the intervention of the Office of the University Architect. Our experience during the early stages of the project led to small design changes to avoid situations in which students, doubtful of their own interpretations, resorted to information provided for outreach visitors. We have endeavored to supplement the limited signage with brochures and information available on the Web, accessible via QR codes installed in the garden (Fig. 5).

CONCLUSIONS

The Geoscience Garden is a unique facility designed to teach undergraduate students skills that are important in geologic mapping: good observations, 3D visualization, and interpretation of geologic histories. The garden also has an important outreach capability, bringing awareness of the role of solid Earth in landscapes and human activity to a broader community, including primary and secondary school children, members of the university community, and the public. The Geoscience Garden has been well received by our students. Our surveys have shown that students perceive that it has helped bridge the conceptual gaps between theoretical classroom-based teaching and the practice of field geology. It also helps students new to fieldwork to prepare for the physical and mental challenges of the field experience in an accessible campus environment.

Acknowledgments

At the University of Alberta, we are grateful to Wayne McCutcheon and University of Alberta Buildings and Grounds Services for guidance and assistance throughout the project and to the Office of the University Architect for making available the site for the Geoscience Garden. Initiation of the project received enthusiastic support from the Faculty of Science, including Greg Taylor, Brenda Leskiw, and Rob Holte. The project could not have been undertaken without the generous support of the University of Alberta Teaching and Learning Enchantment Fund, for which we thank Carl Amrhein, Olive Yonge, Bill Connor, and Theresa Curry. Katherine Boggs and the staff of Mount Royal University helpfully shared their experiences with an outdoor geoscience installation. In the Department of Earth and Atmospheric Sciences, we particularly thank Igor Jakab for masterminding our Web presence; Mary-Jane Turnell, Martin Sharp, and Rob Creaser for handling diverse administrative needs; and Tom Chacko, Theresa Garvin, and Lisa Budney for their help in various stages of the project. Much of the landscaping was undertaken by Edmonton Stone Designers, led by Doug and Michele Fowler. We are indebted to Aecon Construction Group Inc., Baymag Inc., Commerce Resources Corp., Devon Energy, Graymont Ltd., Louis Kamenka Quarries, TransAlta Corp., and Unimin Corp. for samples. We are indebted to Parks Canada for allowing us to use numerous rocks displaced by road-building operations in Banff National Park and to Alberta Sustainable Resource Development for access to boulders from Crowsnest Pass. We are most grateful to the students of EAS 233, 421, and 521 for their participation in and enthusiasm for the development of the garden. Finally, we thank journal editor Kirsten St. John, the journal's curriculum and instruction editor and associate editor, and two anonymous reviewers for their helpful comments.

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