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Undergraduates Discovering Folds in "Flat" Strata: An Unusual Undergraduate Geology Field Methods Course

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ABSTRACT

Undergraduates learned to measure, map, and interpret bedding plane attitudes during a semesterlong geology field methods course in a field area where strata dip less than 9°. Despite the low dip of the strata, 2011 field course students discovered a half-kilometer-wide structural basin by using digital levels and Brunton pocket transits to measure bedding plane attitudes at numerous outcrops along a riparian greenway. Students reproduced faculty dip directions in all five structural domains and mean bedding plane attitudes in four of five structural domains ($p < 0.05$). Of 21 students who completed a field map, only 6 had trouble either measuring and plotting attitudes or drawing and labeling geologic contacts. The mean student evaluation score was 4.1 on a 5-point scale, and all seven evaluation category means were well within one standard deviation of departmental means. However, the course evaluated poorly relative to the other five junior- and senior-level geology courses taught during fall 2011 because mean evaluation scores for those courses ranged from 4.2 to 4.9. Results show that students can learn to measure, map, and interpret bedding plane attitudes in a field area where strata dip less than 10°. © *2014 National Association of Geoscience Teachers*. [DOI: 10.5408/12-371.1]

Key words: field geology, structural geology, undergraduate education, platform

INTRODUCTION

Many geology undergraduates complete a semesterlong introductory field methods course during the academic year, and then they complete a comprehensive nonacademic year summer field camp (e.g., Douglas et al., 2009; Puckette and Suneson, 2009; Sisson et al., 2009). The measurement and interpretation of bedding plane attitudes (Fig. 1) is a major component of these courses. For practical reasons, undergraduates enrolled in the introductory field course generally investigate the geology of an area close to their campus. However, in many places within the North American interior, the rocks near campus are poorly suited to the investigation of bedding plane attitudes because the strata are nearly flat (dip less than 10°). To get around this problem, many instructors simulate outcrops and structures with tilted wooden boards or other means (Greenberg, 2002; Benison, 2005; Matty, 2006; Benson, 2010). In contrast, this paper describes an introductory geology field methods course in which undergraduates discover folds by measuring, interpreting, and mapping the attitudes of subhorizontal bedding planes near the Middle Tennessee State University (MTSU) campus in Murfreesboro, Tennessee.

What Is Original About Undergraduates Discovering Folds in Nearly Horizontal Strata?

Almost all undergraduate geology field courses and summer field camps are taught in areas where the dip of most strata exceeds 10° and the range of dip measurements exceeds 15°. Indeed, little has been published on field experiences in which students discover folds by measuring the orientation of strata dipping less than 10°. For example, some of the papers in the *Journal of Geoscience Education* special issue on teaching in the field (e.g., Anderson and Miskimins, 2006; Hemler and Repine, 2006) describe field experiences in which students measure bedding plane attitudes, and all of these experiences use areas where dips exceed 10° and the range of dip measurements exceeds 15°. Likewise, many Geological Society of America special papers on field geology education (e.g., Douglas et al., 2009; Puckette and Suneson, 2009; Sisson et al., 2009) describe field experiences in which students measure bedding plane attitudes in moderately and steeply dipping strata. See Mogk and Goodwin (2012) and Liben and Titus (2012) for vignettes describing typical geology field activities in areas where the dip of most strata exceeds 10° and the range of dip measurements exceeds 15°.

Other types of field experiences (e.g., LaSage et al., 2006; Tedesco and Salazar, 2006; Lee et al., 2009) can be taught in areas with nearly horizontal strata, but those experiences are not like the one described in this paper and in the papers cited above because the measurement, mapping, and interpretation of bedding plane attitudes are not major parts of those experiences. The collection and interpretation of bedding plane attitudes are central to field geology courses of the kind described here because two major goals of these courses are (1) preparation of undergraduates for a summer field camp of the kind described by Sisson et al. (2009) and (2) providing a field camp–like experience to undergraduates who do not complete a summer field camp. Beyond undergraduate education, a field geology course of this kind acquaints undergraduates with the kinds of bedrock data, interpretations, and geologic structures encountered in groundwater, mining, oil, and natural gas investigations.

Why Move an On-Campus Geology Field Course Into the Field?

Given the novelty of undergraduates discovering folds by measuring, mapping, and interpreting bedding plane attitudes in subhorizontal strata, why not have students

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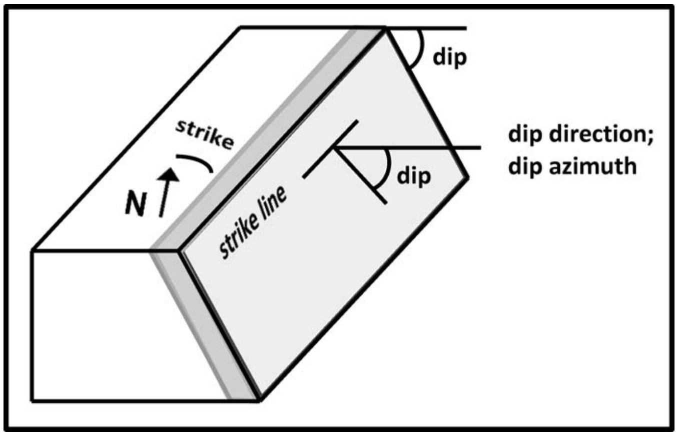

FIGURE 1: Orientation of a bedding plane (gray). The strike line is a horizontal line on the surface of the bedding plane, and the orientation of the strike line can be described as an azimuth (a horizontal angle between 0 and 360° measured clockwise from north with a compass). The dip direction is perpendicular to the strike line and can be described as a direction (e.g., east) or as an azimuth. The dip is tilted from the horizontal plane and measured in degrees with a clinometer. A horizontal plane dips 0°, and a vertical plane dips 90°. A Brunton pocket transit is useful for measuring the orientation of bedding planes because it is a tool combining a compass and a clinometer. There are no set definitions for qualitative descriptions of dip, but gently dipping rocks are subhorizontal (close to a 0° dip) and rocks dipping more than 60° are often described as steeply dipping.

learn to make and interpret observations by measuring the attitude of moderately and steeply dipping wooden boards on campus? I moved the field course into the field because many geoscientists think authentic field experience is inherently different from nonfield alternatives and many think field experiences provide educational benefits not conferred by the alternatives. A few reasons are listed here:

- Importance to the community of practicing geologists. As described in recent reviews of the literature, there is a long history of field courses within undergraduate geology programs (e.g., Whitmeyer et al., 2009a; Mogk and Goodwin, 2012). In recent years, 99% of undergraduate geology programs have required some kind of field experience (Mogk and Goodwin, 2012), and summer geology field camp enrollments were generally stable between 1998 and 2008 (Whitmeyer et al., 2009a). In addition, the publication of a field geoscience education theme issue of the *Journal of Geoscience Education* (Manduca and Carpenter, 2006) and a Geological Society of America special paper (Whitmeyer et al., 2009b) show that field geology education remained important during the first decade of the 21st century.
- Positive impact within the affective domain. For many students, field courses may be motivational (Mogk and Goodwin, 2012), fostering connections with Earth as described in van der Hoeven Kraft et al. (2011) and mentioned in McConnell and van der Hoeven Kraft (2011).
- Educational growth by overcoming challenges. Field courses may provide unique opportunities for growth because students have to surmount challenges including geographical, cognitive, and psychological barriers (Orion and Hofstein, 1994; Atchison and Feig, 2011) and disembedding tasks (Goodwin, 1994; Mogk and Goodwin, 2012), which differ from those in nonfield alternatives.
- Embodiment. Field learning engages the student's sensory and motor systems in ways that differ from classroom and simulated experiences. Indeed, Mogk and Goodwin (2012) specifically use the measurement of bedding plane attitudes in a natural environment and mapmaking in the field as examples of embodied learning, and Hutchins and Renner (2012) elaborate on these examples.
- Making and interpreting first inscriptions. By making and recording observations, students gain firsthand experience with the beginning of the chain of inscriptions, which constitute the body of scientific knowledge (Hutchins and Renner, 2012; Mogk and Goodwin, 2012).
- Initiation into a community of practice. Culturally, a field geology course provides an initiation into the community of geologic practice (e.g., Mogk and Goodwin, 2012; Stokes and Feig, 2012), and Hutchins and Renner (2012) suggest that students may even pick up scientific behaviors without being aware that they are learning these behaviors.

Some Reasons to Not Move an On-Campus Geology Field Course Into an Unusual Field Area

As described above, the MTSU geology field course differs from existing experiences, so it is reasonable to question the applicability of the reasons listed in the prior section. For example, the practitioner community largely agrees that field experiences are important, but to this community, "field experience" means experiences like those described in the peer-reviewed literature (e.g., Manduca and Carpenter, 2006; Whitmeyer et al., 2009b). The lack of field geology courses like the one described in this paper could be seen as evidence that the community does not think this kind of field geology course is important, although this kind of criticism could be leveled against any innovation. Also, given the differences between the course described here and other field experiences, one could reasonably question whether undergraduates are being initiated into the same community of practice.

In addition, a field course like the one described here may be more challenging, perhaps so much so that student performance and student attitudes could be significantly harmed. Students might experience great difficulty learning to measure and interpret bedding plane attitudes in an area where strata are nearly horizontal because the embodied experience differs from that in other field geology courses. Specifically, students learning to measure the attitude of moderately and steeply dipping bedding planes can clearly see that the rocks are dipping, and they can feel the tilt of their Brunton pocket transits when they are measuring the dip. They can also see that large differences in dip (e.g., 10 versus 40°) lead to different numerical measurements with the clinometer on a Brunton transit. In addition, students walking through an area can clearly see that strata at one location dip in one direction (e.g., 15° southwest) and strata at another location dip in another direction (e.g., 20° northeast), helping them discover folds more easily. In contrast, students examining gently dipping bedding planes have trouble seeing that the rocks are dipping, that dip varies (e.g., 2 versus 8°) from location to location, and that the strata dip in different directions at different locations. Given these challenges, it is also reasonable to question the positive impact of the MTSU field geology course within the affective domain. In addition to becoming frustrated because of the challenges involved in making and interpreting measurements, students might be less motivated because they cannot see (unaided by tools) spectacular folds.

WORKING HYPOTHESIS

By fall 2009, I thought faculty, graduate, and undergraduate research had shown that if I moved large parts of the on-campus geology field course off campus, the course would work because the benefits described earlier would outweigh the preceding disadvantages. My hypothesis was based in part on Vanderbilt University master's theses (Berquist, 1970; Matthews, 1971) and my faculty research (Abolins, 2010), which showed that it is possible to measure the attitude of subhorizontal strata in central Tennessee. Furthermore, Abolins (2010) described a potential undergraduate geology field area containing a previously undescribed half-kilometer-scale structural basin within 2.7 km of the MTSU campus. Mentored undergraduate research, which was externally funded through the National Science Foundation (NSF) Science, Technology, Engineering, and Mathematics Talent Expansion Program (STEP), showed that 10 undergraduates (seven male and three female) could also measure and interpret the attitudes of subhorizontal bedding planes. (These results are not described here because undergraduate research is tangential to the theme of this paper.) Undergraduate research showed that students with a range of interests and abilities could learn to make and interpret the measurements because four of the undergraduates were nongeology science, technology, engineering, and mathematics (STEM) majors; had almost no prior Earth Science knowledge; and had ACT math scores below 21. However, a few nongeology STEM majors who chose to participate in a special undergraduate research program are not necessarily representative of a larger population of geology majors who are required to take a field course.

Consequently, I examined student performance (ability to measure, map, and interpret bedding plane attitudes) and student attitudes (course evaluations) in the MTSU Field Methods in Geology course during fall 2009 (see the Formative Assessment section below) and fall 2011 (see the Summative Assessment section below). As described in the Discussion section, these results suggest that overall students perform well and have a positive attitude about the course and that remaining problems in the course can be addressed by modifying how the course is taught (e.g., the number of assignments or the amount of academic credit) as opposed to a return of the course to campus. The study demonstrates the feasibility of offering an unusual field geology course, opening the door to more comprehensive phenomenological and empirical mixed-methods research (e.g., Atchison and Feig, 2011; Huntoon, 2012) in the undergraduate educational experience in this unusual setting.

THIS STUDY AS ACTION RESEARCH

Some parallels exist between this study and geoscience action research into the use of alternative instructional methods (e.g., virtual field trips) to help disadvantaged (e.g., mobility impaired) students learn (Atchison and Feig, 2011). Although undergraduates completing the MTSU field geology course are physically able and mostly white and male, they are disadvantaged in the sense that they are learning to measure, map, and interpret bedding plane attitudes in an area where strata are subhorizontal. Because of this limitation, many practicing geoscientists might regard these students as having received a lower-quality field geology education than students who investigated moderately and steeply dipping strata, which vary in attitude. In an action-research context, a reason to conduct this study and publish the results is to demonstrate to practicing geoscientists that the alternative methods work and, consequently, that the students have received a higher-quality field education than many geoscientists would suppose given the field area in which the students completed the field geology course.

Negative perceptions among practicing geoscientists are hypothetical, but this hypothesis is reasonable because of the predominance of traditional field geology courses in which students measure and plot the attitudes of moderately and steeply dipping strata, which vary in attitude. For example, most of the papers in Whitmeyer et al. (2009a) describe traditional courses, and traditional field geology courses have been offered for decades (Whitmeyer et al., 2009a; Mogk and Goodwin, 2012). This paragraph explains why many academics might be skeptical about a flat-rock field geology course, and the next two paragraphs explain why many nonacademics might be skeptical. Skepticism among academics is relevant because many undergraduates apply to graduate programs. In general, the literature on resistance to change in academia (e.g., Lane, 2007) suggests that many academics are protective of current, long-standing practices and, consequently, that many academics are skeptical of alternatives. For example, this skepticism is likely to be at least partially responsible for the resistance of many higher-education faculty members to the adoption of educational technology in general (e.g., Moser, 2007) and the slow acceptance of ruggedized laptops and field tablets in field geology courses in particular (e.g., De Paor and Whitmeyer, 2009; Whitmeyer et al., 2010).

Many nonacademic geologists completed traditional field geology courses, and it is reasonable to hypothesize that their conception of a good field geology course reflects their education. In addition, employment among MTSU bachelor's degree holders (including those who eventually earn master's degrees) likely parallels national hiring trends (Wilson, 2013). Nationally, 56% of spring 2013 geosciences bachelor's degree graduates accepted jobs in oil, gas, and environmental services, and 74% of master's degree graduates accepted jobs in oil and gas. The Geological Society of America (GSA)/Exxon Mobil Field Camp Excellence Award, an article in the American Association of

Petroleum Geologists's *AAPG Explorer,* and the National Association of State Boards of Geology (ASBOG) Fundamentals of Geology examination all suggest employer support for the traditional field geology experience. For example, the Indiana University (IU) geology summer field course won the GSA/Exxon Mobil 2012 Field Camp Excellence Award (GSA, 2012), and much of this field course is traditional (Douglas et al., 2009). An article in *AAPG Explorer* (Friedman, 2009) also suggests that oil and gas employers generally approve of the IU geology field camp's traditional approach. The IU example is supported by the 2013 Field Camp Excellence Award recipient, the Wasatch-Uinta Field Camp (GSA, 2013), which is also a traditional geology field camp (Oleson, 2013).

The licensure process in the environmental services sector suggests that environmental geoscientists value traditional field geology and structural geology. Many recent graduates entering the environmental services sector will eventually pass the ASBOG Fundamentals of Geology exam. The exam is largely based on the typical academic geology program, and 31% of the exam involves field geology, structural geology, and allied subdisciplines (ASBOG, 2013).

Within the geosciences action-research literature, this study bares some similarity to the use of virtual field trips to improve learning by mobility-impaired students (Atchison and Feig, 2011) in that this study also involves technological innovation. Specifically, I implemented alternative instructional methods described below in the section related to developing a pilot course, and these methods included the use of a digital level, a relatively new tool that was developed within the last couple of decades. This study differs from other geoscience action-research studies in that most described by Feig (2011) as action research, self-describing as action research, or referencing the action-research literature were intended to expand participation in undergraduate geoscience courses by members of underrepresented groups (e.g., Riggs et al., 2007; Kitts et al., 2009; Atchison and Feig, 2011; Ellins et al., 2013), involved service learning or community outreach (Prakash and Richardson, 1999; Feig and Girón, 2001; Tedesco and Salazar, 2006), investigated the integration of scientific and nonscientific ways of knowing (e.g., Riggs, 2005), focused on improving precollege Earth Science teaching (e.g., Williams and Semken, 2011), or examined high school Earth Science (Schmidt, 2013).

GEOLOGIC SETTING

The field area is along a riparian greenway located 2.7 km from the MTSU campus in the central Tennessee city of Murfreesboro (Fig. 2). All observations are made within a few dozen meters of the West Fork of the Stones River or its tributary, Lytle Creek. This area is on the North American platform, and from oldest to youngest, the Ordovician Murfreesboro Limestone, Pierce Limestone, and Ridley Limestone are exposed (Wilson, 1965; Crawford, 1988). These formations are environmentally important because karst has developed on parts of the Ridley Limestone and, to a lesser extent, on the Murfreesboro Limestone. As in many karst areas, the geology strongly influences subsurface contaminant transport. For example, Ridley Limestone aquifer and aquitard units controlled the subsurface move-

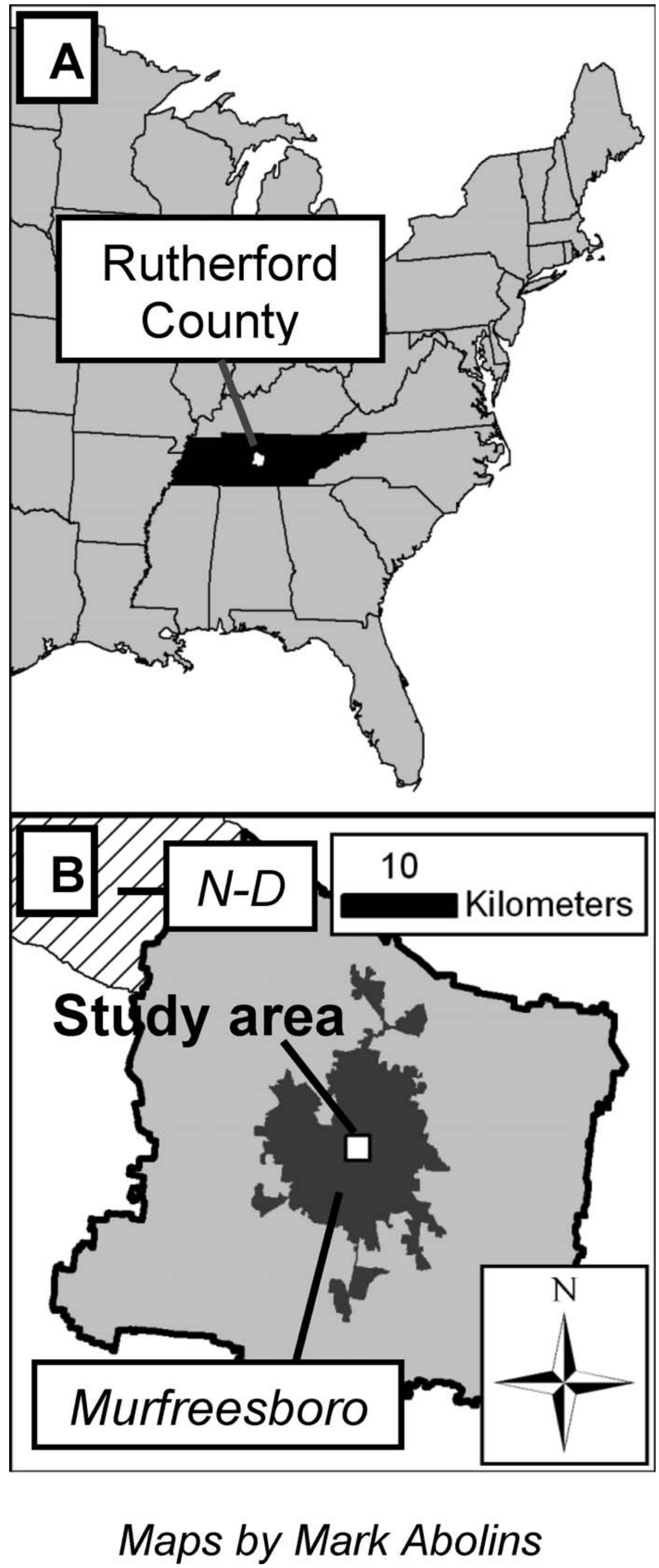

FIGURE 2: (A) Location of Rutherford County (white) within the state of Tennessee (black). (B) Location of the study area (white) within the city of Murfreesboro (dark gray) in Rutherford County, Tennessee. The county borders metropolitan Nashville–Davidson county (N-D, diagonal lines) on the northwest.

ment of contaminants spilled by a 1990 train derailment near Lewisburg, Tennessee (Crawford and Ulmer, 1994).

Unfortunately, the three formations are easily confused in outcrop because all three contain carbonate intervals; the Pierce and Ridley Limestones also contain silty carbonate and shale intervals (Crawford, 1988; Crawford and Ulmer, 1994; Farmer and Hollyday, 1999). Folding further complicates geologic mapping. Regionally, strata are folded into the Nashville Dome (Wilson and Stearns, 1963; Stearns and Reesman, 1986; Reesman and Stearns, 1989), and locally, gentle folds with wavelengths of tens to hundreds of meters and amplitudes of a few meters are visible in road cuts and stream banks. According to existing structure contour maps (Moore et al., 1969; Rima et al., 1977), these folds define elongate basins and domes, but these structures are poorly constrained in most areas because of a lack of measurements, limited exposure, and map errors (Farmer and Hollyday, 1999). Indeed, for some combination of reasons, published geologic maps (Galloway, 1919; Wilson, 1964) depict grossly different outcrop patterns, and subsurface investigations show that published geologic maps are highly inaccurate (Farmer and Hollyday, 1999) at some central Tennessee locations. The Field Methods field area is on the southwest side of a north–northwest/south–southeast trending elongate dome (Moore et al., 1969; Rima et al., 1977) and contains a half-kilometer-wide structural basin (Abolins, 2010), which is not on the Wilson (1965) map. Figure 3 depicts the structure of the field area.

Although the Field Methods field area is structurally on the Nashville Dome, the field area is topographically in the Central Basin. This topographic basin is part of the interior low plateaus geomorphic province.

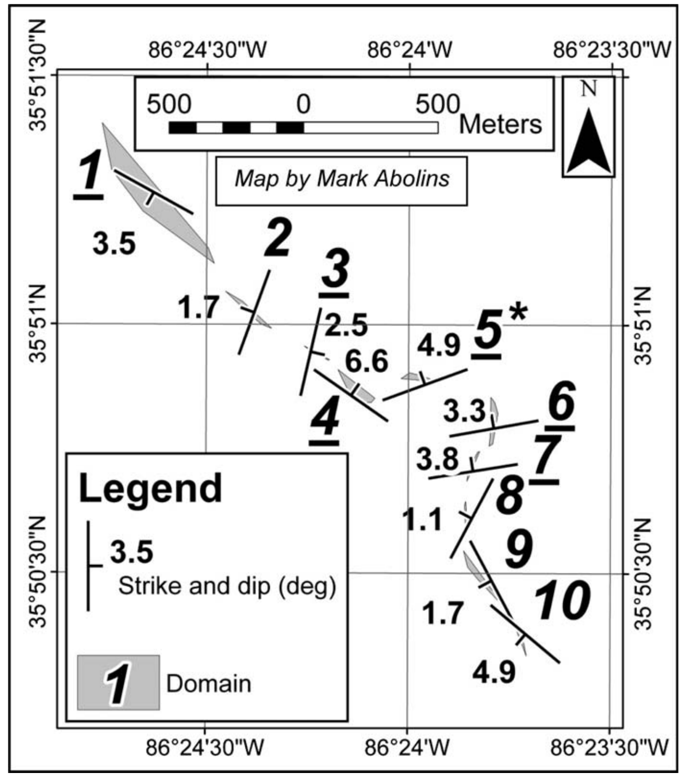

FIGURE 3: The mean bedding plane attitude of each of the 10 structural domains in the field area based on my (faculty) measurements (Abolins, 2008, 2010). Bedding plane attitudes are similar within each domain and differ from bedding plane attitudes in adjacent domains. Fall 2011 Field Methods students measured attitudes in the underlined domains and reproduced my mean in all underlined domains except 5 (asterisk). Data from surrounding areas suggest that strata dip southwest in areas northeast and east of the traverse (Wilson, 1965; Moore et al., 1969; Rima et al., 1977), so Domains 3–5 are interpreted as a structural basin. See Fig. 2 for location.

DEVELOPING A PILOT FLAT-ROCK FIELD METHODS COURSE

Beginning in fall 2009, I moved more than half of MTSU's 2-semester-hour Field Methods in Geology course from the campus (where it had revolved around simulated outcrops and structures) to the field. The course is junior level, required for geology majors, and taught every three or four semesters. It typically enrolls between one and two dozen undergraduates, who are almost exclusively geology majors. The course meets for 3 h and 10 min on a single day each week, and students spend about 2 h and 30 min making observations. (They spend the rest of the time traveling to and from the field area.) Students explore the field area during 8 of the 15 class meetings, and they spend the rest of the course on campus learning to measure the orientation of moderately and steeply dipping boards, plot measurements, pace off distances, use handheld global positioning system (GPS) units, survey with a tape and compass, make indirect measurements of height and distance, plot rose diagrams, and interpret simple geologic maps.

Students use a Macklanburg-Duncan SmartTool 24-in. digital level and a Brunton transit to measure dip and dip azimuth at numerous locations near the greenway. To make a measurement, they place a wooden board on a bed top, and then they place the level on the board (Fig. 4A). To find the strike, they rotate the level until the dip reads 0.0°. Then they use a right triangle to find the dip direction, and they use a Brunton compass to measure the dip azimuth (Fig. 4B). After measuring the dip azimuth, they place the level in alignment with the dip azimuth, and they read the dip off of the digital level (Fig. 4C).

Students use handheld GPS units equipped with the wide area augmentation system to determine position, and they plot bedding plane attitudes on a map. (Low relief and poor visibility, due to vegetation, prevent students from using topographic maps to determine position.) Near the end of the course, the students compile their field data on Mylar and write a report.

In addition to class meetings on campus and in the field area, the 2009 field course students spent 1 d investigating structures (including shatter cones) at the Wells Creek impact structure near Erin, Tennessee, and they spent another day examining Ordovician stratigraphy, penecontemporaneous structures (including probable seismites), normal faults, and fault propagation folds along Tennessee state route 840 near Murfreesboro.

Many of the students later complete a summer field camp, but others (primarily those planning to seek employment immediately after earning a bachelor's degree)

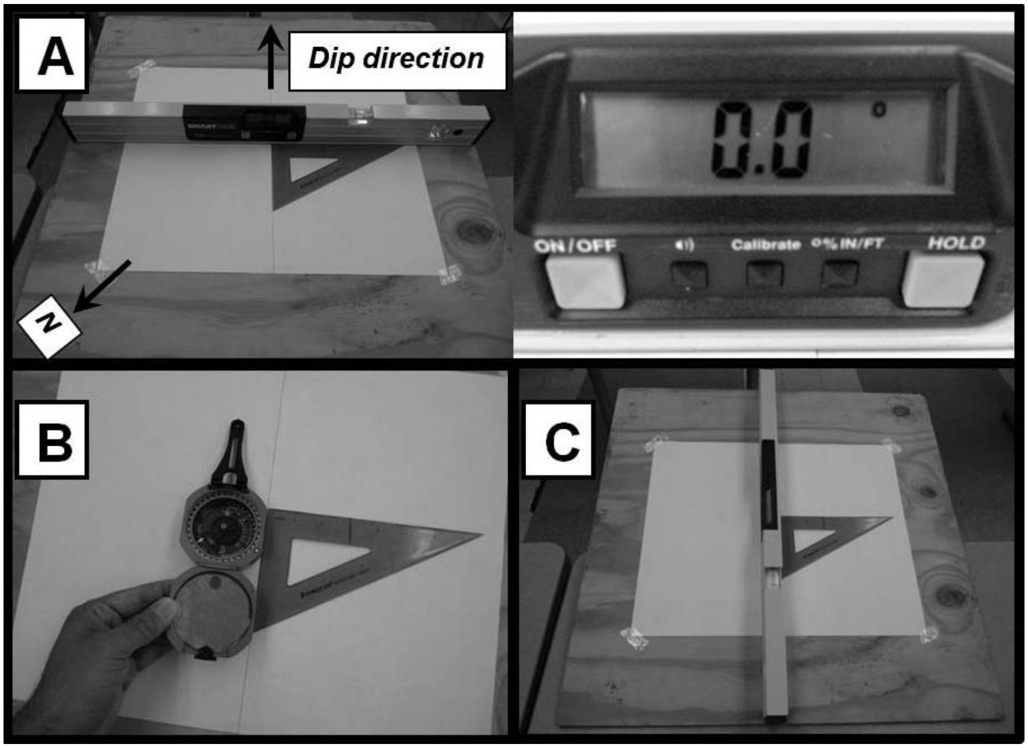

FIGURE 4: Measuring a bedding plane attitude with a digital level and a Brunton pocket transit. See text for more information. (A) Finding the strike. (B) Measuring the dip azimuth. (C) Measuring the dip.

only complete the Field Methods course. Students who completed the course in recent years are now engaged in numerous professional activities, including environmental investigations, oil and natural gas exploration and development, mining, and graduate research.

FORMATIVE ASSESSMENT

During the fall 2009 field course, I tried to get undergraduates to independently discover the half-kilometer-wide structural basin with mixed success. Pairs took turns using three digital levels to measure bedding plane attitudes, while the rest of the class made other field observations (lithology, fossils, spacing of bedding plane fractures, joint orientation, joint spacing, etc.). Many students found the structural basin, but some did not. Perhaps more significantly, I had a somewhat negative perception of the student experience, and course evaluation data (Fig. 5) suggests that the students also had some issues with the course. Of 18 enrolled students, 14 responded to most of the 35 evaluation questions, and no question garnered fewer than 12 responses. Each question required a response on a scale of 1 to 5, where 1 was "disagree," 3 was "neutral," and 5 was "agree." Mean responses to questions within three categories (organization and clarity, assignments and grading, and incorporation of student interaction) were considerably lower than for the MTSU Geosciences Department as a whole (differing by >14%), although questions falling into four of the seven categories (presentation ability, intellectual and scholarly approach, motivating the students, and effectiveness and worth) were about the same (within 6%).

Although the course scored well below departmental means in the three categories listed above, the course scores do not have much meaning in and of themselves because geosciences courses are highly varied; the department offers both geology and geography courses, and the courses range in level from introductory general studies courses to senior seminars. All Field Methods category means exceeded a score of 3 and fell within one standard deviation of departmental category means.

What went wrong? I interpreted the results as suggesting that the course was too open ended and that I had set unrealistic goals. I enthusiastically bombarded the students with numerous graphics and handouts based on my research, and then I asked the students to go into the field and try to reproduce my results. Some students did not understand, and some thought the assignments were too difficult. Also, I may have been too high-handed in correcting misconceptions, leading to the perception that I did not invite criticism of my ideas.

COURSE REVISION

To improve the Field Methods course, I made the course less open ended, provided more scaffolding, set more realistic goals, and modified the strike and dip measurement technique. The fall 2011 course enrolled 22 students, of whom six (27%) were female and none were visible minorities.

Less Open Ended, More Scaffolding

At the beginning of the fall 2011 course, I told the students that most of the field area was a southwest dipping

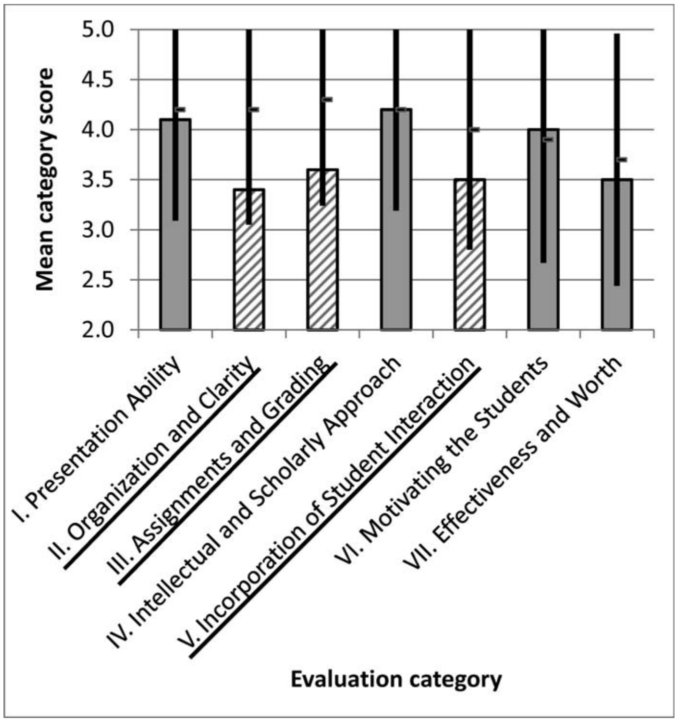

FIGURE 5: Mean fall 2009 Field Methods evaluation scores (columns) and mean and one standard deviation for all fall 2009 MTSU geosciences course evaluations (lines). Diagonal pattern and underlined category names indicate the three most problematic categories.

homocline punctuated by a half-kilometer-wide structural basin, and then I told the students that they were tasked with finding the basin. During the first day in the field area, I walked the students through homoclinal exposures (from oldest to youngest) of the Murfreesboro, Pierce, and Ridley Limestones. On all but 1 d, I accompanied students into the field area, closely supervising them as they measured bedding plane attitudes and made other observations. Scaffolding extended to the course paper and map: I provided specific instructions and made the students submit a draft paper. Of 22 enrolled students, 19 completed at least some part of the draft. I graded drafts on completeness, and I provided each student with specific instructions about what was necessary before submitting the final draft.

More Realistic Goals

Goals were more realistic. For example, students only mapped contacts between the three carbonate formations within a small homoclinal area in the northwest part of the larger field area (Domain 1 in Fig. 3). Although I know the locations of outcrops (from oldest to youngest) of the lower Ridley carbonate aquifer, lower Ridley confining unit, and upper Ridley Limestone from my research (Abolins, 2008, 2010), distinguishing among these informally defined Ridley Limestone members requires experience and detailed structural data that the students could not amass within the time allotted for the course. Also, I did not have students investigate Domains 2 and 3 (Fig. 3) because many of the 2009 students were confused by the relatively complicated stratigraphy and structure, and the time allotted for the course was insufficient to allow an adequate investigation of those domains. In addition to the preceding modifications, I eliminated extraneous trigonometry exercises from the on-campus part of the course. In combination, the changes listed above likely contributed to improved student evaluation scores (see the Summative Assessment section below).

More Strike and Dip Measurements

I modified the strike and dip measurement technique so that students could make more measurements. As in 2009, student pairs took turns using the three digital levels to make measurements, but I also showed the students how to use their Brunton transits to measure the strike and dip of gently dipping bed tops. The Brunton measurements were less accurate than those made with the digital levels, but the students could still determine dip direction (e.g., southwest as opposed to northeast) and distinguish between beds dipping 2° and those dipping 8°.

To use a Brunton transit to measure the strike and dip of a gently dipping bed top, students placed a wooden board on the bed top. Then the students set the clinometer level to 0° and placed the transit against the board as if they were about to measure dip. They found the strike by rotating the transit until the bubble was in the center of the clinometer level. After finding the strike, the students placed a triangle against the transit to find the dip direction. Finally, the students used the compass to measure strike and the clinometer to measure dip. By employing the technique described above, each student in 2011 was able to make many more strike and dip measurements than in 2009.

SUMMATIVE ASSESSMENT

Student Performance

Ability to Measure and Plot Bedding Plane Attitudes and Make a Map

Student maps showed that most students grasped the measurement and plotting of bedding plane attitudes, knew how to draw contacts, and could label geologic units. All but 1 of the 22 students submitted an inked Mylar map sheet. Of these 21 students, only 6 (five males and one female) had trouble with the map: 2 students did not measure or plot bedding plane attitudes correctly (or did both incorrectly), and 4 did not draw contacts or label map units correctly (or did both incorrectly). All six of the students who struggled with the map scored below the median on both the final exam and the paper, all scored below the mean on the final exam, and all but one scored below the mean on the paper. The connection between poor performance on the map and below-average performance on the final exam and paper suggests that these six students may have had larger problems learning course material and completing assignments successfully. Perhaps they simply had too little time to devote to the course.

Student Reproduction of Faculty Measurements

Students reproduced my dip direction (north, northeast, east, etc.) in all five domains, and they reproduced ($p < 0.05$) my mean domain bedding plane attitudes in four of five domains (Table I). (I combined Domains 6 and 7 for this paper because mean attitudes are similar in the two domains (Abolins, 2010).) For each domain, I used the F statistic to

TABLE I: Student reproduction of domain mean bedding plane attitudes. Number of measurements in parentheses. Student Domain 5 measurements (in bold italics) failed to reproduce faculty measurements at the $p < 0.05$ level.

Domain	Faculty Mean Attitude (Strike, Dip)	Undergraduate Mean Attitude (Strike, Dip)	*F* Observed	*F* Critical ($p < 0.05$)
1	300°, 3.4° SW ($n = 9$)	302°, 4.1° SW ($n = 63$)	0.81	3.06
3	013°, 3.5° E ($n = 5$)	343°, 2.5° E ($n = 9$)	1.59	3.40
4	305°, 6.6° NE ($n = 7$)	308°, 7.0° NE ($n = 16$)	0.18	3.22
5	***250°, 5° N (n = 9)***	***275°, 4.4° N (n = 12)***	***3.34***	***3.24***
6 and 7	253°, 2.5° N ($n = 14$)	263°, 2.9° N ($n = 23$)	1.38	3.13

compare faculty and student bedding plane attitudes using the method of Watson (1956).

In Domain 5, faculty and student bedding plane attitudes are statistically different, but faculty and student measurements are similar in that both the faculty and the student mean dip directions are north and mean dip azimuths differ by only 25° (340° for the faculty mean versus 5° for the student mean). Consequently, the difference in the mean attitudes does not alter the interpretation of the structure as a basin.

I attribute failure of the *F* test to higher water levels on Lytle Creek during the 2011 Field Methods course. Because the water was higher, students were unable to measure many of the bed tops that I measured; consequently, the student mean differed from mine. Qualitative observations and stream gauge data support this interpretation. Qualitatively, I noted a distinctive Domain 5 outcrop in August 2009, and I noticed that the outcrop was largely submerged in November 2011.

Going beyond my notes on the above-mentioned outcrop, stream gauge data supports the interpretation that water levels were higher during 2011 data collection. Although Lytle Creek is ungauged, a nearby gauge (U.S. Geological Survey 03428200) on the West Fork of the Stones River recorded minimum daily flows of 38 and 44 cubic feet per second (cfs) while the students collected their data on the afternoons of November 2 and 9, respectively, and the gauge recorded maximum daily flows of 21–27 cfs while I collected my data August 15–19, 2009. These measurements are consistent with lower flows on Lytle Creek during 2009, although these measurements are not conclusive because Lytle Creek drains a much smaller area; consequently, flows are more readily influenced by local hydrologic conditions.

Both the undergraduates and I mostly recorded north–northwest dips of 3.9–6.0° in Domain 5, but because of higher water levels, the undergraduates made more measurements at outcrops dipping 6.0° or more to the northeast. Specifically, 3 of the 12 undergraduate measurements have strikes of 316–322° and northeast dips of 6.3–6.7°, while only one of my nine measurements is of a northeast dipping bed (strike of 279° and dip of 7.2° to the north–northeast). The differences described in the preceding sentence account for the failure to reproduce my data: if the northeast dipping beds are removed from both datasets, then the two are statistically identical (*F* observed = 1.58, *F* critical = 3.32) at the $p < 0.05$ level.

Student Discovery of the Structural Basin

Although the students did not reproduce my Domain 5 mean bedding plane attitude, each of their domain means (including the Domain 5 mean) was statistically different ($p < 0.05$) from every other domain mean (Table II). Consequently, the class as a whole found that the strata were not homoclinal and were instead folded into a basin.

Student Evaluations

Comparison of 2011 With 2009

Both the 2011 students and I perceived the course in a more positive way. Each of the 35 evaluation questions garnered 19 (out of a possible 22) responses for a total of 665 responses. Of these responses, 74% ($n = 450$) were 4 or 5, 14% ($n = 95$) were scores of 3, and 11% ($n = 73$) were scores of 1 or 2. (There were 2 "not applicable" responses.) The mean score rose from 3.8 in 2009 to 4.1 in 2011, and the minimum item score rose from 2.6 to 3.4. As shown in Fig. 6, responses revealed gains in all seven evaluation categories except motivating the students, which remained the same. The biggest gains were in the three problematic categories: organization and clarity (18% improvement), assignments and grading (17% improvement), and incorporation of

TABLE II: Statistical distinctiveness of student mean domain bedding plane attitudes. (See Table I for domain means.) *F* observed for each domain pair and *F* critical (parentheses) for $p < 0.05$.

Domain	Domain				
	1	3	4	5	6 & 7
1	—	55.48 (3.06)	257.00 (3.05)	111.71 (3.06)	158.42 (3.05)
3	—	—	25.20 (3.20)	14.01 (3.24)	36.60 (3.15)
4	—	—	—	14.78 (3.18)	68.39 (3.12)
5	—	—	—	—	5.61 (3.14)
6 & 7	—	—	—	—	—

TABLE III: Summative assessment of the 2011 Field Methods course, revealing strengths and weaknesses in the three most problematic 2009 Field Methods evaluation categories. The mean evaluation score and the percentage of improvement over 2009 are in parentheses. The strengths are the two highest-scoring items within each category and the weaknesses are the two lowest-scoring items, except in incorporation of student interaction, because that category only contains three items. Items that were also strengths or weaknesses in 2009 are italicized.

Evaluation Category	Strengths	Weaknesses
Organization and clarity (4.0, 18%)	States objectives for each class session (4.6, 28%) *Is well prepared (4.3, 10%)*	Speaks in a manner that is easy to understand (3.8, 12%) *Knows whether the class is understanding him/her (3.6, 38%)*
Assignments and grading (4.2, 17%)	*Is accessible to students outside class (4.7, 9%)* *Gives assignments related to the goals of this course (4.4, 10%)* Assigns grades fairly (4.4, 19%)	*Given nature of assignments and exams, returns them quickly (3.9, 30%)* Explains the grading system clearly (3.6, 3%)
Incorporation of student interaction (3.8, 9%)	*Relates to students as individuals (4.0, 11%)*	*Invites criticism of own ideas (3.4, 6%)*

student interaction (9% improvement). (These three categories are described as problematic because mean evaluation scores differed from departmental means by more than 14% in fall 2009.) Gains (an average of 8% for all seven categories) were tempered, because the department as a whole was 5% higher in every category in fall 2011.

Within the three problem categories, individual questions reveal improvements in most strengths and weaknesses (Table III). In 2011, no question yielded a response average below 3.4 (invites criticism of own ideas in the incorporation of student interaction category had the lowest average). In addition, no strengths or weaknesses declined between 2009 and 2011, although small (<7%) improvements in the assignments and grading category (explains the grading system clearly) and in the incorporation of student interaction category (invites criticism of own ideas) likely have little meaning because departmental evaluation scores were 5% higher across the board in fall 2011. On one hand, two items—in the organization and clarity category (states objectives for each class session) and in the assignments and grading category (assigns grades fairly)—emerged as strengths after posting big gains (28% and 19%, respectively). On the other hand, two 2009 weaknesses—in the organization and clarity category (knows whether the class is understanding him/her) and in the assignments and grading category (given nature of assignments and exams, returns them quickly)—posted big gains (38% and 30%, respectively) but remained weaknesses relative to other items. (Grading and returning assignments quickly can be a challenge because I do not have a teaching assistant.) One item in the organization and clarity category (speaks in a manner that is easy to understand) emerged as a weakness relative to other items after posting only a modest (12%) gain, and another item (explains the grading system clearly) emerged as a weakness in the assignments and grading category because it remained about the same while other item means rose.

The course was also offered during spring 2013, and, while spring 2013 evaluations mostly fall outside the scope of this study, they support the contention that the course improved after 2009. Specifically, the mean spring 2013 evaluation score improved to 4.5, matching the spring 2013 departmental mean.

Comparison With Other Junior- and Senior-Level Geology Courses

Although all seven fall 2011 Field Methods category means were well within one standard deviation of geosciences departmental means, the Field Methods course evaluated poorly relative to the other five junior- and senior-level geology courses taught during fall 2011. The other courses were geoliterature (an introduction to geoscience literature) and report writing, hydrogeology, inorganic geochemistry, meteorology, and mineralogy. The Field

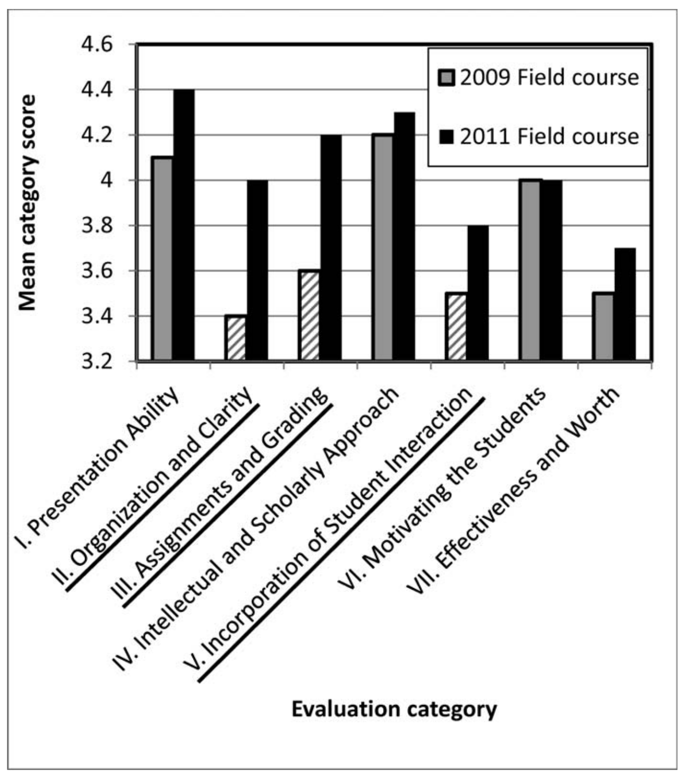

FIGURE 6: Changes in mean Field Methods evaluation scores, 2009–2011. Diagonal pattern and underlined category names indicate the three most problematic 2009 categories.

Methods course roughly tied one of the other courses for lowest evaluation score in organization and clarity (3% above the lowest score), presentation ability (same as the lowest score), intellectual and scholarly approach (same), and motivating the students (2% below the next lowest score), and the course was at the bottom in assignments and grading (5% below the next lowest score), incorporation of student interaction (7% below), and effectiveness and worth (12% below). Assignments and grading and incorporation of student interaction were both identified as problem categories in 2009, but the comparison with other junior- and senior-level fall 2011 geology courses identified effectiveness and worth as an additional problem category.

Polarization explains some of the trouble with the effectiveness and worth category: one of the two items in this category was the second-most-polarizing item in the Field Methods evaluation. The item question is "Focusing now on course content, how worthwhile was this course relative to other courses you have taken at the university?" and 11 students responded with a 4 or 5 score, 5 students responded with a 1 or 2 score, and only 3 students responded with a 3 score. The Field Methods course was the most polarizing junior- and senior-level geology course taught during fall 2011 (Fig. 7A): for 11 of 35 items, more students responded with a 4–5 and a 1–2 score than with a 3 score.

However, polarization was not the sole cause of the trouble with the effectiveness and worth category. The category mean was also pulled down by the large percentage of students who responded with a 3 score to the other item in this category: "Considering both the limitations and the possibilities of the subject matter and course, how would you rate the overall teaching effectiveness of the instructor?" More students (32%) responded with a 3 score to this item than to any other, and this item was the only one differing by more than two standard deviations from the mean number of responses with a score of 3 (14%). Ambivalence was also a problem in the course evaluation, because on average, more students responded with a 3 score to each item than on any other fall 2011 junior- or senior-level geology course evaluation (Fig. 7B).

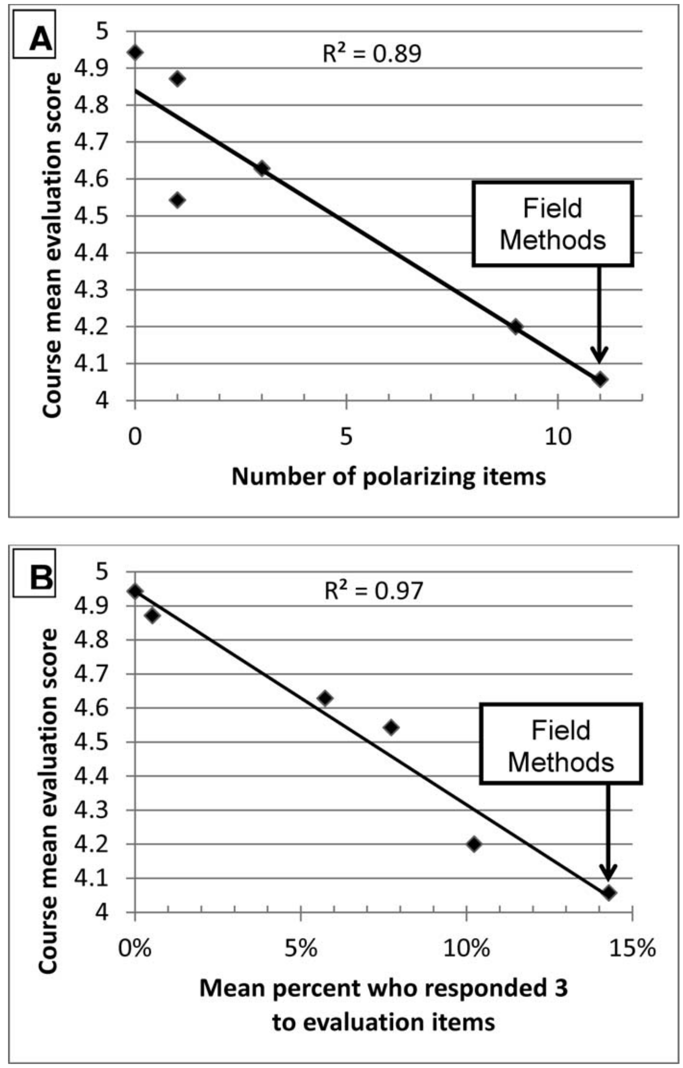

FIGURE 7: Mean evaluation scores for six junior- and senior-level geology courses taught during fall 2011. (A) Relationship between mean course evaluation score and number of polarizing items (more students responded with a 1–2 or a 4–5 score than with a 3 score). (B) Relationship between mean course evaluation score and mean percentage of students who responded with a 3 score to evaluation items.

DISCUSSION

Implications for the Hypothesis

Summative assessment results support the hypothesis that half of a geology field methods course can be taught in a field area where strata are subhorizontal without harming student performance or provoking a student rebellion. Problems with the 2009 field course were successfully addressed by improving the way the course was taught: making the course less open ended, providing more scaffolding, setting more realistic goals, and modifying the strike and dip measurement technique. There was no need to move the entire course back on campus.

The feasibility of this course opens a new door to comparative research on the impact of different field geology experiences. Specifically, the way students feel about the geology and the way students learn to measure the orientation of bedding plane attitudes likely differ between field areas where strata are subhorizontal and field areas where strata dip moderately to steeply and folds are spectacularly visible. Future research would likely be both phenomenological and empirical and would involve mixed methods (e.g., Atkinson and Feig, 2011; Huntoon, 2012).

Implications for Further Improvement

Results described above in the Summative Assessment section suggest that any improvement efforts should focus on assignments and grading, incorporation of student interaction, and effectiveness and worth. Improvements would seek to reduce the number of responses scored 1–3 to the weak items listed for assignments and grading and for incorporation of student interaction in Table III and for both items in the effectiveness and worth category. Some possible improvements are obvious (e.g., return assignments and exams more rapidly), but others are open to interpretation.

For example, the perception of some students that assignments and exams are not reasonable in length and difficulty may indicate that some students think they are receiving too little academic credit (2 semester hours) for a course meeting for 3 h and 10 min each week and on one weekend and requiring completion of a midterm, final, draft paper, final paper, and map. If a perceived imbalance between the amount of credit and the amount of coursework is the problem, the solution might be to increase the amount of credit. Alternatively, I could reduce the amount of coursework as long as most students still learn all requisite skills (e.g., making and plotting structural measurements).

In the short term, I reduced the amount of coursework: in spring 2013, I eliminated the midterm and one of the two off-campus field trip days (the trip to the Wells Creek impact structure), and I reduced the number of topics assessed by the final exam. Spring 2013 field course evaluations suggest that these changes may have contributed to a jump in the mean assignments and grading evaluation score from 4.2 in 2011 to 4.5 in 2013. This gain was achieved without sacrificing student performance: only 2 of 17 students who completed maps had trouble measuring or plotting attitudes, drawing and labeling geologic contacts, or both. However, in the long term, the department chair decided to increase the academic credit to three units, and the course will be worth three units (and require additional contact) the next time it is offered.

How should I improve the effectiveness and worth of the course? I suggest two hypotheses. One is that the course is too narrow (focusing mostly on structural geology) and will evaluate better if it addresses a few additional content areas (e.g., mass wasting and fluvial and karst geomorphology) valued by some students. Presumably, I would have to accomplish the preceding while not pulling down organization and clarity or increasing the amount of coursework. Another reason to add geomorphic content with caution is that any addition at the expense of structural geology would shift the course toward content less relevant to most summer field camp experiences (e.g., Sisson et al., 2009). A second hypothesis is that many students believe many valuable skills are technological; consequently, the course would evaluate better if it included more technology instruction (e.g., instruction in the use of field tablets). As with the addition of content, the addition of technology instruction would have to be accomplished without pulling down other categories or increasing the amount of coursework. The mean effectiveness and worth evaluation score improved from 3.7 in fall 2011 to 4.5 in spring 2013 without making either of these hypothetical changes.

The need for improvements that consume faculty time, are costly, or do both is questionable because the course is already successful when judged by most criteria. Most students learned skills, and in most ways, the course evaluation can be described in positive terms: the mean evaluation score exceeded 4, and all mean category scores were well within one standard deviation of departmental means. Expectations for improvement would also have to be tempered by the possibility that some Field Methods students enjoy laboratory and classroom geoscience but do not like this kind of geologic field investigation. Regardless of any improvements, these students may not consider the course effective or worthwhile, and they may not like the nature and amount of coursework.

Implications for Implementation Elsewhere

Although the results described in the Summative Assessment section and discussed in the preceding paragraph show that the course succeeded when judged by most criteria, a fair question might be "Why teach a course in this way?" As an alternative, some summer field camps offer a short pre–field camp introduction to field methods, and some MTSU geosciences students substitute these pre–field camp experiences for the academic year field course described in this paper.

The preceding notwithstanding, there are four major reasons to offer the field methods course described in this paper:

- Students examine firsthand the bedrock aquifer and aquitard units important in the local area (central Tennessee).
- Students learn firsthand that flat platform strata are folded. Shale gas exploration and development require an understanding of gentle folds within the North American platform. After completing undergraduate programs at MTSU and many other institutions, some undergraduates earn master's degrees and then find lucrative employment working with shale gas.
- Students discover firsthand an error in a published geologic map. Working as geologists, they will likely discover many more errors in published maps, data, and interpretations.
- The course can provide a starting point for near-campus, field-based undergraduate research projects. A few undergraduate research projects may even develop into master's projects.

Although few faculty members will teach an entire flat-rock structural geology field methods course, a single flat-rock field exercise could be included in a field course or a structural geology course (as a field trip stop, for example) if suitable outcrops exist where the course is taught. If a class can make measurements in two areas differing in strike and dip, they can compare their measurements using a F test. Application of this statistical technique would fit within the goals and objectives of many structural geology courses.

SUMMARY AND CONCLUSION

Summative assessment results support the hypothesis that half of a geology field methods course can be taught in a field area where strata are subhorizontal without harming student performance or provoking a student rebellion. Student maps showed that most students grasped the measurement and plotting of bedding plane attitudes, knew how to draw contacts, and could label geologic units. Students reproduced my discovery of a half-kilometer-wide structural basin (Abolins, 2010) in an area depicted as a homocline on a published map (Wilson, 1965). They found the basin even though the strata dip less than 9° throughout the field area. The mean fall 2011 evaluation score was 4.1 (on a 5-point scale), the lowest category mean was 3.7, and all category means were well within one standard deviation of departmental means, although the mean evaluation score was slightly lower than the next lowest mean evaluation score (4.2) of junior- or senior-level geology courses offered that semester. These findings show that although embodied learning and processes within the affective domain are likely different within this unusual field setting, these differences do not preclude the success of an undergraduate field geology course in which students measure, map, and interpret the attitude of strata dipping less than 10°.

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