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Undergraduate Education

Assessing Learning Outcomes Related to Geospatial Science Using Students' Deliverables

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ABSTRACT To equip undergraduates with needed background, instruction in geospatial science was integrated across curricula and courses in the Department of Forestry and Environmental Resources at North Carolina State University. The effectiveness of the integration was unknown; therefore, we developed a framework to assess learning outcomes related to geospatial science. Faculty and program administrators in the department participated in structured interviews designed to identify learning conditions they perceived as successful. Content analysis of interview data revealed faculty's intended learning outcomes, where they believed evidence of learning could be observed or measured, and their criteria for success. These data provided a basis for development of assessment methods, which included rubrics, tracking questions, pre- and post-tests, and longitudinal surveys. Herein, we describe how we used taxonomies of educational objectives and students' deliverables to assess learning outcomes related to geospatial science. We believe the assessment of students' deliverables revealed differences in outcomes attainment among degree programs. For example, assessments show forestry seniors met skills-based, information literacy, and conceptual knowledge learning outcomes in their understanding of capstone management plans, whereas natural resources seniors demonstrated affective outcomes by voluntarily adopting to use the tools in their capstone management plans. We believe assessments based on students' deliverables allowed us to draw inferences about our students and their learning styles. However, due to the changing nature of assignments and deliverables, and concern for the consistent application of the rubrics over time, we intend to rely on pre- and post-test assessments and longitudinal surveys moving forward.

Geospatial tools and technologies provide spatial data and analysis capabilities that enhance the ability to study natural resources. As a result, natural resource professionals were early adopters of geospatial technologies (Weir, 1989). For example, the Canada Geographic Information System of the 1960s was used to analyze Canada Land Inventory data for management and planning purposes (Tomlinson and Toomey, 1999). Today, use of geospatial tools and technologies are core competencies for natural resource professionals (Hess and Cheshire, 2002; Wing and Bettinger, 2003; Merry et al., 2007; Wing and Sessions, 2007).

Studies and labor statistics show demand for skilled geospatial practitioners is high and likely to increase (e.g., U.S. Department of Labor, 2005, 2012; Merry et al., 2007; North Carolina Office of State Budget and Management, 2008). Thus, higher education institutions have become the primary provider of geospatial education and training (Wing and Sessions, 2007). Efforts have been undertaken to integrate geospatial science within natural resources curricula and courses, and study their use in an academic setting (e.g., Sader and Vermillion, 2000; Stout and Lee, 2004; Linehan, 2006; Wing and Sessions, 2007; Simmons et al., 2008; Mitzman et al., 2011). However, geospatial tools and technologies are frequently used as a means to deepen students' understanding of discipline- or course-specific knowledge, and the degree to which learning objectives related to geospatial science are met is not well reported.

Outcomes-based assessment has been important in higher education for some time (Carter, 2003). Ewell (1991, p. 75) stated that "assessment has become, for many institutions, a condition of doing business." Stakeholders are demanding greater accountability and that student learning be documented (e.g., Cook et al., 2006; Prager and Plewe, 2009). In response, we developed an assessment process to understand the effectiveness of the integration, and to improve student learning. In this article, we describe how we used taxonomies of educational objectives and students' deliverables to assess learning outcomes related to geospatial science.

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Abbreviations: GIS, geographic information systems; GPS, global positioning systems.

MATERIALS AND METHODS

Instructional Setting and Learning Outcomes

Course-embedded instruction in geospatial science, including geographic information systems (GIS), global positioning systems (GPS), and remote sensing, has been integrated for decades across undergraduate curricula and courses in the Department of Forestry and Environmental Resources at North Carolina State University. These course-embedded activities are designed to complement students' ongoing coursework, demonstrate application of the tools in a real-world context, and expose students to geospatial tools and technologies in multiple years of their program (Hess and Cheshire, 2002). Integration efforts initially focused on the Forest Management and Natural Resources curricula. However, as demand for geospatial skills increased, integration expanded to include the Fisheries, Wildlife, and Conservation Biology curriculum, and the Environmental Technology and Management curriculum.

Faculty and program administrators in the department frequently commented that learning outcomes related to geospatial science were important but not expressly articulated. In response, we worked with the University Planning and Analysis office to develop structured interviews. During the interviews, faculty and program administrators were asked to describe their objectives, intended learning outcomes, where they would look for evidence of student learning, and their criteria for success. Four program administrators and 10 faculty members participated in the structured interviews. Interviews typically lasted 90 minutes and were digitally recorded; interview notes were also taken by the interviewer (JDC).

We performed content analysis of the interview data using grounded theory (Glaser and Strauss, 1967) and categorical coding (Miles and Huberman, 1994) methods. Interview data was used to develop a list of possible response categories for each interview question. Response codes for each category were developed that identified the specific learning behaviors desired by participants. The key action words participants used to describe the desired learning were used to assign an intended learning level to each response code based on the domains of educational objectives (Bloom et al., 1956; Krathwohl et al., 1964), and Anderson and Krathwohl's (2001) taxonomy. Categories and codes were added, removed, changed, grouped, and ungrouped as oversights, clarifications, and connections emerged through the reflective and iterative process.

The content analysis showed faculty and administrators expected students to attain several recurring student learning outcomes in five learning objective categories (Table 1). Outcomes ranged from skills-based tasks such as the ability to read, make, and communicate with maps, to affective outcomes such as adopting use of the tools as part of becoming a natural resource management professional. Faculty and administrators were also asked where they would look for evidence of student learning, to describe their criteria for success, and to set an initial performance target. In general, participants indicated they would seek evidence of student learning by evaluating students' course work, direct testing, observation, surveys, and questionnaires. Participants' criteria for success included the appropriate use of spatial analysis in planning and conducting projects and field work, communicating spatial methods and findings effectively in reports, increasing use of the tools in their assignments and projects without prompting, and active participation in classroom discussions using proper concepts and terminology. There was disagreement on how and at what level to set an initial performance target; therefore, we set our initial performance target at 80% satisfactory for each assessment of each outcome.

Assessment Using Students' Deliverables

During the structured interviews, faculty and administrators indicated that they believed evidence of student learning was demonstrated through students' coursework. Therefore, one assessment approach was to collect students' deliverables and evaluate them to determine how well learning outcomes were being met. These data consisted of maps, lab reports, term projects,

Table 1. Content analysis of structured interviews revealed stakeholders intended student learning outcomes.

Learning objective categories	Times mentioned	Desired performance levels	Student learning outcomes Students should possess the ability to:
Skills-based	98	apply and analyze	1. Read, make, and communicate with maps 2. Perform routine spatial analysis tasks 3. Perform rudimentary spatial statistics 4. Plan and execute a GPS field data collection mission
Factual knowledge and information literacy	21	remember, understand, and apply	5. Define and use terminology correctly 6. Recall specific details related to the discipline 7. Identify reliable information sources 8. Download and organize information
Conceptual knowledge	24	understand and apply	9. Recognize spatial problems and propose possible solutions 10. Recognize what data and analysis techniques are needed 11. Explain how the tools can be used together to solve problems 12. Link the tools, fieldwork, analysis, and reporting
Self-awareness and problem solving (metacognitive)	12	understand and apply	13. Recognize their own levels of understanding 14. Identify strategies to seek help 15. Devise strategies to solve problems
Feelings and values (affective)	27	value and characterize (adopt and internalize)	16. Willingly include geospatial approaches in their methodologies and reporting 17. Identify use of the tools and technologies as part of becoming a resource management professional

and capstone course management plans. Students' maps and lab reports were collected at the conclusion of geospatial activities embedded in courses. Term projects came from courses with projects that contained a geospatial component. Management plans were from capstone courses and represented semester-long group efforts.

We used Anderson and Krathwohl's (2001) taxonomy as an analytic rubric to identify the knowledge type and cognitive process expressed in each deliverable for the skills-based, factual knowledge, conceptual knowledge, and metacognitive objective categories. Affective learning behaviors were evaluated using the *Taxonomy of Educational Objectives*. *Handbook 2*: *Affective Domain* (Krathwohl et al., 1964). Each time geospatial science related learning was demonstrated in each deliverable, the learning outcome and performance level demonstrated were documented. These observed learning outcomes were then compared with the desired learning outcomes that emerged from content analysis of the structured interviews. Tallies of students' performance were kept for each deliverable by course and year. To determine if the 80% performance target was met, the number of deliverables from each instructional intervention that satisfactorily demonstrated the desired learning outcome was divided by the total number of deliverables evaluated.

We evaluated 215 maps from 7 courses (representing 309 students during 3 years) with geospatial integration ranging from first-year students to seniors. Evidence of learning present in students' maps varies depending on the activities involved and progress as student advance through their programs. Early in their coursework, students are expected to successfully manage data, produce a map, and deliver it to us digitally (Outcomes 1 and 8). During the sophomore and junior years, students' maps should demonstrate evidence of routine spatial analysis, rudimentary spatial statistics, and GPS planning and data collection (Outcomes 1, 2, 3, 4, and 8). Toward the end of their programs, students are expected to build upon this foundational knowledge and produce polished, audience-appropriate maps.

We evaluated 24 lab reports (representing 56 students during three semesters) from a senior forest management course. During the semester, students collected a variety of field data at a common site. In their reports, students were expected to describe the link between their field measurements and results of six spatial analyses comparisons (Outcomes 2, 3, and 12), support their findings using ancillary spatial data they find on their own (Outcomes 7 and 8), and compose polished maps contrasting surface interpolation with zonal averaging (Outcomes 1, 2, and 3).

We evaluated four term projects (representing 74 students during four semesters) from a junior natural resource measurements course. These deliverables were final reports to cooperators and stakeholders after semester-long service-learning projects. Students were expected to develop the skills needed to solve problems they encounter during the project, thereby exposing them to a variety of learning outcomes. We also evaluated seven term projects from a senior environmental impact assessment course. These students were only required to include general location maps in their reports (Outcomes 1, 2, 7, and 8), but were encouraged to use any resources available to them, including spatial analysis, to address the problem. Projects and learning outcomes in the natural resources and impact assessment courses vary year to year.

We also evaluated five capstone management plans (representing 18 students from one semester) from a senior natural resource management course, and five capstone management plans (representing 23 students during four semesters) from a senior forest inventory and planning course. The natural resources students were only required to include a map of current practices and conditions, and a map of their final management prescriptions (Outcomes 1, 2, 7, and 8) in their reports. Forestry students were required to meet all skills-based, factual knowledge, and conceptual knowledge outcomes (Outcomes 1–12). Each forestry capstone management plans was several hundred pages long, and some contained dozens of maps representing advanced spatial analyses. Therefore, complete rubric tallies were not kept for the forestry capstone management plans. As the plans were read, each occurrence of a learning outcome and the associated performance level was initially tallied. Once reviewers deemed an outcome to have been met, tallies were no longer documented for that deliverable.

RESULTS

Assessment of students' maps showed 77% (23 of 30) of all outcomes demonstrated in students' maps satisfactorily met intended performance targets (Table 2). First-year students in a forestry course failed to successfully manage data, produce a map, and deliver it to us digitally (Outcomes 1 and 8). Sophomores and juniors in forestry, wildlife, and natural resources courses satisfactorily met all expected outcomes present in their deliverables (Outcomes 1, 2, 3, 4, and 8). All three senior courses successfully met the routine spatial analysis, GPS planning and data collection, and information organization outcomes (Outcomes 2, 4, and 8). However, all three senior courses failed to satisfy the rudimentary spatial statistics outcome (Outcome 3), and two senior courses failed to demonstrate the ability to make and communicate with maps (Outcome 1).

Assessment of lab reports from a senior forest management course showed 61% (11 of 18) of all outcomes demonstrated in the reports were satisfactorily met (Table 3). In all three semesters, students satisfactorily met the routine spatial analysis, rudimentary spatial statistics, and linking analysis with reporting outcomes (Outcomes 2, 3, and 12). However, these seniors failed to satisfactorily demonstrate the ability to make and communicate with maps (Outcome 1) in 2010, or meet the information sources and organization outcomes (Outcomes 7 and 8) in any year.

Assessment of semester-long term projects from a junior natural resources measurements course showed 88% (49 of 56) of the maps and figures presented in their final reports satisfactorily met the mapping and communication, and routine spatial analysis outcomes (Outcomes 1 and 2) (Fig. 1). Although the number of occurrences was considered too low to view the outcomes as satisfactorily met, the reports demonstrated evidence of progress toward satisfying the GPS planning and data collection, use of terminology, information sources, and organizing information outcomes (Outcomes 4, 5, 7, and 8).

Term projects from the senior natural resources impact assessment course showed students satisfied the mapping and communication (83%, 25 of 30), and spatial

Table 2. Six outcomes were assessed in seven courses using maps from students' assignments.

Course (year)	Class	Learning outcomes					
		Maps assessed	Make maps and communicate	Spatial analysis	Spatial statistics	Collect GPS data	Organize information
			%				
Forest Mapping and Mensuration I (2010, 2011)	first-year students	47	59				48
Forest Mapping and Mensuration II (2009, 2010, 2011)	sophomores	30	88†	93†	86†	93†	93†
Wildlife Ecology and Management (2011)	juniors	18	92†	100†	100†	100†	100†
Natural Resource Measurements (2009, 2010)	juniors	29	86†			100†	95†
Forest Management (2010, 2011)	seniors	40	78	100†	7%	100†	100†
Forest Inventory and Planning (2009, 2010, 2011)	seniors	40	83†	100†	67	97†	99†
Practice of Environmental Technology (2011)	seniors	11	73	82†	64	91†	82†

† The number of maps satisfactorily demonstrating the desired learning outcome exceeds the 80% performance target.

Table 3. Six outcomes were assessed during three semesters using lab reports from a senior forest management course.

Year	Reports evaluated	Make maps and communicate	Spatial analysis	Spatial statistics	Information sources	Organize information	Link tools, fieldwork, and reporting
		%					
2009	6 reports (20 students)	83†	83†	83†	67	67	83†
2010	7 reports (14 students)	71	86†	86†	57	57	86†
2011	11 reports (22 students)	82†	91†	82†	73	73	82†

† Student performance satisfactorily met the desired learning outcome at the 80% performance target.

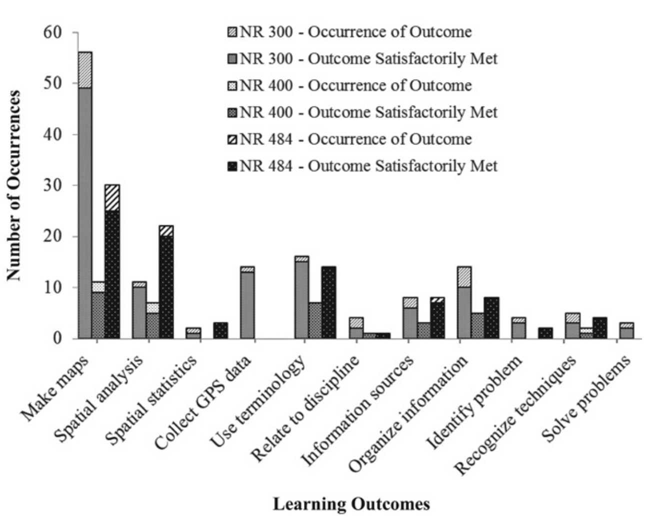

Fig. 1. Assessment of term projects and capstone management plans show students in the natural resources measurements (NR 300) and natural resources impact assessment (NR 484) courses were successfully meeting some learning outcomes. However, the natural resources management (NR 400) capstone management plans did not contain a sufficient geospatial component to result in evidence of learning.

analysis (91%, 20 of 22) outcomes (Outcomes 1 and 2). Although the outcomes were not met, these reports also demonstrated some evidence of proper use of terminology, information sources, organizing information outcomes, and affective outcomes (Outcomes 5, 7, 8, 16, and 17).

Capstone management plans from the natural resources management course failed to meet any outcomes; however, we interpreted students' choosing to use the tools above and beyond the required basemaps, which occurred in all five reports evaluated, as an indication of some progress toward meeting affective outcomes (Outcomes 16 and 17). Detailed spatial analysis, technical writing, and polished maps were present throughout the five forest inventory and planning capstone management plans. The reports showed students were operating at the application and analysis levels of the cognitive process dimension. The forestry capstone plans were deemed to satisfy the 80% performance target for all skills-based, factual knowledge, information literacy, and conceptual knowledge outcomes.

DISCUSSION

Assessment results show first-year students failed to meet intended learning outcomes, sophomores and juniors satisfied all learning outcomes required of them, and seniors generally failed to satisfy Outcomes 1 and 3.

Table 4. Learning outcomes demonstrated in students' term projects and capstone management plans varied.

Course	Class	Plans evaluated	Number of maps in plan	Examples of analyses	Learning outcomes
Environmental Impact Assessment	senior	7 reports from 2 semesters	2 to 7	classification feature extraction sampling	skills-based outcomes varied widely; some evidence of affective outcomes (adoption and internalization)
Forest Inventory and Planning	senior capstone	5 reports from 4 semesters	6 to 37	area calculation buffer/clip classification overlay sampling selections	skills-based, factual knowledge, information literacy, and conceptual knowledge were met above 80% performance target
Natural Resource Management	senior capstone	5 reports from 1 semester	2 to 7	area calculation buffer/clip classification selections	skills-based outcomes varied widely; some evidence of affective outcomes (adoption and internalization)

We expected first-year students to have difficulty meeting performance targets. In our experience, many first-year and transfer students have not previously used the tools. We were pleased sophomores and juniors met each outcome available to them; however, we did not expect seniors would fail to satisfy mapping and communication, and rudimentary spatial statistics outcomes. In these senior courses, maps evaluated come from assignments with sophisticated procedures that rely on an understanding of factual and conceptual knowledge. However, these assignments are intended to prepare students for their term and capstone projects, and do not contribute substantially toward course grades. We believe the lack of a grade incentive is reflected in the quality of the deliverables and resultant lack of demonstrated learning. Although students' maps were an indicator of some skills-based and data management outcomes, because they lack discussion of the underlying concepts and analysis, we are beginning to question use of maps as a source of assessment data.

The 24 lab reports from a senior forest management course that did include written descriptions of analysis procedures and the interpretation of results provided richer assessment opportunities than maps alone. For example, a representative excerpt from a team of four students from 2011 states follows:

> "…We used two types of GIS analysis: interpolation and stand averaging. Interpolation takes the values found in the field for each point, finds the trend from one point to another, and then estimates geographic patterns in the data … For the Barred Owl the surface interpolation gives you a better representation of where the habitat is than a stand average does. You can easily see certain spots that have a high HSI and where their concentration is…"

In this excerpt, students' satisfactorily demonstrate factual and conceptual knowledge at the understanding and application levels. We believe this type of reporting reinforces how geospatial tools can be used to solve problems, and how the tools, field work, analysis, and reporting are linked (Outcomes 11 and 12). However, students consistently failed to meet both of the information literacy outcomes (Outcomes 7 and 8) in their lab reports. Some teams failed to find, discuss, and show supporting ancillary data, and this omission affected Outcomes 7 and 8 equally.

Outcomes demonstrated in students' term projects and capstone management plans varied (Table 4). Juniors in the natural resource measurements course used spatial analysis creatively. For example, maps were used to communicate field data by attribute and location (e.g., coarse woody debris by volume), and to demonstrate discrepancies between published maps and their field observations (e.g., blue-line streams missing on 7.5-minute topographic maps). Students successfully integrated and communicated spatial information in the reports; however, these reports represented a substantial portion of students' course grade.

Use of spatial analysis varied among the seven term projects from a senior environmental impacts course. For example, one group simply met assignment requirements by providing a general location map, whereas others performed complex analyses such as automated feature extraction from digital imagery. Although no learning outcomes were satisfactorily met, students were generally operating at the application level of the knowledge dimension. However, it should be noted that some students chose to incorporate a great deal of spatial analysis into their reports, which we believe demonstrates some attainment of affective outcomes.

Maps and derived spatial data were common in the five natural resource management capstone plans; however, the complexity and number of analyses varied among the reports. Common maps included general reference, soils, topography, and land cover. There was little discussion of spatial analysis in the reports because the project focused on economic impacts of environmental tradeoffs. Example analyses included identifying suitable firebreak locations, determine wetland mitigation banking potential, and perform area calculations so net present value of management alternatives could be compared. Rubric tallies indicated students were operating at the lower application levels of the cognitive process dimension (i.e., the routine application of analysis procedures to familiar tasks); however, learning demonstrated in the reports failed to meet intended performance targets. We believe these management plans do show some evidence of affective outcomes attainment (e.g., adoption and internalization) because students consistently elected to use spatial analysis beyond the required basemaps. In our opinion, many natural resources students exhibit social and educational characteristics Rogers (1995) ascribed to early adopters, which may explain the voluntary use of geospatial approaches by natural resources students.

Capstone management plans from a senior forest inventory and planning course frequently referenced maps and derived data. Common analyses included classifying land cover, delineating stand boundaries, identifying riparian buffers, establishing wildlife plots, and performing area calculations. The quality of the work was quite high, and indicated that students were operating at the application and analysis levels of the cognitive process dimension. The forestry capstone plans satisfied the 80% performance target for all skills-based, factual knowledge, information literacy, and conceptual knowledge outcomes. However, in-depth use of spatial analysis is required, and students are given detailed expectations and numerous examples to follow.

Hess and Cheshire (2002) asserted that students need frequent exposure with repeated hands-on use in a disciplinary context to retain what they learn. This assertion has been supported in more recent literature on the value of targeted, repeated practice (Ambrose et al., 2010). However, Karpicke (2012) advocates retrieval-based learning and warns repetition leads to rote rather than meaningful learning. This critique of repetition should be considered in the design and implementation of instructional activities and assessment instruments.

In this study, we found students' maps indicated some learning outcomes were met; however, we are beginning to question the usefulness of maps as an assessment data source when they are not accompanied by a discussion of the meaning of the underlying analysis. Reports that included maps and written geospatial methods and interpretation provided richer assessment opportunities. Anderson and Krathwohl's (2001) taxonomy has proven to be useful when used as a "generic" rubric for assessing factual, conceptual, and procedural knowledge present in students' deliverables. Rubrics can be time consuming to develop and change when instruction or outcomes change. Using the same instrument makes it easier to evaluate students' deliverables consistently through time, which is important when comparing data across semesters and assuring that assessment and evaluation of students is fair and equitable.

Other Assessment Methods

Assessment works best when multiple methods and measures are used (Fitzpatrick et al., 2011). Structured interview participants identified a number of intended outcomes and possible data sources; therefore, we developed assessment instruments including, tracking questions, pre- and post-tests, and longitudinal surveys (Carr et al., 2011). These instruments are used in a variety of courses and are beginning to produce useful outcomes data. For example, recurring tracking questions in a first-year student natural resources course are used to track students' factual and conceptual knowledge. Tracking questions in a senior environmental technology course are used to track students' procedural knowledge of how geospatial technologies can be used to design and conduct an environmental study. Additionally, pre- and post-tests are being used to determine if students' knowledge and skills change after course-embedded activities, and longitudinal surveys are used to determine if students' awareness of and confidence in their ability to use the tools change during their programs. We believe survey and questionnaire data will provide us with opportunities to challenge the inferences we drew from the assessment of students' deliverables.

CONCLUSIONS

We believe students are benefiting from geospatial integration efforts; however, we are not meeting our intended performance targets. To improve student learning, we are revising instructional modules, adding a reflective component to assignments when possible, and working with faculty to more seamlessly integrate activities within courses in ways that complement students' ongoing coursework. We are also seeking ways to validate our data and believe that continuous outcomes monitoring will help us identify integration and assessment problems and that confidence in methodology will increase over time if the instruments continue to produce consistent data.

Although this study provides insights into our assessment process, it also raised other key questions including barriers to success (e.g., transfer students, underrepresented groups, and first generation college students), considerations that are forefronted in conversations about students today. Another potential research question surrounding our assessment process involves viewing pre-test questionnaires as retrieval-based learning (Karpicke, 2012) opportunities in addition to establishing students' prior knowledge.

Many institutions have integrated geospatial instruction within their environmental resource programs. We believe an important step in advancing environmental resource and geospatial education is for colleges and universities to assess their outcomes and report their successes and lessons learned. Different institutions will undoubtedly have unique goals, needs, and circumstances, but it is difficult to benchmark performance without communication of findings. Outcomes assessment represents an opportunity for wide-ranging disciplines to advance the environmental resource and geospatial education knowledge base.

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