Mapping the Future: Geomatics as an Essential Element of the Next Generation of Civil Engineering Curriculum

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MAPPING THE FUTURE: GEOMATICS AS AN ESSENTIAL ELEMENT OF THE NEXT GENERATION OF CIVIL ENGINEERING CURRICULUM

Introduction

In 2017, the National Science Foundation awarded Clemson University's Glenn Department of Civil Engineering with the CULTIVATE Grant (Clemson University: Learning Teams and Innovation Ventures for Adaptable Training in Engineering). The grant was given with the ultimate goal of "produc[ing] a new breed of civil engineers capable of creating solutions for 21st-century problems that are posing unprecedented threats to our society." To accomplish this goal, the philosophy of complexity leadership theory is currently being employed to transform the department through several tactics, the first being restructuring the Civil Engineering curriculum to create unique opportunities for nontraditional faculty-student interactions and relationships [1].

One of the central components of the restructured curriculum is the creation of a sequence of courses (Springer 1, Springer 2, Junior Studio, and Keystone Design) that incorporate skills and concepts presented in the traditional Civil Engineering courses offered at Clemson. However, these courses differ from the norm in that they employ a project-based learning approach, thereby exposing students to a collaborative environment consisting of their peers, teams of faculty members, and stakeholders from the greater community. This sequence of courses culminates in a Keystone Design project in a student's senior year.

This paper traces the evolution of Geomatics at Clemson University from a traditional, late-twentieth-century surveying course into a robust and engaging geomatics course that is perfectly positioned to fit snugly into Clemson's ongoing curriculum transformation. Through the integration of additional topics such as Geographic Information Systems (GIS), Global Positioning Systems (GPS), Digital Terrain Modeling (DTM) and Photogrammetry and Remote Sensing, Geomatics at Clemson has leapt forward into the 21st century, equipping students with not only fundamental surveying and spatial data concepts, but also practical hands-on experience with GIS and Civil Engineering enhanced CAD software, both of which are widely used in industry.

The first objective of the paper is to describe the evolution of surveying education in the United States. To understand the current state of surveying education in the U.S., it is helpful to build context, tracing the attitudes that colleges and universities have had toward surveying throughout the nation's history.

The second objective of the paper is to determine if Clemson's Geomatics course offering is consistent with top Civil Engineering programs in the U.S. An inventory of surveying and spatial data courses is compiled and analyzed to capture the current state of American geomatics education. Geomatics, a subject increasingly overlooked by Civil Engineering departments across the United States, is foundational to many fields of Civil Engineering and is therefore a fitting complement to a course that casts as wide a net as Springer 1. Concepts related to spatial data permeate almost every aspect of Civil Engineering, but the analysis of course offerings in top U.S. Civil Engineering programs nationwide reveals that spatial data courses are hardly mandatory, if offered at all.

The third objective of the paper is to demonstrate the interplay of the department's long-required Geomatics course and the newly created Springer 1 (the sophomore-level course in the Keystone sequence), which presents a parking lot land development problem to student teams. The paper first describes the effects that the NSF RED program has had on the department's structure and course offerings. Then, the paper illustrates how Geomatics (which is a corequisite/prerequisite course to Springer 1) can give students practical experience that is applicable to Springer 1.

The skills students acquire in Geomatics are directly transferable not only to the sequence of Springer courses, but also to other upper-level Civil Engineering courses, the proposed Keystone course that will replace the Capstone course, and the workplace. Even if students never survey land, create maps, or model terrain while working in Civil Engineering, they will almost certainly encounter those who do, and being conversant in the language of spatial data will prepare students for success in those kinds of interactions.

The fourth objective is to assess student learning outcomes of the course via an analysis of SALG (Student Assessment of Learning Gains) survey data. Following the spring and fall semesters of 2019 and the spring semester of 2020, students completed a SALG survey, which measures achievement of learning outcomes. The results of the survey are then used to evaluate the effectiveness of current teaching practices, while helping to shape the future of the course as it evolves to fit the technology and needs of the future of Civil Engineering.

The fifth objective is to apply the results of the SALG data to make recommendations that will improve the course in the future. Emerging technologies in spatial data, such as LiDAR and drone technology, are also recommended for inclusion in the curriculum.

Historical Background of Surveying Education

To make a well-rounded argument for the necessity of spatial data in Civil Engineering Curricula today, it is useful to briefly review the historical trajectory of spatial data education in the United States and around the world. In practice, forms of surveying have been employed by civilizations since ancient times, used for constructing ancient wonders like the Great Pyramids of Giza and the aqueducts of the Roman Empire [2]. Surveying, as an applied form of the more abstract disciplines of geometry and mathematics, is naturally a very practical discipline, which lends itself well to on-the-job training by experienced professionals. Therefore, throughout much of its history, the primary method of learning surveying techniques was through working experience.

Surveying in the early years of the United States reflected this fact; although there were some surveying education programs in the country in the early 19th century (at Union College and West Point), the primary on-ramp to a career in surveying was in the field. The desire by settlers to survey vast expanses of land west of Ohio after the Northwest Ordinance of 1785 meant on-the-job training for aspiring surveyors was plentiful [3].

The demand for surveyors continued to explode as white settlers moved westward and Congress carved out with the stroke of a pen the regular geometric state shapes that make up the American map. When U.S. colleges and universities started experiencing more widespread enrollment in the late 19th century and early 20th century, surveying was very clearly viewed as a major component of a standard Civil Engineering curriculum. In the late 1920's, the University of Washington required 27 credits of surveying courses, which comprised 14% of the credits for the Civil Engineering program [3].

Surveying was clearly having its heyday during this time, but by the mid-20th century, the importance of surveying relative to other areas of Civil Engineering slowly started to diminish. As Civil Engineering broadened its purview, it began to include subdisciplines such as structural engineering, geotechnical engineering, environmental engineering, construction science and management, transportation and traffic engineering, and hydraulic engineering. In addition, Civil Engineering became a much more academically focused discipline, with research becoming increasingly important in CE departments. According to J.E. Colcord, "As other areas of civil engineering began to do research and to use it, the relevance of teaching surveying courses that were becoming technician's courses was correctly questioned by the engineering faculty" [3]. Civil Engineering curricula started to become crowded, leaving surveying as a footnote in a typical program; if a surveying course were offered at all, it might or might not be required. Increasingly often, surveying became viewed as a subject for technical schools and community colleges, losing its place as a featured aspect of a four-year CE program.

Current State of Surveying Education in the United States

The consequences of this shifting attitude toward surveying in CE curricula manifest themselves in the United States today in the form of wildly varying offerings and requirements of surveying and spatial data courses in U.S. Civil Engineering departments. An analysis of over 200 top U.S. Civil Engineering programs conducted as part of this research revealed that even one surveying course is hardly guaranteed to be a part of a standard Civil Engineering program at all. Even if surveying is offered, it is sometimes only an elective. Figure 1 shows the percentages of the programs that require at least one course in surveying, offer it as an elective, or do not offer it at all. The analysis included the top 207 Civil Engineering programs in the nation according to collegefactual.com's 2020 list [4]. The course curricula of the Civil Engineering programs were studied, and each surveying or spatial data course offered by the department was included in the analysis. The courses were then flagged as either required or offered as an elective, depending on the specific department's curriculum structure. Finally, the publicly available course descriptions were searched for the following keywords specific to the field of surveying:

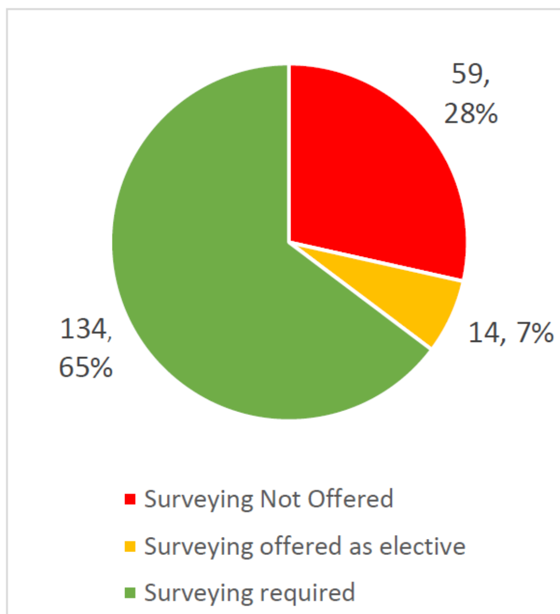

Figure 1: Chart showing the number and percentage of schools that require surveying, offer surveying as an elective, and don't offer surveying

- Surveying
- Traverse

- Traversing
- Angle
- Angular

The results of the analysis show that almost one in three CE departments does not offer surveying at all, a very significant portion of the schools in the analysis. It is alarming that roughly 30% of Civil Engineering graduates will not have had coursework in surveying, considering that surveying is foundational for many areas of Civil Engineering.

Why Should Surveying Be a Part of CE?

Surveying is a field of study in and of itself. There are entire four-year university programs dedicated to only surveying and geomatics, one of which is a very well-developed program offered by the University of Florida [5]. Those programs are incredibly helpful, and often necessary, for students wanting to become licensed surveyors. However, there is a great case to be made for at least one surveying course to be required in Civil Engineering programs. All subdisciplines of Civil Engineering deal with constructing large-scale infrastructure in the context of physical space, which naturally requires precise measurements of large distances over stretches of land. Even if Civil Engineering graduates never end up surveying land themselves, the projects they work on will most likely rely on previously conducted survey work.

Therefore, it would behoove all Civil Engineering degree-granting institutions to at least expose its graduates to basic surveying concepts and techniques. A Civil Engineering graduate without any exposure to surveying or distance measurement will not be as prepared to take on the increasingly interdisciplinary problems engineers face in the 21st century.

Surveying is included on the Fundamentals of Engineering (FE) Exam, one of the first steps that aspiring Civil Engineers take toward licensure [6]. Therefore, it logically follows that surveying should be included in a standard Civil Engineering curriculum. The surveying topics covered on the FE exam are included in Table 1, and all of these are covered by Clemson's Geomatics course.

Table 1: Surveying Topics included on the FE Exam

Surveying Topics included on the FE Exam
A. Angles, distances, and trigonometry
B. Area computations
C. Earthwork and volume computations
D. Coordinate systems (e.g., state plane, latitude/longitude)
E. Leveling (e.g., differential, elevations, percent grades)

The Importance of Surveying Combined with Spatial Data Topics

It is encouraging that 65% of schools reviewed in the analysis require at least one surveying course in their Civil Engineering curriculum. However, to truly give students a solid foundation in surveying education, it is valuable to expose them to related technology such as Geographic Information Systems, Global Positioning Systems, and Digital Terrain Modeling. These technologies utilize spatial data to help make informed engineering decisions and may be even more likely than surveying to be encountered by civil engineers working in industry. A very effective way to expose students to these spatial data technologies is within the context of a surveying course, but that does not happen very often.

Considering that in many cases Civil Engineering programs are already becoming too crowded for surveying, it would follow that the supplementary topics of GIS, GPS, and DTM are even more rarely required. Although it is not uncommon for Civil Engineering departments to offer separate required courses and electives that cover GIS, GPS, and DTM, a deeper analysis of the top 207 CE departments reveals that it is exceedingly rare that schools cover more than one of these topics in their surveying course. If students are not exposed to these additional topics early in their college career, they may never know to pursue them. They may also graduate with an incomplete picture of the pervasiveness that spatial data has in all areas of Civil Engineering.

The Venn diagram in Figure 2 includes only the CE programs that require a surveying course. The diagram divides the surveying courses into those that only include surveying (88 programs on the outside of the diagram), and those that combine surveying with one or more of the additional topics of GIS, GPS, and DTM in the same course. The keywords used to search the publicly available course descriptions for these additional topics are listed in Table 2. Out of the 207 schools included in the analysis, only 3 of them (1.4%) offered surveying, GPS, GPS, and DTM in the same course: Clemson University, Virginia Tech, and George Mason University. It should also be noted that a unique finding of the analysis was that there was only one school which required more than one course in surveying: The Citadel in Charleston, South Carolina. The Citadel's unique requirement is fitting for a military college: surveying has historically been closely tied with the military. Students going through the Citadel's program will experience more of an emphasis on surveying, and schools wanting to emphasize surveying more could use the Citadel as a model for implementing more surveying courses.

Table 2: Keywords used to search course descriptions

Supplemental Spatial Data Topic	Keywords
GIS (Geographic Information Systems)	• GIS • Geographic information system • Geographical information system
GPS (Global Positioning System)	• GPS • Global positioning system
DTM (Digital Terrain Modeling	• DTM • Terrain model • Land model

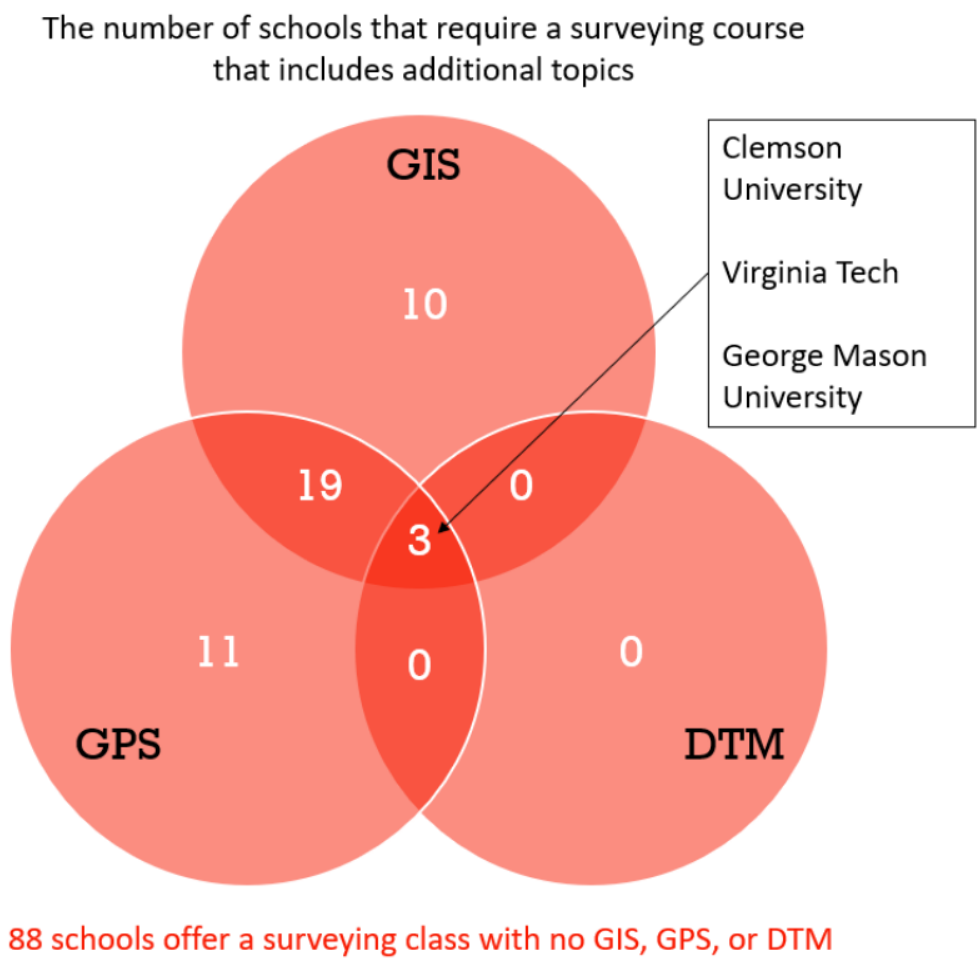

Figure 2: Venn diagram of required surveying courses with additional topics

The Goals of the NSF RED Program

As part of a 2017 grant called CULTIVATE (Clemson University: Learning Teams and Innovation Ventures for Adaptable Training in Engineering) granted to Clemson's Glenn Department of Civil Engineering by the National Science Foundation, the structure of the course offerings of the department is being reimagined. One of the grant's stated goals is to "produce a new breed of civil engineers capable of creating solutions for 21-st century problems that are posing unprecedented threats to our society" [1]. As society worldwide becomes more complex, the problems that face 21st century engineers are becoming increasingly interdisciplinary, requiring a plethora of soft skills such as communication, teamwork, and critical thinking, skills that have not necessarily been explicitly or consistently emphasized in engineering programs.

One of the aims of the NSF RED program is to use complexity leadership theory to transform the traditional student-faculty relationship. Under the complexity leadership model, students engage with each other and with faculty in a more collaborative environment than a typical classroom, usually working on a real-world project that has no defined solution.

Students gain experience working in heterogeneous teams, refining problem statements, and communicating complex ideas to each other and to stakeholders. By "encourage[ing] faculty members and students to interact dynamically under pressure to be innovative, adaptive, and productive" [7], RED hopes to engage students, reduce the dropout rate and foster an environment in which students can develop professional skills.

Springer 1

One of the most visible changes that the Glenn Department of Civil Engineering has seen from the NSF grant is the creation of a sequence of courses called "Springer" courses. Springer 1 and Springer 2, usually taken in a student's sophomore year. Springer 1 is designed to insert students into the context of a real-world engineering problem. In teams, they collaborate to solve a site design problem with certain restraints, consulting with faculty advisors and actual stakeholders throughout the semester. Near the end of the semester, the teams participate in a design charrette in which they present their ideas to stakeholders, receive feedback, and develop a final design plan. A large portion of the Springer 1 grade is based on how well students communicate both within their teams and with faculty and stakeholders [8].

Springer 1 is one of the most unique courses in Clemson's CE department because not only does it reinforce fundamental engineering concepts, it also pays significant attention to the soft skills, like teamwork, public speaking, and self-motivation, that make engineers effective in industry. By simulating what a real engineering project is like, the course gives students a realistic understanding of the major and career path they have chosen very early on in their undergraduate careers.

History of Geomatics at Clemson University

In the 1990's Clemson's Civil Engineering program offered a solely surveying course that covered topics such as distance measurement, leveling, angles, traverse calculations and adjustments, and earthwork calculations. In the fall of 2000, the surveying course was replaced with a course on geomatics that included additional topics of mapping, GIS, GPS, and DTM, and photogrammetry and remote sensing to expose students to modern spatial technologies that were emerging at the time. Geomatics is a term that includes not only the collection of spatial data, but also the manipulation, storage, and display of that data for purposes of engineering decision-making and analysis [9]. Clemson, The Citadel, and Georgia Tech were some of the first universities to design these Geomatics courses as required elements of Civil Engineering curricula [9].

Clemson's Current Geomatics Course and Lab

Today, Clemson's Geomatics course is a 2-credit course and a corequisite 1-credit lab, usually taken during the fall semester of a student's sophomore year. The lecture portion of the course meets for two 50-minute lecture periods and covers theoretical concepts. The lab portion of the course meets once a week for 2 and a half hours. Labs are consistently updated as software and technology evolve, and labs are accordingly adapted to varying extents. There are 13 labs per semester, as shown in Table 3 [10].

Table 3: Geomatics Lab topics and their descriptions

Lab Title	Instruments/Software Used	Learning Objectives
1. Taping and Pacing	• 100-ft tape • Plumb bobs	• Determine average pace • Demonstrate proper taping technique
2. Autolevel	• Autolevel • High Rod	• Level an Autolevel • Read a high rod • Create leveling field notes
3. Profile Leveling	• Autolevel • High Rod • CAD Software	• Perform basic stationing arithmetic • Read Autolevel stadia lines • Create a plan/profile drawing from field notes
4. Angles I	• Theodolite	• Operate a theodolite
5. Angles II	• Theodolite	• Use a theodolite to collect traverse interior angles and side lengths
6. Total Station I	• Total Station • Prism Rod	• Use total station to measure traverse side lengths • Perform a traverse adjustment based on field notes • Create a traverse drawing from field notes in AutoCAD
7. Total Station II	• Total Station • Prism Rod	• Use total station to collect angles and distances • Convert angles and distances to coordinates • Make a digital terrain model of a field

8. GIS I	• GIS Software	• Understand the basic functionalities of a GIS
9. GIS II – Walmart Traffic Study	• GIS Software	• Explain how a GIS applies to a traffic study • Perform advanced GIS functions for a real-world application
10. GPS I	• Juno 3B Receiver • Trimble R4 Receiver	• Read a sky plot • Perform post-processing differential corrections • Use GIS to display results of differential corrections
11. GPS II - Geocaching	• Juno 3B Receiver	• Link an image as an attribute in a GIS • Use GPS to locate a geocache
12. DTM I	• Civil 3D	• Digitize a contour map into CAD software • Create a surface in CAD from digitized contours and surveyed point data
13. DTM II	• Civil 3D	• Model a building pad in CAD • Calculate earthwork

The lab topics outlined above offer students a unique experience to develop skills that are applicable in numerous situations: the sequence of Springer and Keystone courses, other upper-classman-level courses in the Civil Engineering Department, and the workplace.

Geomatics and Springer 1

After the restructuring of the Civil Engineering curriculum and the addition of the Springer courses, Geomatics was made a prerequisite/corequisite course to Springer 1, and with good reason. The main design problem in Springer 1 is a parking lot/site design problem, which utilizes the following skills that are developed in Geomatics:

1. Use of CAD software applied to a project

Several Geomatics lab assignments make significant use of CAD software that is widely used in the Civil Engineering industry. Geomatics and Springer 1 are both usually taken in a student's sophomore year, which is the first year that students enroll in the Civil Engineering program after completing their freshman year in General Engineering. Therefore, Geomatics is likely to be the first course in which a student is exposed to this software in a specifically Civil Engineering context, even if they have been exposed to the software previously. Having a basic awareness of the capabilities of CAD software is invaluable for a course like Springer 1, in which students must use 3D surfaces to analyze runoff patterns and design parking lots according to specifications.

2. Teamwork

Geomatics labs are usually conducted in groups of four, and the groups are assigned alphabetically by last name. This normally ensures that students are working with others they may not be personally close to, or that may not match their leadership style. This mixing of personalities forces students to compensate for each other to complete a given lab successfully. A typical surveying lab has multiple pieces of equipment that must be operated simultaneously. There are also usually multiple separate processes that must occur that may be unrelated to each other. The number of moving parts combined with a two-and-a-half-hour time limit means that groups must work both efficiently and accurately to complete the lab. Working under pressure with constraints is one of the central components of Springer 1, and Geomatics lab simulates those experiences well.

3. Refining Problem Statements and Using Engineering Judgment

As a design course, Springer 1 forces students to confront problems that lack both a defined scope and a clear-cut path to a solution. Surveying labs often require students to make multiple decisions that TA's do not cover while introducing the lab. For example, a group is often required to set up an instrument at an arbitrary point in space, but the location of the instrument must offer clear sightlines to other points in space.

Groups must also think two or three steps ahead when planning a route of surveying to ensure they will be able to take measurements properly. Decisions like these are likely some of the first times that students are asked to make an engineering judgment call in a Civil Engineering context. Judgment calls like these are littered throughout Springer 1 and having experiences with them in a sophomore-level course can only help prepare students for those choices in the future.

Geomatics as a Building Block for Future Courses

As mentioned previously, surveying and the modern technologies associated with spatial data are both foundational to many subdisciplines of Civil Engineering. There exist today several instances of overlap between Geomatics content and content from higher-level classes in Clemson's CE curriculum. In addition, there are many opportunities to incorporate Geomatics content into upper-level classes to both enrich those course experiences as well as reinforce fundamental concepts and techniques.

1. Roadway Design

The department offers a course in Roadway Design, which has both a lecture and a lab component. In lecture, the fundamentals of geometric design of roadways are covered, including route selection, horizontal and vertical alignment, and sight distances. In the lab component, student groups are tasked with designing a roadway virtually from scratch. Groups are given a map representing a topographically diverse section of land and must create alternate routes to traverse the area while keeping in mind the constraints of minimizing cost and maximizing safety. Students then use CAD software extensively to bring their design ideas to life, eventually creating a final plan/profile drawing of a roadway that could be presented to decision-makers.

Concepts such as roadway stationing, reading contour maps, calculating earthwork, and easting and northing coordinates are covered in Geomatics and are directly built on in the Roadway Design course. DTM is used in the lab portion of the course to model the elevation changes over the topography. GIS, while not currently used in Roadway Design, could easily be incorporated into both the lecture and lab portions of the course.

2. Environmental Engineering

An important element of environmental engineering, especially as it relates to Civil Engineering, is designing and constructing best management practices (BMPs) that reduce runoff. Deciding where on a site to place BMPs is a spatial data problem. Digital Terrain Modeling could be used to model earthwork for BMPs like bioswales and can be used to create 3D models of pollutants in groundwater.

3. Earth Slopes and Retaining Structures

Digital Terrain Modeling can be used to model the shapes of both earth slopes and retaining structures on a site. The effects of different alternatives can also be observed quickly and cheaply using modeling software.

4. Geotechnical Engineering

GIS could be used to map different soil types in a region, and to explore what the varying soil types mean for construction in certain regions of the country and the world.

5. Stormwater Design

DTM is used for basin delineation, and contour maps are used to analyze runoff patterns.

6. Capstone/Keystone Design

CAD software is used extensively in Capstone Design, especially for purposes of site design and hydrology. Site design requires creating grading plans, which are introduced in Lab 13 of Geomatics.

Overview of SALG Survey

The SALG Survey (Student Assessment of Learning Gains) is a survey used by educators to evaluate students' achievement of learning outcomes. It takes a different approach to traditional student evaluations because it assumes that "students can make realistic appraisals of their gains from aspects of class pedagogy and of the pedagogical approach employed" [11]. At the end of the spring and fall 2019 semesters, students taking Clemson's Geomatics course were asked to complete a SALG survey, which asked them a wide variety of questions about their attitudes toward both the course overall as well as specific topics and labs.

Table 4: Summary of SALG Survey Questions

	Number of Questions	
Question Groupings	Categorical	Long Answer
Understanding of course content	12	2
Increases in your skills	8	1
Class impact on your attitudes	7	1
Integration of your learning	3	0
The class overall	3	2
Class activities	3	0
Assignments, graded activities, tests	8	1
Class resources	3	1
The information you were given	3	1
Support for you as an individual learner	6	1
How interesting were the labs?	13	2
Usefulness of the labs	13	1

The survey consisted of 12 sections, which are listed in Table 4. In all sections of the survey, students were asked a series of categorical questions, in which they rated their response on a five-point scale. Most sections included one or more free response questions, where students could offer more nuanced and specific feedback.

A wealth of very useful information the survey can provide is a sense of how students respond to the labs. The lab portion of the course is where students are directly involved in hands-on learning. Therefore, understanding their feedback specifically regarding the labs can help inform instructors about the efficacy of both the Clemson Geomatics course and geomatics courses at other colleges and universities.

Categorical Questions

38 students responded to the survey in spring 2019 and 90 students responded in fall 2019. Figures 3 and 4 detail responses to two categorical questions posed to the students in the SALG survey. The first asks students to rate how much each lab interested them with “not at all” being coded as 1 and “extremely interested” being coded as 5. The results of this question indicate that overall, students find the surveying labs (labs 1-7) to be interesting, with average ratings hovering between 3.5 and 4.5 (a score of 4 represents highly interested). However, the scores are more varied for the spatial data labs (labs 8-13). Particularly, the GIS labs (labs 8 and 9) are cited as some of the less interesting labs.

The second categorical lab question asks the students how much they agree that each lab was useful in reinforcing class concepts. “Strongly disagree” was coded as 1, and “strongly agree” was coded as 5. The results show that students overwhelmingly find the labs to be useful in reinforcing class concepts, with almost all labs being rated an average of 4 or better (4 representing “agree”).

The results of these two categorical questions show that in a geomatics course, students recognize that a lab portion is a key element in supporting their success The hands-on and active learning in which students participate is valuable not only for reinforcing class concepts, but also for piquing their interest in surveying and geomatics as a subject area. The strong interest in the labs could very well translate to increased interest in pursuing further studies in geomatics and further engaging students in the quickly growing field of spatial data in Civil Engineering.

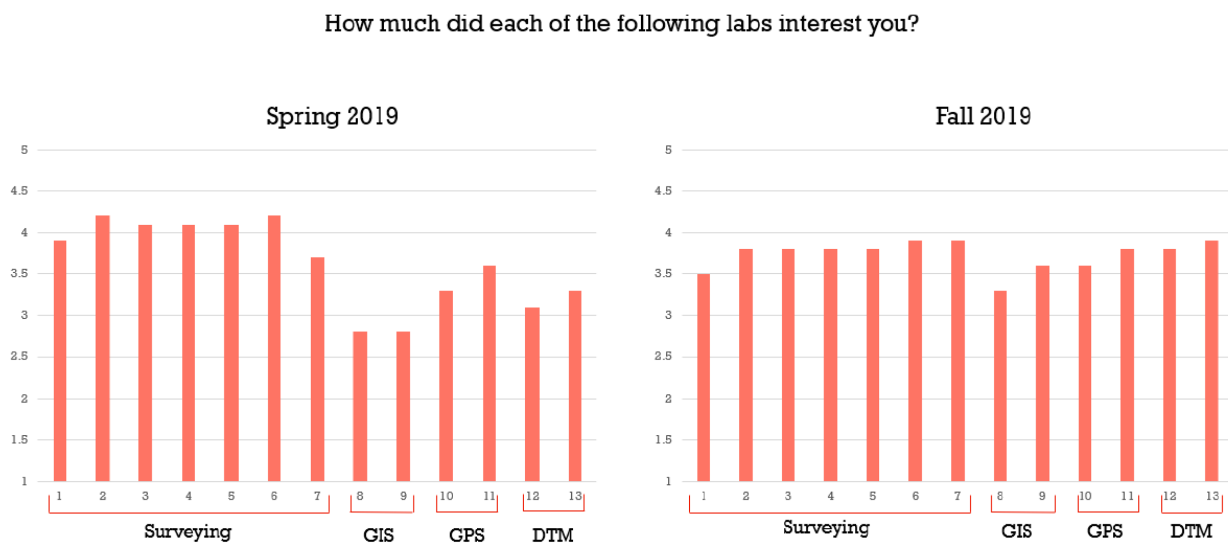

Figure 3: Summary of students' interest in labs

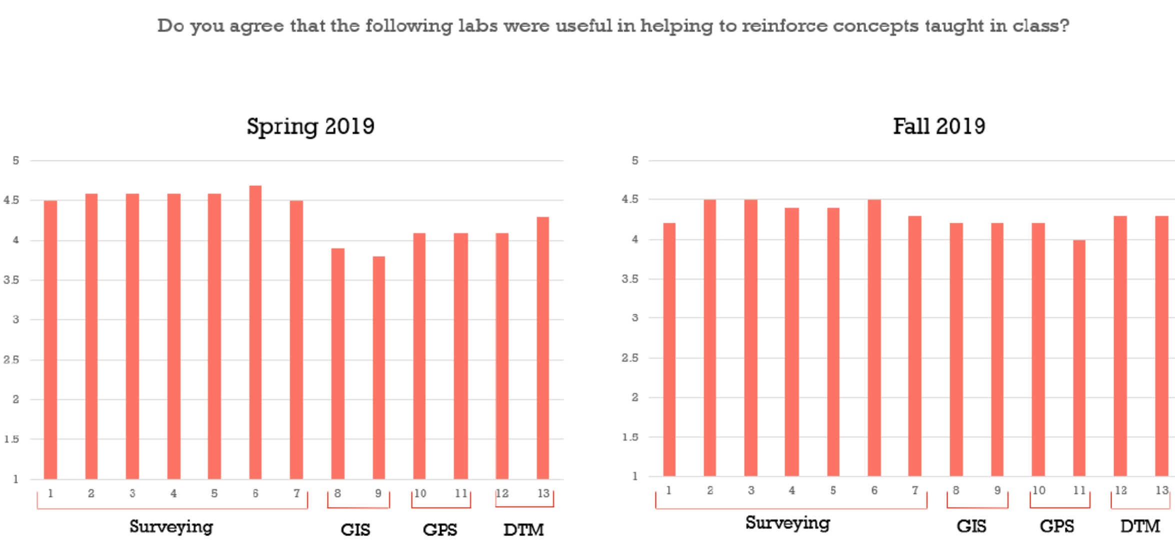

Figure 4: Summary of lab usefulness to students

Free Response Questions

The SALG survey also included two free response questions about the labs. One asked the students to comment on what they liked most about the labs, and the other asked them to comment on what they felt could be improved about the labs. When asked what they liked about the labs, 51 out of the 128 students who took the survey specifically mentioned something related to the surveying labs, whether it was being outside, learning surveying techniques, or working with specific surveying instruments. Another aspect of the lab that students enjoyed was the application of the lab to the lecture material, with 15 responses mentioning it. Additionally, 14 of the responses included getting hands-on experience with equipment and software.

When asked what they feel could most be improved, 28 students mentioned that one or both GIS labs needed to be improved. 16 responses mentioned the DTM labs. Many of the critiques of the GIS and DTM labs centered around the fact that it is easy to get lost in the procedure of the lab while missing the larger purpose behind individual keystrokes and tasks. The students who responded generally felt less confident with the underlying concepts of the GIS and DTM labs and felt that the lab was more about mimicking the TA's keystrokes rather than learning why each task was being done. Sample quotes from students are included in Table 5.

Table 5: Sample Free Response Answers (Spring/Fall 2019)

What students liked	What students felt should be improved
"I really enjoyed the labs because they allowed me to get a hands-on experience working with the instruments."	"I did not like the GPS lab. I didn't feel like I learned much from it."
"I loved the fact that we got to go out and actually survey a field."	"Some of the labs on the computer go by too fast."
"I enjoyed the building pad lab. I liked being able to create something based on points we actually surveyed."	"Some aspects could make the lab more time efficient."
"The Walmart lab was the one I found the most interesting because I felt like I was solving a real-world problem."	"I think the GIS labs could be more organized and more well thought out."

Questions related to NSF RED Goals

To measure how Clemson's Geomatics course is preparing students for the complex society they will face as civil engineers, the results of several categorical survey questions related to the goals of the NSF RED program are analyzed below. These questions relate more to the soft skills students acquire and are generally centered around interpersonal relationships and active learning. The first grouping of questions asked students, "As a result of your work in the class, what gains did you make in the following areas?" The second grouping asked, "How much did the following aspects of the class help your learning?" The results to the following questions are shown in Figures 5 and 6.

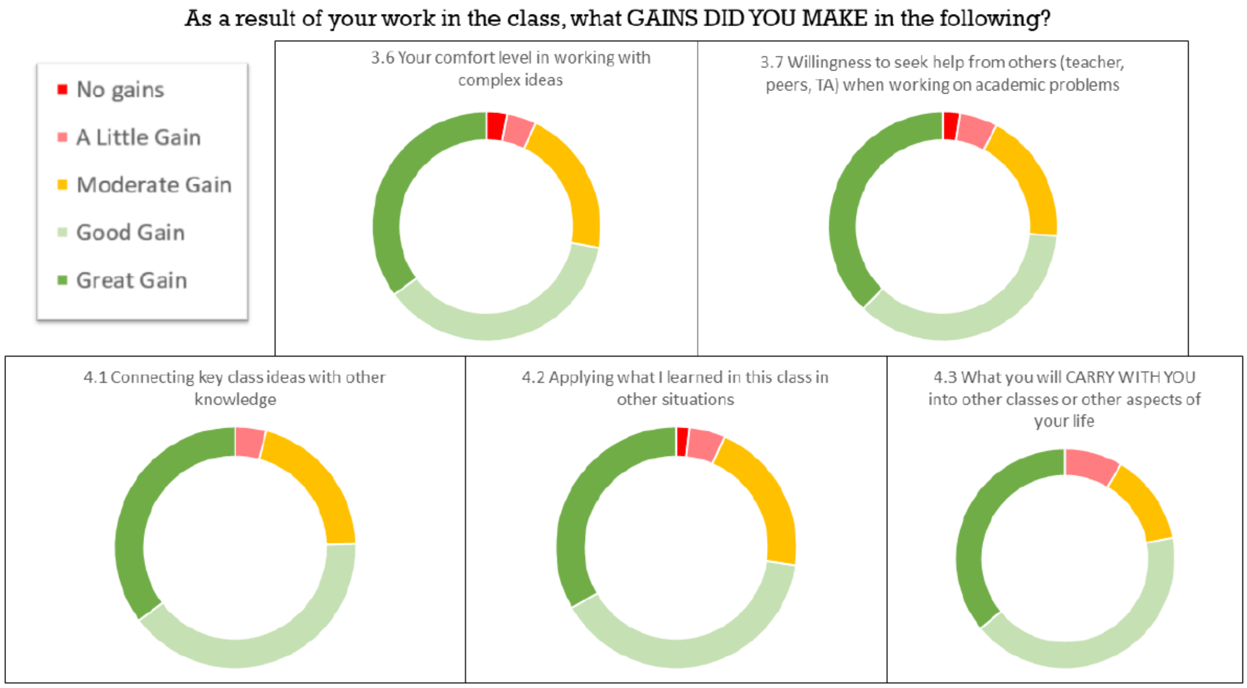

Figure 5: SALG questions related to learning gains

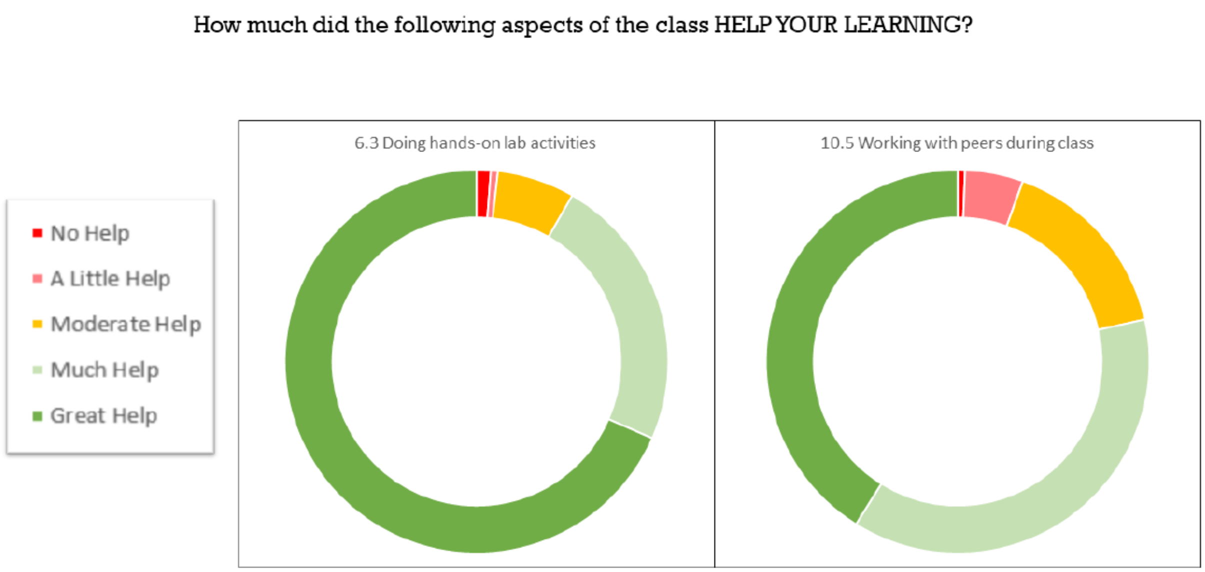

Figure 6: SALG questions related to aspects of the class helping learning

The questions regarding learning gains show that roughly three quarters of students responded with either “Good Gain” or “Great Gain” to each of the topics selected. This implies that students who take Geomatics are improving in soft skills that will benefit them both in the sequence of Springer courses and in the broader Civil Engineering workplace. The results show that an overwhelming majority of the students surveyed experienced at least moderate gain in the skills shown, which points to Geomatics being a course that provides students with more than just spatial data knowledge.

The next set of questions, related to hands-on learning and working with peers during class, asked students about how much the activities helped their learning. The responses for the hands-on lab activities are very convincing, with roughly two thirds of the respondents reporting that the hands-on lab activities and active learning were a great help to their learning. Roughly 3 quarters of the students also reported that working with their peers during class was either “Much Help” or “Great Help” to their learning. Again, the overwhelming majority of respondents experienced at least “Moderate Help” from active learning and working with peers, which signals that Geomatics is giving students opportunities to engage with the course content in ways that improve their ability to function in an increasingly complex and interdisciplinary world.

The Impact of Covid-19

The Coronavirus pandemic that upended life across the globe in the year 2020 has also affected Clemson’s Geomatics course significantly, forcing many of the labs to be conducted virtually. The pandemic has tested the resiliency and flexibility of instructors, teaching assistants, and students. Below is a description of the adaptations that have been employed in response.

Clemson University transitioned to 100% virtual learning in the middle of March 2020, when there were still four surveying labs yet to be taught. To adapt to virtual learning, teaching assistants created videos on proper use of the surveying equipment and asked students to read raw data from the instruments. Then, after students completed field notes based on the data from the videos, they conducted calculations and created drawings in CAD to supplement the material in the videos.

The first five weeks of the fall 2020 semester were online as well, which necessitated major changes in the order of labs. Four of the spatial data labs, which would have normally been taught at the end of the semester, were moved to the beginning of the semester. Then, the teaching assistants created a combination of synchronous and asynchronous labs that were held over Zoom. TA’s would either create pre-recorded videos which students could watch at their own pace, or they would guide students through the lab step-by-step on a Zoom call, answering any questions students had along the way.

SALG Survey Analysis

A SALG survey was sent to students at the end of the fall 2020 semester, and the last set of questions asked the students to evaluate the effectiveness of the online labs. 57 students responded to the survey, and the results of the survey are analyzed below in Figures 7 and 8.

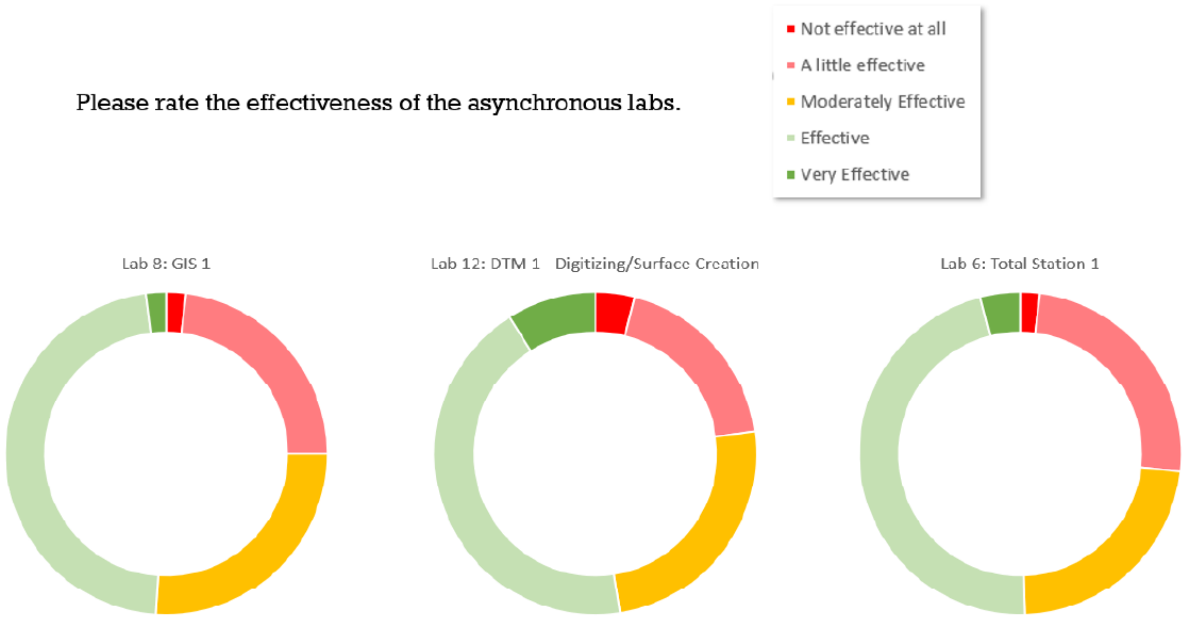

Figure 7: Effectiveness of asynchronous labs

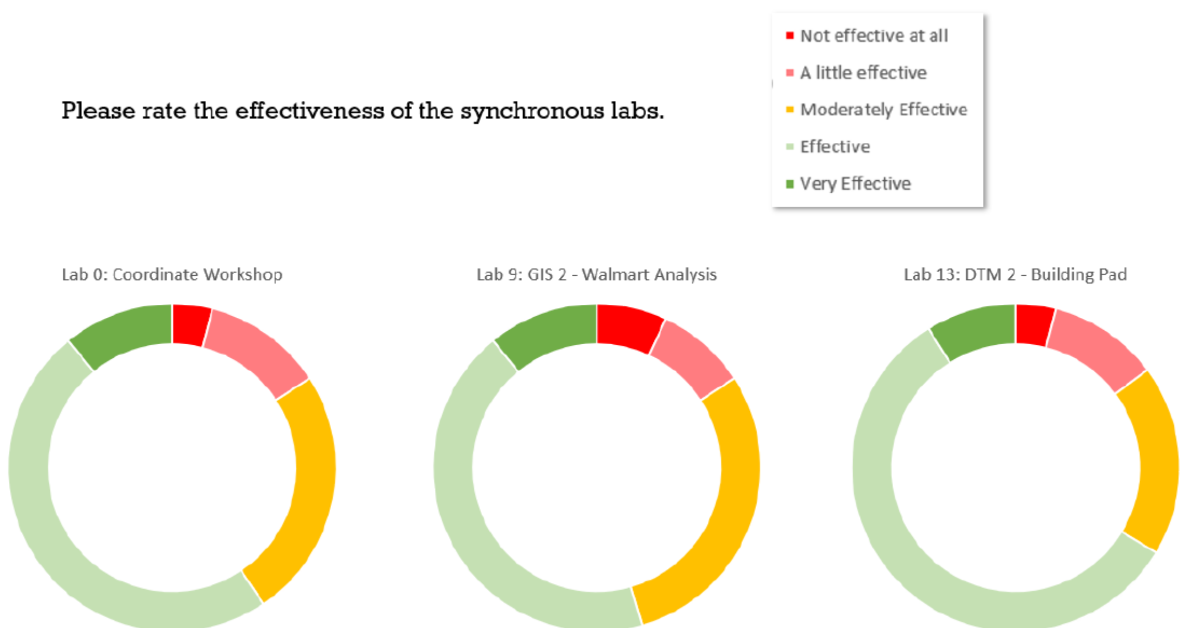

Figure 8: Effectiveness of synchronous labs

The results of the survey show that roughly half to two thirds of the respondents found the online labs either “Effective” or “Very Effective.” While those results are encouraging, there are significant percentages of the students that responded with “Not Effective at All” or “A Little Effective.” This points to the unique challenges that are created when virtually conducting labs that are usually completed in person. Some of those challenges were highlighted in free response questions posed to the students, in which they were asked what they liked and disliked about the online labs. Some sample responses are included in Table 6.

Table 6: Sample Free Response Answers (Fall 2020 Online Labs)

Asynchronous Labs	**Synchronous Labs**
“The asynchronous labs weren't quite as engaging, but it was nice that I could finish them on my own time.”	“I enjoyed the synchronous labs more than the asynchronous labs because it kept me accountable for doing them at a specified time.”
“I thought each of these labs were fun and every informative. Going along with a video was super helpful.”	“The only thing I didn't like about these synchronous labs were that if one person got stuck on something, everyone had to wait for them to catch up before moving forward. These labs would definitely be better asynchronous.”
“I liked the freedom to do them at my own pace but I also felt like I procrastinated and ended up rushing through them.”	“Sometimes it was difficult to keep up the pace of the synchronous labs because of having to look at the shared screen and then go into whatever software and perform the steps all at the same time. It sometimes just got to be a lot to juggle. ”
“In these labs I simply followed each keystroke. If I was to figure this out more on my own it could have been better.”	“I enjoyed having a guided lab that would have live feedback.”

Generally, students enjoyed the asynchronous labs because they were able to pause the instructional videos and work at their own pace. However, many students also cited a lack of engagement and interaction that would have typically come with an in-person or synchronous lab. Some students also missed the accountability that synchronous labs require of them. The main critique of the synchronous labs was that it was difficult to operate the software and follow along with the TA’s instructions of the Zoom call at the same time. If a student only has one computer monitor, it makes the task more challenging. The format of the lab also caused delays if one or more students got behind, leading to some inefficiencies. Students did like being able to ask questions instantly and get instant feedback from the TA’s.

The feedback from the SALG survey shows that Geomatics has the potential to be a very flexible course and can adapt to changing circumstances. There are still ways to improve the online lab experience, but the course has been resilient in the face of unprecedented changes to education brought on by the Coronavirus pandemic.

Conclusions

Geomatics, while possibly not always front-of-mind in the world of Civil Engineering, is in fact a crucial foundation for a wide variety of civil engineering subdisciplines (in addition to being an entire field of study on its own.) Through the research conducted here, the following objectives have been accomplished:

1. Examining the history of surveying and spatial data education in the U.S.

In the early days of the U.S., surveying was central to the efforts of white settlers to draw boundaries on land that did not belong to them. As a result, colleges and universities heavily emphasized surveying in their Civil Engineering programs. But as surveying began to be seen as a technical school subject amid growing CE departments, surveying requirements became very scattershot throughout the nation.

2. Determining where Clemson's Geomatics course offering stands in comparison to other top CE programs in the United States.

Surveying education, and by extension, education on the supplementary topics of spatial data, is not uniformly expected across U.S. Civil Engineering departments. Only 65% of the top 207 Civil Engineering programs in the nation require surveying, while 28% do not offer it at all. Even within the 134 schools that do require surveying, 88 of them offer a surveying course that does not cover the additional spatial data topics of GIS, GPS, and DTM, all of which are extremely relevant to civil engineers today. Only three schools, Clemson University, Virginia Tech, and George Mason University, require a surveying course with all three supplementary data topics.

3. Constructing a robust geomatics course that fits into the newly created Springer 1, and supplements other upper-level CE courses

The geomatics course at Clemson ambitiously covers many topics that would be pushed to the wayside in a typical college surveying course. The surveying, GIS, GPS, and DTM content students learn in lecture are all reinforced strongly in the form of a required corequisite lab section, in which students get hands-on experience with equipment and software that brings fundamental surveying and spatial data concepts to life. The course also aligns very well with the goals of the NSF RED program, preparing students for success in the sequence of Springer courses through opportunities to use CAD software, teamwork, and engineering judgment. The course instills many skills that students need in future Civil Engineering courses. Due to the nature of Civil Engineering, concepts that are introduced in Geomatics like measurement, grades, and slopes, resurface in higher-level courses often.

4. Assessing student learning outcomes via an analysis of a SALG survey

The results of the SALG survey indicate that students respond well to Geomatics, especially the lab portion. Despite some improvements to specific labs that students suggest, overall, the survey results show that they are very happy with not only how the labs assist in their understanding of the course content, but also are genuinely interested in the material. They enjoy getting outside to work with surveying equipment and each other (this is even more apparent in students that have taken the course during the Covid-19 pandemic). In addition, the course teaches both fundamental surveying and spatial data concepts alongside soft skills such as effective communication, working with peers, and problem solving, that civil engineers need more than ever to tackle the problems that will face them in industry.

5. Offer recommendations for improving the course in the future

Geomatics has the potential to incorporate even more modern technology such as LiDAR and drone technology. LiDAR is a technology that has wide-ranging applications in the fields of surveying and spatial data. It is used for making 3D digital elevation models of terrain, which can be the next topic that Geomatics labs can incorporate to show students the state of the art in spatial data technology [12]. Discussions on drone technology can also be incorporated seamlessly in the photogrammetry and remote sensing portion of the course, and a lab could be created in which students use drone footage or aerial photographs to solve real-world engineering problems. Further research in these two areas is recommended for inclusion in the Geomatics curriculum.

REFERENCES

[1] "Award Abstract #1730576 IUSE/PFE:RED: Clemson University: Learning Teams and Innovation Ventures for Adaptable Training in Engineering (CULTIVATE)." *National Science Foundation*. https://www.nsf.gov/awardsearch/showAward?AWD_ID=1730576&HistoricalAwards=false. Accessed 18 June 2020.

[2] P. Wolf, "Surveying and Mapping: History, Current Status, and Future Projections." *Journal of Surveying Engineering*, vol. 128, no. 3, pp. 79-107, 2002.

[3] J.E. Colcord, "Surveying Engineering Education for the 21st Century." *Journal of Surveying Engineering*, vol. 114, no. 1, pp. 37-46, 1988.

[4] "2020 Best Colleges for Civil Engineering." *College Factual*. https://web.archive.org/web/20200804104648/https://www.collegefactual.com/majors/engineering/civil-engineering/rankings/top-ranked/. Accessed 4 August 2020.

[5] A. Abd-Elrahman, et. al., "Geomatics Education at the University of Florida: A Case Study of Challenges and Adaptation." *Surveying and Land Information Science*, vol. 78, no. 1, pp. 5-16, 2019.

[6] "Fundamentals of Engineering (FE) CIVIL CBT Exam Specifications." *NCEES*. https://ncees.org/wp-content/uploads/FE-Civil-CBT-specs-1.pdf.

[7] P. Alongi, "Civil Engineering reboot backed by $2 million from the National Science Foundation." *Clemson University Newsstand*. 25 July 2017, https://newsstand.clemson.edu/mediarelations/civil-engineering-reboot-backed- by-2-million-from-the-national-science-foundation/.

[8] W. Sarasua, N. Kaye, S. Sanders, and S. Crocker. Syllabus for Springer I,Department of Civil Engineering, Clemson University, Clemson, Spring 2019.

[9] W. Sarasua, W.J. Davis, "Including Geomatics as an Essential Element ofthe Civil Engineering Curriculum." *ASEE Annual Conference*, 2003.

[10] W. Sarasua, Syllabus for Geomatics, Department of Civil Engineering, Clemson University, Clemson, Fall 2020.

[11] E. Seymour, D.J. Wiese, and A. Hunter. "Creating a Better Mousetrap: On-line Student Assessment of their Learning Gains." *National Meetings of the American Chemical Society Symposium*, 27 March 2000, San Francisco.

[12] L. Xiaoye. "Airborne LiDAR for DEM generation: some critical issues." *Progress in Physical Geography*, vol. 32, no. 1, pp. 31-49, 2008.