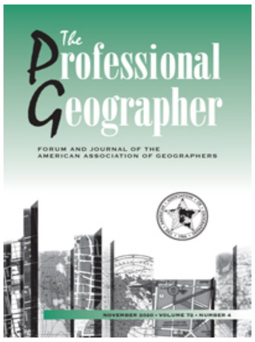

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Emerging Geospatial Technologies in Instruction and Research: An Assessment of U.S. and Canadian Geography Departments and Programs

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Academic geography is the nexus for geospatial learning and research on many college and university campuses. Along with offering courses and programs in established areas such as geographic information systems and remote sensing, geography instruction and research have increasingly used new or emerging geospatial technologies (EGTs) for capturing, processing, and visualizing spatial data. Examples of EGTs include unoccupied aircraft systems, location-based services, and virtual reality devices. Although EGTs are expanding rapidly within higher education institutions, we know less about the nature of their adoption within geography instruction and research. For example, which EGTs are most firmly established and in what project domains (data capture, data analysis, and data delivery) are they used most frequently? In this article, we present findings from a Web-based survey of U.S. and Canadian geography departments and programs aimed at exploring the adoption and use of EGTs. Among other results, our findings suggest that EGTs are often employed across more than one project domain. Along with assessing rates of adoption and frequency of use, we examine sources of funding used in the acquisition of EGTs. **Key Words: geography departments, geospatial technology, higher education.**

地理系是许多院校开展地理空间学习和研究的纽带。除了开设地理信息系统和遥感等成熟领域的课程和专业，在空间数据采集、处理和可视化方面，地理教学和研究越来越多地采用新的地理空间技术(EGT)。EGT的例子包括无人机系统、基于位置的服务、虚拟现实设备。尽管EGT在高等教育里发展迅速，我们对地理教学和研究中采用EGT的本质还不甚了解。例如，哪些EGT最完善、EGT在哪些方面的应用最频繁(数据采集、数据分析、数据发送)？为了探索对EGT的接纳和应用，本文展示了对美国和加拿大的地理系和地理专业的网络调查结果。结果认为，EGT常常在多项工作中得到应用。除了接纳率和使用频率，我们还审视了获取EGT所需资金的来源。 **关键词：地理系，地理空间技术，高等教育.**

La geografía académica es el punto de confluencia para el aprendizaje y la investigación geoespacial en muchos recintos universitarios. Junto con la oferta de cursos y programas en áreas ya establecidas como los sistemas de información geográfica y la percepción remota, la instrucción y la investigación en geografía crecientemente están usando tecnologías geoespaciales nuevas o emergentes (EGTs) para captar, procesar y visualizar datos espaciales. Ejemplos respecto de la aplicación de EGTs incluyen sistemas de aeronaves desocupadas, servicios basados en localización e instrumentos de realidad virtual. Aunque las EGTs se están expandiendo rápidamente en las instituciones de educación superior, poco es lo que sabemos acerca de la naturaleza de su adopción dentro de la instrucción y la investigación geográficas. Por ejemplo, ¿cuáles de las EGTs están más firmemente establecidas y en el ámbito de qué proyectos (captura de datos, análisis de datos y entrega de datos) se usan con mayor frecuencia? En este artículo presentamos los hallazgos de un estudio basado en la Web sobre departamentos y programas de geografía americanos y canadienses, estudio orientado a explorar la adopción y uso de las EGTs. Entre otros resultados, nuestros hallazgos sugieren que las EGTs se emplean a menudo a través de más de una esfera de proyectos. Junto con la evaluación de las tasas de adopción y frecuencia de uso, nosotros examinamos las fuentes de financiación a las que se acude para adquirir EGTs. **Palabras clave: departamentos de geografía, educación superior, tecnología geoespacial.**

Geography instruction and technology share a long history (Wilbanks 2004). More than a hundred years ago, Nicholls's (1912) list of equipment needed for teaching geography included globes, ordnance maps, drawing tools, and surveying instruments. Along with basic equipment, geography instruction and research has also come to rely on specialized technologies such as barometers and streamflow gauges used by physical geographers and photogrammetry instrumentation necessary for the creation of terrain maps (Pease et al. 2002). Beginning in the 1960s, some geography departments developed dedicated research and instructional facilities for computer mapping, geographic

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information systems (GISs), and satellite-based remote sensing (Stoddard 1973; Palladino and Kemp 1991), the so-called geospatial technologies. Today, the term *geospatial technology* refers to tools employed in the mapping and analysis of the Earth's surface features, including human and other activities (American Association for the Advancement of Science 2018). In other words, geospatial technology is "equipment and software used to visualize and analyze Earth's features" (Makinster, Trautmann, and Barnett 2014, 3). An expanded definition might also embrace technology that interfaces with mapping or global navigation satellite system (GNSS)-enabled devices.

The importance of geospatial technology within geographic research and instruction is well documented. Aina (2012) noted that geospatial technologies provide opportunities for students to view problems from multiple perspectives. Others assert that geospatial technology facilitates critical thinking (Sinton 2012) and spatial awareness (Wise 2018). Another trend associated with geospatial technology is improved accessibility to information. For example, methods for visualizing spatial data that were previously inaccessible to all but specialists are now ubiquitous (Sui, Goodchild, and Elwood 2012) and a part of everyday life (Goodchild 2007; Makinster, Trautmann, and Barnett 2014; Olson 2014; DeMers 2016).

Despite the widespread availability of these technologies, educators face ongoing challenges in the design and integration of activities that use geospatial technologies within college and university courses. Problems include, but are not limited to, the high cost of acquiring and maintaining equipment and software, the need for specialized training, and the absence of pedagogical strategies (ESRI 2002; Manson et al. 2014; Mathews and Wikle 2019). Additionally, geospatial technologies evolve quickly. To illustrate, the National Geospatial Advisory Committee (2016) identified five trends currently shaping geospatial technologies: (1) advances in real-time data capture, (2) miniaturization, (3) new sensor platforms, (4) the expanded use of wireless and web networks, and (5) increasing computing speeds.

Fortunately, the literature offers examples of how geospatial technology can be integrated within geography and related disciplines. For example, exercises and teaching strategies are available on topics ranging from GNSS (specifically, Global Positioning System [GPS]; see Wikle and Lambert 1996; Myers et al. 2003; Mathews and Flynn 2018) to the use of small unoccupied aircraft systems (UAS) for remote sensing (Vasuki et al. 2014; Birtchnell and Gibson 2015; Jordan 2015; Williams, Tooth, and Gibson 2017; Hardin et al. 2019). Others have outlined recommendations for engaging students in mobile data collection (Armstrong and Bennett 2005; Glass 2015; Peirce 2016). Geospatial instruction is also noted as being important within teacher preparation and K–12 instruction (Bednarz and Audet 1999; Kerski 2003, 2015; Gatrell 2004; Harte 2017).

Our Inquiry

Geospatial teaching and research facilities used today bear little resemblance to the ones in place when automated cartography, GIS, and remote sensing courses were first offered in the 1960s and 1970s. Powerful desktop computers coupled with high-resolution displays and other visualization tools (e.g., virtual or augmented reality devices) have replaced light tables, tape-based storage systems, and cathode ray tube displays. The nature of data collection and analysis has also changed. Today, personal devices such as tablets and smartphones are increasingly used to manipulate, integrate, and display data. Along with field data collection with UAS, students and faculty now take advantage of spaceborne innovations such as CubeSats and new techniques for data visualization, including three-dimensional (3D) printing. Unfortunately, although geography departments and programs have made significant investments in geospatial technology, we know little about the specific application areas involved or the sources of funding used to acquire such technologies.

Given widespread use of newer geospatial applications and the rapid pace of change, we suggest the need for a closer look at new or emerging geospatial technologies (EGTs) that have grown in importance within academic geography. In this article we assess the adoption of EGTs in geography instruction and research with consideration of the types of EGTs that have been adopted most frequently, the extent to which EGTs are used within teaching and research, and the sources of funding most important in their acquisition. Specifically, we identify EGTs that have been widely adopted by geography departments, their frequency of use, and the ways in which EGTs are deployed in teaching and research. Our goal is to provide insight into larger trends in the use of geospatial technologies that support discussions about the unique role of geography departments and programs in exposing students to EGTs.

Material and Methods

The principal source of information used for our exploration of geospatial technology was a fifty-four-question Web-based survey of U.S. and Canadian geography departments and programs. As a framework for organizing data, we created seven categories to represent groups of similar EGTs with respondents asked to identify the frequency at which

Table 1 *Select survey prompts for geography department chairs/heads*

Which of the following geospatial technologies is/are currently used by undergraduate and/or graduate students in your department?
Which of the following GNSS are utilized by students in your department using GNSS instrumentation?
What type of GNSS receivers are used by students in your department utilizing GNSS instrumentation?
What type of GNSS antenna(s) is/are used by students in your department utilizing GNSS instrumentation?
In which project domain(s) is/are your department's GNSS receivers and other instrumentation employed?
Do students in your department utilize postprocessing software for differential correction or other purposes with collected GNSS data?
To what extent are students in your department exposed to use of GNSS technology, either in course work or research?
Which of the following best describes the use of GNSS instrumentation by students in your department?
Approximately how many GNSS receivers and associated instrumentation (e.g., external antennas) are available for use by your department's students for instruction and/or research?
What are the primary sources of funding used to purchase GNSS instrumentation in your unit?

Note: GNSS = global navigation satellite systems.

EGTs are used within each category for instruction, research, or both. We also requested details about specific hardware and software identified within each EGT category, the principal project domain where the technology is employed, and the level (undergraduate or graduate) at which technologies are used in the classroom. In addition, we requested information about the ways in which EGTs are used for research and the source of funding that facilitated equipment or software acquisition. Table 1 presents a sample of questions asked.

For the purpose of this study, we defined geospatial technologies as a broad range of tools for the collection, processing, or analysis of geographic data. These include, but are not limited to, GIS, GNSS, and remote sensing. As a subset of geospatial technologies, we define EGTs as location-based tools that have been recently adopted by geospatial practitioners, even if they have been around for several years. In some cases, these technologies are not mutually exclusive or might be closely related to other technologies. Further, we recognize that our list is not all-inclusive (e.g., high-performance computing as it pertains to geospatial data is not included). In what follows, we present an overview of the categories of emerging technology we explored in our survey.

EGT Category 1, unoccupied autonomous and semiautonomous vehicles, is any class of vehicle without a human on board. For our purposes, we include remotely operated vehicles whose navigation can be automated despite varying degrees of direct human input. These vehicles are controlled autonomously by onboard computers, manually via remote control, or through both autonomous and manual methods. For both types of control, the remote navigator uses a link between the ground control segment (e.g., handheld remote controller) and the vehicle. Most autonomous vehicles are equipped with (an) onboard GNSS receiver(s) (Elkaim, Lie, and Gebre-Egziabher 2015) and many feature cameras, multispectral sensors, or weather instrumentation for data capture. The most common type of autonomous vehicles are aircraft or rotorcraft UASs equipped with cameras for aerial photography (Mathews and Frazier 2017). Other unmanned autonomous or semiautonomous vehicles used to collect geospatial data include unmanned ground vehicles (Bonadies and Gadsden 2016), unmanned surface vehicles (Dunbabin, Grinham, and Udy 2009), and unmanned underwater (submersible) vehicles (Bellingham 2009).

EGT Category 2, GNSSs, refers to systems that provide positioning, navigation, and timing services. GNSSs include ground stations, a satellite constellation, and receivers. The best known is the U.S. Government's NAVSTAR GPS, which uses a constellation of medium Earth-orbiting satellites (currently thirty-one that are operational; GPS.gov 2019). Others are Russia's GLONASS, the European Union's Galileo, and China's BeiDou. Broadly speaking, GNSSs are not an emerging technology (e.g., Stansell 1971; Pace et al. 1995). Nonetheless, we included them in our survey because Galileo, BeiDou, and regional systems (IRNSS, QZSS) have become or are nearing full operational capability and because several types of EGTs are dependent on GNSS.

EGT Category 3, Web mapping technologies, includes Internet-based technologies that deliver maps and other visualizations of spatial data to end users via a standard desktop or mobile Web browser or a smartphone or tablet app. Although Web mapping applications include both static and interactive maps (Mitchell 2005), our focus is on tools that enable users to browse and analyze dynamic geographic data in a Web environment and on methods that involve both the creation and consumption of Web maps. Web map creation once involved specialized skills to develop and maintain Web mapping sites. For instance, knowledge of Web servers, database management systems, Web mapping application programming interfaces, and markup and programming languages, such as HTML, CSS, and JavaScript, were prerequisites for the implementation of Web mapping applications. Although such knowledge and skills remain beneficial, cloud-based data storage and WYSIWYG Web map toolkits enable the creation of Web mapping applications with minimal or even no coding. In recent years, the consumption of Web mapping applications has to some degree democratized access to and the use of large repositories of geographic data (not overlooking the digital divide; see Sui, Goodchild, and Elwood 2012). Web mapping applications, from Google Maps and ArcGIS Online to custom Web GIS platforms and readily available geospatial data sets, provide tools for a wide range of users, from novices to experts.

EGT Category 4, laser scanning technologies, including light detection and ranging (LiDAR), includes active remote sensing devices that use pulsed or continuous wave lasers to measure variable distances (ranges) to a target (National Oceanic and Atmospheric Administration 2019). A discrete-return LiDAR system fires hundreds of thousands of pulses per second and calculates time needed for light striking a target to return to a sensor. The distance from the sensor to the target is calculated as half of the time between transmission and receipt of the pulse multiplied by the speed of light (Gregersen 2016). Conversely, continuous wave LiDAR transmits a continuous laser beam with a prescribed, changing frequency. The constant rate of frequency change results in frequency differences between the outgoing and incoming beam proportional to the distance of the object being measured (FMCW—Frequency Modulated Continuous Wave Lidar 2019). Individual returns can then be mapped to create a point cloud, forming a collection of XYZ vector data points representing 3D space. Although LiDAR technology has been available since the 1960s, it was not a viable tool for geospatial data capture until the widespread commercial availability of GNSS (for positioning) and inertial measurement units for orientation. Currently, LiDAR is primarily used in airborne mapping applications, including UAS (and by way of satellite; e.g., ICESat-2, GEDI), as well as on ground-based or terrestrial sensors.

EGT Category 5, location-based services (LBS), uses GNSS receivers, real-time geospatial data, and a mobile user's current location (Goodrich 2013). Common LBS applications include asset tracking, emergency management, local traffic and weather, advertising, infotainment, augmented reality (AR), and citizen science initiatives. As with Web mapping technologies, geographers are often interested in both the creation and consumption of LBS applications. For example, the availability of numerous LBS software development kits, application programming interfaces, configurable apps, and app builders provides tools and methods for developers and nondevelopers to deploy custom LBS apps. In addition, LBS can be used as a learning platform for a variety of subjects and might be useful for enhancing spatial thinking (Kolvoord, Keranen, and Rittenhouse 2017).

EGT Category 6, virtual reality (VR), involves the use of computer technology to create and experience a simulated and scaled, 3D environment. VR experiences enable users to become immersed within a simulated environment (Strickland 2019). In contrast, AR adds computer-generated elements to a live view, enhancing our perception and blending real and virtual worlds. Both VR and AR exist along the reality–-virtuality continuum. At one end is the real environment governed by the laws of physics and at the other is total immersion in a synthetic environment (Milgram et al. 1995). AR and VR both bring GIS to nonpractitioners (Tarolli 2017). For example, urban planners have combined GIS technologies with 3D VR and AR models to aid in designing future development scenarios (Schaller et al. 2015; Arisona 2018). Likewise, municipalities can augment real-time street view data with GIS overlays of underground utilities to aid field maintenance crews in locating underground assets (Meehan 2017).

EGT Category 7, peripheral devices, includes both output and input devices. An output device, such as a printer or monitor, converts computer-generated information into human-viewable formats. Conversely, an input device, such as a scanner or digitizing tablet, converts analog or digital information into a machine-readable format. Although not used to capture or manipulate data, peripheral devices such as large-format scanners and plotters, 3D printers, and laser engravers or cutters are changing the manner in which data are processed within GIScience and other geospatial fields. For instance, 3D printing and laser cutting can be used to create scaled models of any environment.

Following the identification of EGTs to be assessed within our survey, we created a typology to categorize EGTs based on the principal project domains where each is used and where they are deployed (i.e., laboratory vs. field). Three nonmutually exclusive project domains were used to classify EGTs (Figure 1): data capture, data analysis, and data delivery. For our purposes, *data capture* refers to the use of EGTs to collect geospatial information ranging from geographic coordinates to aerial imagery. In comparison, *data analysis* involves the use of existing geospatial information to discover spatial patterns, relationships, and processes; *data delivery* represents the transfer of spatial information to other users. *Deployment* means the introduction of technologies in the laboratory or field. Web mapping technologies, laser scanning technologies, VR, and peripheral devices were classified as laboratory based, whereas unoccupied autonomous and semiautonomous vehicles, GNSS, and LBS were identified as mostly field based. Depending on how they are used, a few EGTs might fall into both categories. For example, students who operate LiDAR equipment in the field might later use the data in a laboratory activity.

Survey Dissemination and Response Rate

Our survey was disseminated using a list of all geography programs in the United States and Canada published in the *Guide to Geography Programs in the Americas 2017–2018* (American Association of

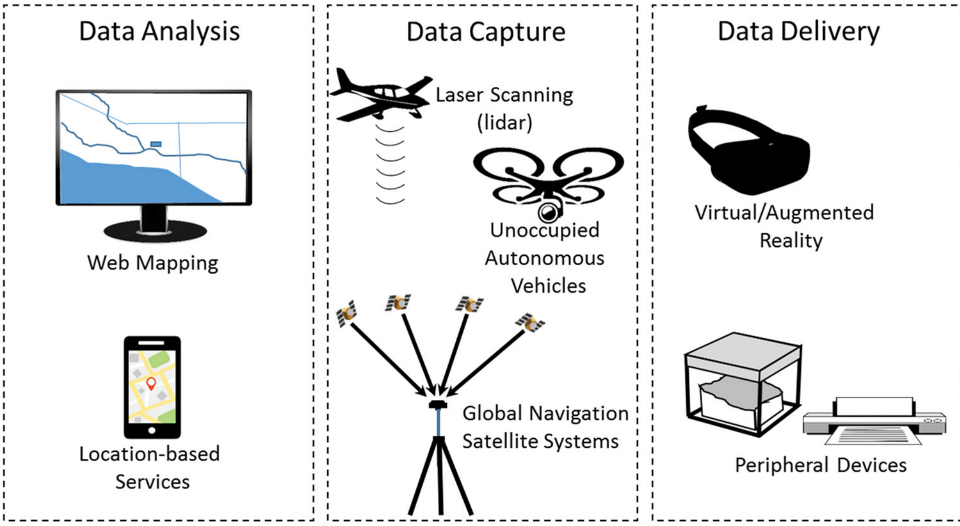

Figure 1 *The three nonmutually exclusive project domains identified to assess emerging geospatial technologies in teaching and research: data capture, data analysis, and data delivery.*

Geographers 2018). This included departments as well as programs with related or similar names (e.g., Department of Geography and Environment; see Frazier and Wikle 2017). For all 337 programs listed, we identified contact information for the chair, head, or program director. In mid-December 2018, an e-mail message was sent to each that introduced our project and requested assistance through the completion of a brief Web-linked survey as a representative of their academic unit.

A total of four messages were returned as undeliverable. In addition, a few recipients wrote back to say they were no longer serving in a leadership position, with some suggesting others who should be contacted. In cases where a message was returned as undeliverable or where a leadership change was noted, we sent an additional message. Our assumption was that all or most messages reached their recipients. The survey was closed in late January 2019 with 106 completed questionnaires, giving us a response rate of 31.5 percent. A few surveys were not usable, including two where respondents opted out after the first question and fourteen where no information was provided. Additionally, a few respondents completed portions of the survey, resulting in slightly different sample sizes across questions. A total of ninety respondents (26.7 percent) completed some or all of our survey.

Supplemental Web Site Content Analysis

To supplement data captured in our Web-based survey, we examined the extent to which academic geography programs highlight geospatial technologies. Given that program Web sites have become a principal method for promoting academic programs and research, we visited the main Web page (landing

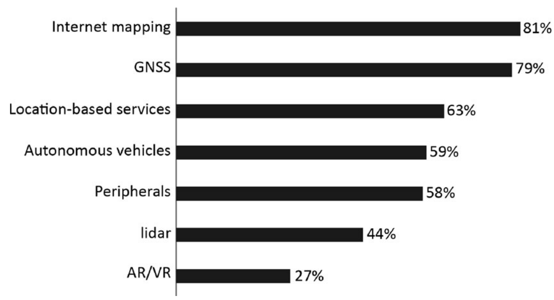

Figure 2 *The variety of geospatial technologies currently adopted by departments for coursework, research, or both. GNSS = global navigation satellite system; AR/VR = augmented reality/virtual reality.*

page) for all U.S. and Canadian geography programs. Using information featured on the landing page, we assessed the extent to which individual geography programs are outwardly promoting their use of EGTs.

Results

It was no surprise that EGTs have been adopted within an overwhelming number (90 percent) of geography departments and programs surveyed. Looking broadly, slightly more than 12 percent of programs surveyed use EGTs within the three categories we assessed, 21 percent use five, and 13 percent use EGTs within all seven categories. In looking across specific technologies, 81 percent use Web mapping or enterprise GIS solutions, 79 percent GNSS instrumentation, 63 percent LBS, 59 percent autonomous vehicles, 58 percent peripheral devices, 44 percent LiDAR, and 27 percent virtual or augmented reality (Figure 2).

Student Use of Laboratory-Based EGTs

As a means of assessing EGTs in instruction, respondents were asked to estimate the frequency of student use on a five-point scale (1 = *infrequent*, 2 = *somewhat infrequent*, 3 = *neutral*, 4 = *somewhat frequent*, 5 = *frequent*). Although Web mapping technologies were used in the largest number of programs, the extent of use varied considerably from 20.0 percent of respondents indicating frequent use to 39.2 percent indicating somewhat infrequent to infrequent use (Figure 3). The majority of respondents (63.0 percent) suggested that these technologies were employed at both undergraduate and graduate levels.

In comparison, VR/AR technologies are used in a smaller number of departments, with just twenty-four (27 percent) departments having adopted VR/AR in teaching. Additionally, the extent of use was not extensive, with only one respondent indicating frequent use and two others indicating somewhat frequent use.

Along with other laboratory-based equipment, the survey explored the frequency of specialized geospatial equipment used in instructional laboratories. Output devices such as 3D printers and laser engravers are used by 58 percent of programs. It is noteworthy that over 69 percent of the respondents reported undergraduate and graduate student use of these devices. Only forty (44 percent) of the respondents reported using LiDAR (sensors or data products), with 29 percent identifying somewhat frequent to frequent use.

Student Use of Field-Based EGTs

As demonstrated by the survey, GNSS was the second most common EGT used within geography programs. Relative to other technologies, though, the degree to which GNSSs are employed was low, with only 25 percent of the respondents indicating frequent or somewhat frequent use by students and 44 percent noting somewhat infrequent to infrequent use (Figure 3). Much like Web mapping technologies, the majority of respondents (60.4 percent) indicated that both undergraduate and graduate students use GNSS receivers within coursework or research. LBS, which are almost entirely dependent on GNSS technologies (with the exception of location based on Wi-Fi, multilateration of cellular signals, or other means), were the third most important technology used within geography programs. Although approximately 63 percent noted that LBS are available, the extent of use was relatively low, with just 3 percent reporting frequent use and 12 percent noting somewhat frequent use. Conversely, more than two thirds (68 percent) of the respondents indicated somewhat infrequent to infrequent use within undergraduate and graduate coursework.

Of particular note, our survey demonstrates that autonomous vehicles are widely used within geography programs, although the extent of student use is somewhat low, with 68 percent indicating infrequent to somewhat infrequent use and only 9 percent indicating somewhat frequent to frequent use. Overall, autonomous vehicles have been adopted at slightly lower rates (58 percent) than other emerging technologies.

Funding Sources

Along with questions about the frequency of use, respondents were asked about sources of funding used to purchase EGTs. A nonmutually exclusive list was used to identify external funding sources such as federal or state instructional or research grants to private donations and internal sources including department budgets, college or university

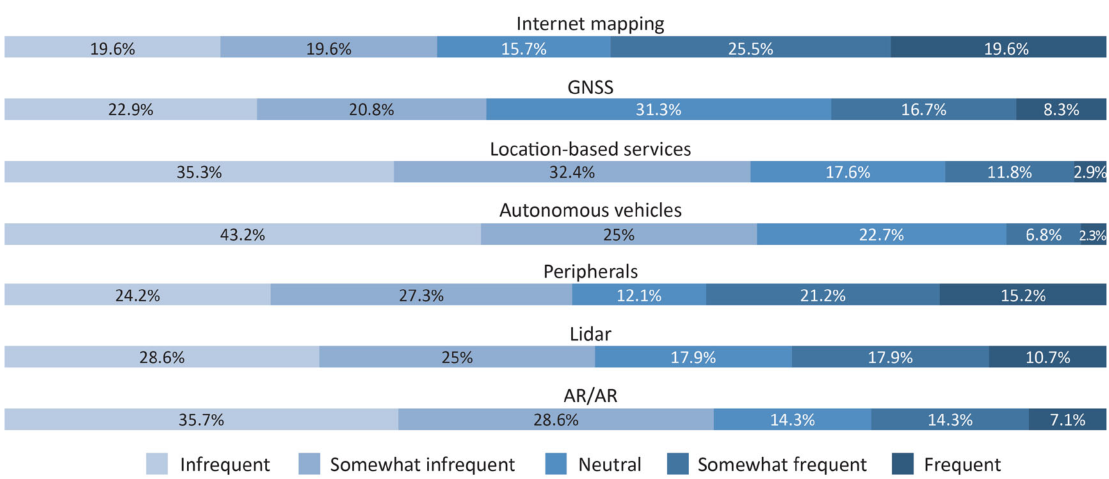

Figure 3 *Extent of use of the emerging geospatial technologies by students in U.S. and Canadian geography departments and programs. GNSS = global navigation satellite system; AR/VR = augmented reality/virtual reality.*

transfers, and student fees. Our findings demonstrate that departmental budgets (41 percent) and federal or state instructional grants (33 percent) are the two most important sources of funding used to purchase EGTs. The next two most important sources are college or university transfers (24 percent) and student fee allocations (14 percent). In comparison to other sources, private donations were noted by a relatively small percentage of respondents (7 percent). A few respondents identified forms of support we had not considered, such as research startup, industry sources, and other types of grants (e.g., foundations, municipal governments, and nongovernmental organizations).

Looking by category of EGT, departmental budgets are the most common financial source for purchasing Web mapping technologies (50 percent), GNSS hardware and software (44 percent), and the technology needed for LBS (33 percent). Autonomous vehicles are also largely funded by departmental budgets. Federal and state sources were identified as the second most important source of funding for acquiring Web mapping technologies (33 percent) and GNSS hardware and software (30 percent). A few respondents noted that students themselves provide the necessary hardware (e.g., a smartphone or tablet) for LBS. A few programs take advantage of industry funding as a source for purchasing autonomous vehicle hardware and software. Similarly, 48 percent of respondents indicated that federal or state grants were the principal source of funding for acquiring departmentally commissioned LiDAR products or LiDAR technology. Finally, both departmental budgets and federal or state grants were cited as sources of funding used to purchase laboratory peripherals and VR or AR devices.

Project Domains and Resources

In considering application areas, survey findings suggest that EGTs are becoming increasingly important within a broad range of learning environments and research applications. As a means of understanding how EGTs are used, we considered project domains where they are employed (refer to Figure 1). In addition, findings suggest that geography students use EGTs in all three project domains, with 47 percent of respondents identifying data analysis, 46 percent data capture, and 22 percent data delivery. In considering this information, we acknowledge that these groups might fall short of capturing all elements tied to each individual technology. For instance, Web mapping is more closely associated with data analysis and data delivery than it is to data capture. Concerning the former, 63 percent of the respondents identified both visualization and data analysis functions. In contrast, 44 percent of the respondents indicated the use of Web mapping for data access and delivery. Looking in greater detail, 55 percent of the respondents reported using cloud-based solutions such as ArcGIS Online, G Suite, and Amazon Web Services, whereas 67 percent use desktop production software including ArcGIS and QGIS. In comparison, only 25 percent use spatial databases or engines such as PostGIS, SpatiaLite, and ArcSDE.

In considering the use of GNSS equipment, two thirds of respondents identified data capture for mapping and surveying applications, 24 percent for navigation purposes, and 16 percent for tracking. It is noteworthy that respondents use both single-constellation (48 percent; e.g., GPS only) and multi-constellation (32 percent; e.g., GPS and GLONASS) systems. In addition, a small minority (7 percent) operate multifrequency receivers. Respondents also reported using a variety of GNSS receiver antennas, with 18 percent using geodetic antennas, 60 percent using rover antennas, and 58 percent using handheld receiver antennas. Moreover, 28 percent of the respondents use real-time correction such as DGNSS and RTK, and 24 percent reported using augmentation systems such as the Wide Area Augmentation System.

Departments and programs reported using LBS in a variety of ways such as geotagging (65 percent of the respondents) and in citizen scientist initiatives (26 percent), including iNaturalist and mPing. Some respondents also noted that students use these services for navigation (42 percent), location or situational awareness (16 percent), and AR applications (5 percent). Additionally, 25 percent of the respondents reported that their students use app-building software such as Collector for ArcGIS, Survey123, or AppStudio to develop customized LBS for data collection.

Survey findings revealed that autonomous vehicles are largely used for data acquisition, with just over half (51 percent) of respondents using them for videography or to capture imagery needed for creating orthomosaics. Respondents also noted other activities and data products associated with autonomous vehicles such as mapping (76 percent) and image classification (62 percent). A few noted the use of autonomous vehicles for capturing physical measurements, terrain modeling, measuring atmospheric moisture, and sampling water quality. In terms of the type of autonomous vehicles in use, a majority of respondents (68 percent) use multirotor aircraft and 40 percent use fixed-wing aircraft. A smaller number of respondents (8 percent) reported using unmanned underwater vehicles, with just one respondent noting the use of unmanned surface water vehicles. Along with the vehicles themselves, a few respondents mentioned sensors deployed in conjunction with their autonomous vehicles, including digital cameras (79 percent), multispectral sensors (43 percent), thermal sensors (34 percent), and LiDAR (23 percent).

In exploring use, peripheral devices are largely employed for cartographic output (67 percent of respondents), data capture and conversion (44 percent), and visualization (44 percent). The most common devices noted were large-format plotters (69 percent), large-format scanners (39 percent), digitizing tablets (27 percent), and 3D printers (27 percent). A few respondents also noted using laser cutters or engravers for creating 3D terrain models.

Of forty respondents who reported using LiDAR, 60 percent use airborne sensors, 23 percent terrestrial or ground-based sensors, and 20 percent spaceborne sensors. Most respondents (58 percent) use LiDAR for topographic or bathymetric mapping, and less than half (48 percent) use LiDAR for forestry or other biological applications (including agriculture), infrastructure mapping (38 percent), coastal mapping (18 percent), geoarchaeology (13 percent), or hydrogeomorphology (3 percent).

Only twenty-four (27 percent) departments reported using VR/AR. Of those, a majority (63 percent) specified visualization as the principal project domain where these technologies are employed. A smaller number noted their use of VR/AR for planning (21 percent) or modeling (13 percent). About a third (33 percent) of programs using VR/AR methods employ VR/AR goggles and topographic sandboxes. Another 25 percent also indicated using tablets or other mobile devices with VR/AR equipment. Only one respondent noted that students use stereo view monitors with accompanying glasses.

Supplemental Web Site Content Analysis

Along with information about EGTs and sources of funding used in their acquisition, we sought information about how geography departments and programs use EGTs in promoting instruction and research. Our investigation of landing pages demonstrated that about a third (107, or 32 percent) of geography departments and programs showcase EGTs or other geospatial technologies using text, photographs, videos, or a combination of visual and sound messaging. Among those that featured geospatial technologies, seventeen (16 percent) focused on more than one geospatial technology. It should be noted that several landing pages included geospatial content without a focus on a specific technology. For example, photographs of GIS laboratories or imagery appeared on the landing pages of thirty-seven departments or programs. Similarly, twenty-nine department or program landing pages featured photographs of students using GNSS receivers and nineteen showcased autonomous vehicles (see Figure 4A). Another twelve displayed content about remote sensing, and five others featured information about VR/AR equipment (e.g., Figure 4B), LBS, or peripherals such as laser scanning technologies (see Figure 5).

Discussion

A decade and a half ago, Gewin (2004) noted the growing importance of the geospatial industry as an emerging field valued at more than $5 billion. At the time, geospatial applications were highly specialized and concentrated mostly within government agencies tied to the environment, defense and security, transportation, or local government issues. Today geospatial technologies are ubiquitous and, for some, essential to day-to-day activities (Brown 2018). For example, geospatial data are central to the so-called Location of Things (LoT) market that relies on geospatial information extracted from connected devices (providing a physical address), GNSS-collected coordinates, and so on. LoT is part of a larger trend known as the Internet of Things that is characterized by the integration of Internet-based technologies into everyday consumer products (Burgess 2018). In 2018, LoT was estimated to be valued at $19.1 billion with an expected compounded annual growth rate of 24.5 percent and a projected value of $128.75 billion in 2027 (Insight Partners 2019).

Although large investments hint at the growing importance of geospatial information, capabilities for collecting and accessing geographic data are becoming increasingly ubiquitous. Along with processing, analyzing, and interpreting spatial data, today's geospatial expert must be well-versed in collecting, collating, and disseminating data and ready to contribute to the planning and development of application areas such as LoT.

Our survey offers an assessment of EGTs that have found their way into college and university geography departments and programs, but the information we present might be less useful for understanding how technologies prepare students for work in geospatial careers. As noted by Metoyer, Bednarz, and Bednarz (2015), exposure to technology does not necessarily contribute to geographic literacy. For example, although valuable for providing exposure to data capture and analysis, exercises that make use of UAS-based mapping and desktop or cloud-based image processing tools such as Pix4Dmapper and Agisoft Metashape are less useful for helping students understand basic photogrammetric principles. Similarly, activities that use GNSS-enabled mobile devices or Web GIS platforms (e.g., Google Maps, OpenStreetMap) might not provide students with the fundamental knowledge or experience needed to interpret spatial information. Nonetheless, our findings offer a starting point for more in-depth discussion about how EGTs can be used in concert with foundation concepts and principles needed to prepare students for careers involving the collection, analysis, and dissemination of geospatial data.

Given their focus on location, dimensionality, proximity, continuity, separation, scale, and other spatial relationships, geography programs are uniquely positioned to use EGTs in promoting spatial thinking and literacy. Our findings

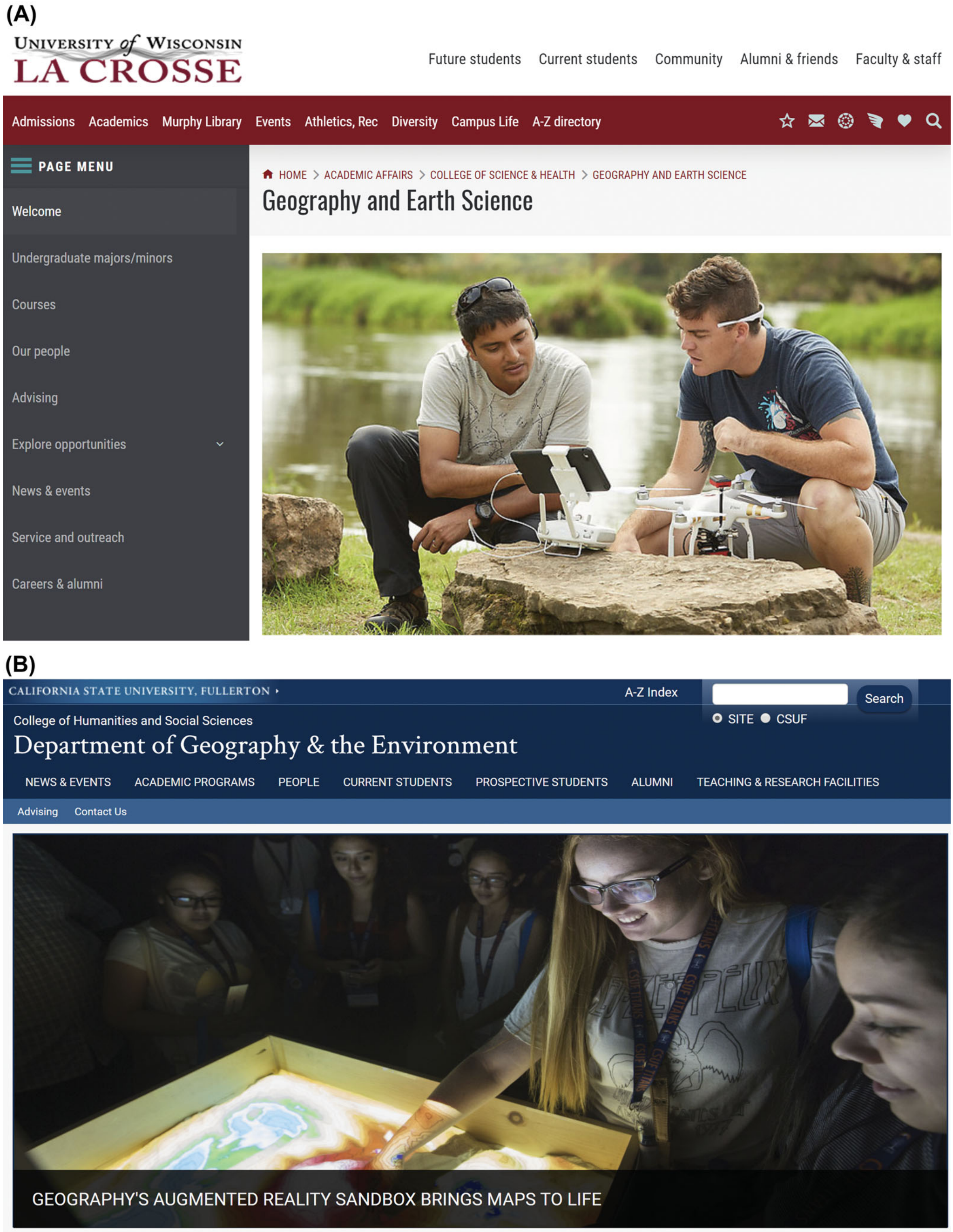

Figure 4 *Geography department Web sites emphasizing geospatial technologies: (A) Unoccupied aircraft system equipment, Department of Geography and Earth Science, University of Wisconsin, La Crosse. (B) Augmented reality sandbox, Department of Geography and the Environment, California State University, Fullerton.*

demonstrate that although EGTs are increasingly used within U.S. and Canadian geography departments, their adoption across project domains is uneven. Information about the manner in which EGTs are employed, their frequency of use, and the project domains in which they are deployed enables us to speculate about the extent to which emerging technologies are associated with higher level geographic literacy. For instance, we found that across all technologies explored, 46 percent of respondents indicated data capture and 47 percent identified data analysis as project domains in which these technologies are employed. Although data capture might require higher levels of geographic

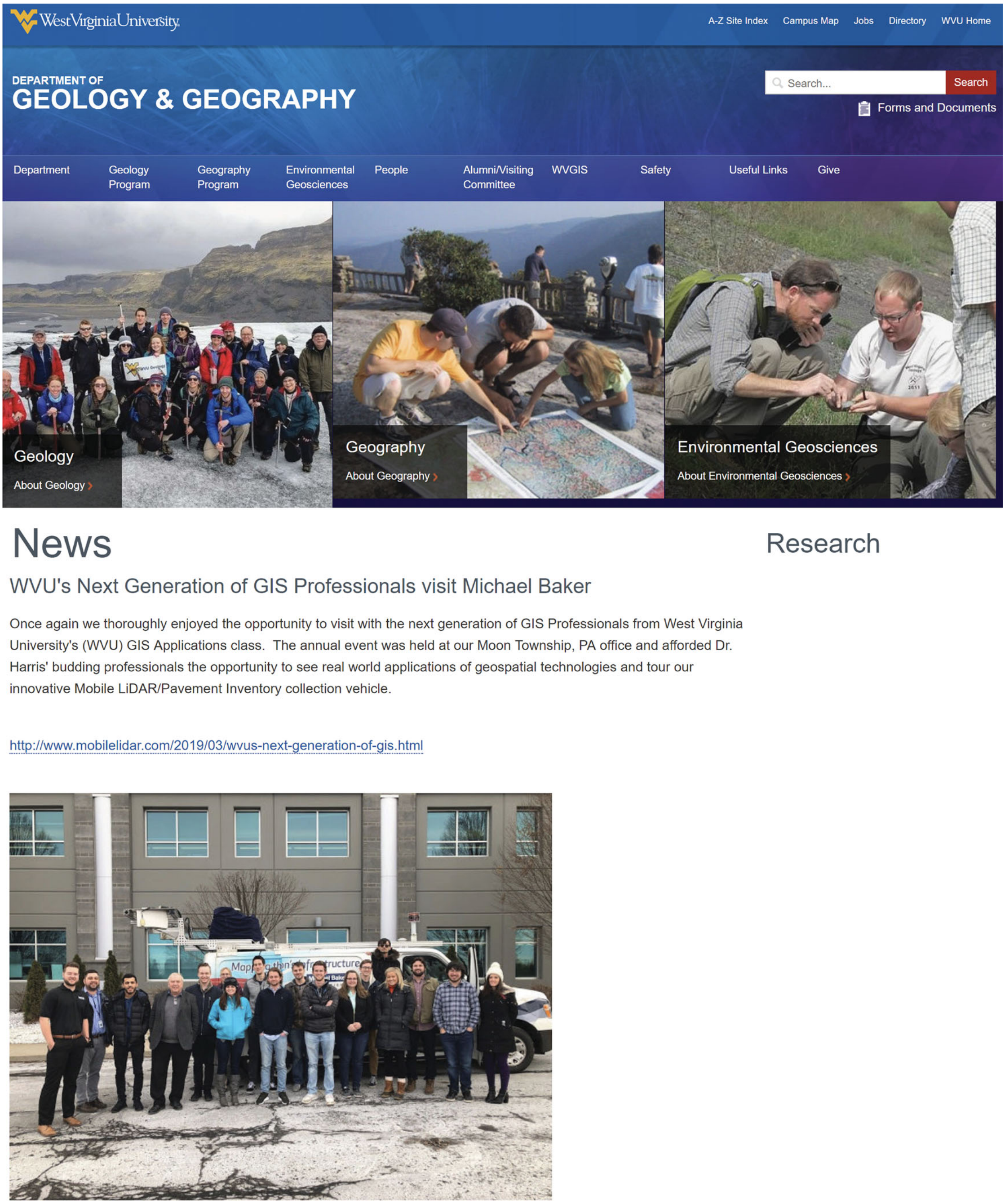

Figure 5 *The Department of Geology and Geography at West Virginia University showcasing vehicle-mounted mobile laser scanning technology on their Web site. GIS = geographic information science; LiDAR = light detection and ranging.*

literacy, in general such operations can be performed by a trained technician. Conversely, data analysis indicates the need for a higher level of geographic literacy to adequately analyze and interpret results.

Similarly, our survey examined variation in how emerging technologies are used within geography departments and programs. Assuming that greater use by geographers roughly correlates with a broader understanding of underlying geospatial principles (see Metoyer, Bednarz, and Bednarz 2015), we found that, aggregated across all technologies, approximately 46 percent of EGTs are used somewhat frequently to frequently. This suggests that, despite the prevalence of these technologies in geography departments' instruction and research, overall use remains somewhat muted. Technological innovations, however, are likely to influence how such tools are used as the geospatial industry expands. For example, advances within GIScience and technology over the last five years are permeating nearly every aspect of life. This is illustrated by GNSS and GIS integration that has been coupled with high-speed wireless communication and inexpensive mobile sensors that capture large volumes of real-time spatiotemporal data (National Geospatial Advisory Committee 2016; Fu 2018). At the same time, low-Earth orbit nanosatellites are transmitting on-demand, high spatial resolution imagery for Earth observation (Singh 2016), and off-the-shelf UAS with integrated optical sensors along with desktop and cloud-based processing facilitate the creation of very high spatial resolution orthomosaics (Mathews 2015) and 3D point clouds (Rodarmel et al. 2019). Finally, geospatial artificial intelligence is combining deep learning techniques within GIS environments to address a range of problems, from modeling urban concentrations of fine particulate matter (Lin et al. 2017) to predicting traffic congestion (Raad 2017). Our survey demonstrates that geography programs across the United States and Canada have recognized this shifting paradigm by investing in EGTs. We speculate that in the coming years, many of the EGTs explored here will become more ubiquitous in U.S. and Canadian geography departments and overall adoption of these technologies will greatly expand, spurred by industry, nonprofit geospatial organizations (e.g., URISA, the National Geospatial Technology Center of Excellence), and trends in higher education.

Conclusion

For the purpose of the assessment we present here, EGTs are tools that have only recently been widely adopted (even if the technologies have long existed). It should be noted that although we considered several emerging technologies, the list of EGTs we examined was not all-inclusive. Likewise, individual technologies we considered should not be seen as mutually exclusive because most are tied to, or closely related with, other technologies. Indeed, the fusion of multiple EGTs, such as LiDAR payloads on UAS or integration of GIS and mobile technology (e.g., mobile GIS), might hasten broader EGT adoption. Today, many geospatial technologies such as smartphone navigation apps are part of the fabric of everyday life. Although some new technologies quickly fade, others will experience rapid growth. It is therefore incumbent on geography departments and programs through their instruction and research to embrace and question the importance of knowledge and training involving both long-established geospatial tools and EGTs. Importantly, this study establishes a baseline for how geography departments and programs are adapting to, although not without challenges, the evolution of geospatial technologies including EGTs. ■

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