NC STATE UNIVERSITY

A Study of Research Support Service Needs for Civil, Construction, and Environmental Engineering Researchers at North Carolina State University

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Introduction

The NCSU Libraries carried out a study of the research practices of civil and environmental engineering researchers (CEE) at North Carolina State University beginning in the Fall of 2017. The purpose of this study was to better understand the resources and services these faculty members need in order to be successful in their research. This project was part of a larger study coordinated by Ithaka S+R, a not-for-profit research and consulting service,[1] and sponsored by the American Society of Civil Engineers (ASCE). Ten other universities in the United States and Canada took part in parallel studies of their CEE researchers at the same time.[2]

This report describes the findings of the study, including details about the researchers' collaboration activities; use of published information and processes for locating and managing information; data use and data management; and publishing practices. The report concludes with recommendations that address a number of the needs uncovered in this study.

Department of Civil, Construction, and Environmental Engineering

The Department of Civil, Construction, and Environmental Engineering (CCEE) at North Carolina State University is one of the largest civil engineering departments in the nation. Degrees are awarded at both the undergraduate (three bachelor's degrees) and graduate levels (four master's degrees and one doctoral degree). An online/distance program also awards two master's degrees. In Fall 2017, enrollment consisted of 777 undergraduate students, 204 Master's students, and 136 PhD students. Of these, 78 students were in the Distance Education program.[3]

The department has 70 faculty members, including emeritus professors, lecturers, and faculty who are currently serving in University administration positions. Approximately 50 faculty members are actively engaged in research, funded by ~$19.9 million in research expenditures. The department's seven core areas of research are: Computing and Systems; Construction Engineering; Environmental, Water Resources, and Coastal Engineering; Geotechnical and Geoenvironmental Engineering; Mechanics and Materials; Structural Engineering and Mechanics; and Transportation Systems and Materials.[4]

[1] http://www.sr.ithaka.org/about/

[2] Other participating institutions: Carnegie Mellon University; Georgia Institute of Technology; Iowa State University; University of Colorado Boulder; University of Delaware; University of Illinois Urbana-Champaign; University of Toronto; University of Waterloo; University of Wisconsin-Madison; and Virginia Polytechnic Institute and State University.

[3] https://www.ccee.ncsu.edu/quick-facts/ (Accessed 28 February 2018)

[4] https://www.ccee.ncsu.edu/research/ (Accessed 28 February 2018)

Study Methodology

The research team consisted of three librarians from the NCSU Libraries. We used a qualitative study approach consisting of semi-structured interviews with CCEE faculty about: research topics and methods; working with others; working with data; working with published information; publishing practices; and future challenges and opportunities. A copy of the interview questionnaire is provided in Appendix A.

We recruited 14 participants for the study from 51 CCEE faculty members who we identified from the department's website as being actively engaged in research activities. (Demographics of the study sample can be found in Appendix B.) Each participant was scheduled for an hour-long meeting in their office with one of the team members. Interviews were digitally recorded with the consent of the participants.

Transcripts of the interviews were manually analyzed using grounded theory methodology, i.e., codes were developed as the transcripts were read instead of starting with pre-existing codes. The identities of all faculty participants were kept anonymous throughout the analysis process and in all subsequent reports. A more detailed description of the study methodology can be found in Appendix C.

Findings

Research Topics

At the time the study began in November 2017, 51 faculty members in the CCEE department were identified as actively engaged in research within the department's seven core research areas, with roughly 40% conducting research in more than one core research area. The distribution of research areas for the 14 faculty members we interviewed were generally proportional to the overall distribution of the larger group of 51. Similar to the larger group, several interview participants conducted research that fell into two research areas (see Table I).

Table I. Core research areas of fourteen interviewed faculty members

Core Research Areas in CCEE	Number of interviewed faculty*
Computing and Systems	1
Construction Engineering	2
Environmental, Water Resources, and Coastal Engineering	5
Geotechnical and Geoenvironmental Engineering	1
Mechanics and Materials	4
Structural Engineering and Mechanics	5
Transportation Systems and Materials	2

*The total is greater than 14 due to individuals whose research covered multiple areas.

The research carried out by these 14 faculty members addressed practical issues and applications. Within civil and construction engineering, this included infrastructure improvement related to both roads and buildings, development of new and advanced materials for structural applications, and development of techniques for construction. On the environmental engineering side, research dealt with air pollution, coastal engineering, sanitation, and solid waste. However, as is often the case in academic research, gaining a fundamental understanding of underlying processes went hand-in-hand with the development of practical solutions.

Research methods

The research methods employed by the participants reflected this dual approach. The majority carried out lab-based experiments and/or analysis and measurements, while a few used data simulations or computational modeling as their primary method. However, nearly everyone conducting experimental and/or field-based research also used modeling, simulations, or computational techniques to better understand their findings. One interviewee remarked how the role of modeling has changed over the years:

> "It used to be that we would validate theories with experiments, but we have gotten to the point that we have to validate experiments with the theory. And we use this experimental data, along with our modeling, to really understand. I do believe the majority of the experimentalists now do this. I would say that almost everyone does this."

While the engineering problems being addressed by these faculty members are not necessarily new, one notable aspect is the increasing degree to which techniques from other fields are used or incorporated. These include biologically inspired approaches to developing new materials; adoption of techniques and tools which were first developed in electrical engineering and computer science; and the application of microbiology to various topics in environmental engineering.

Interdisciplinarity

Historically, civil and environmental engineering (CEE) research can be considered interdisciplinary in and of itself. CEE is made up of a number of sub-disciplines whose "fundamental research is very disparate" as one of the interviewees noted. Nearly all of the participants engaged in interdisciplinary research to varying extents. In most cases, this interdisciplinarity extended beyond the bounds of just CEE. More than half explicitly described their work as interdisciplinary; for others, although they did not use this specific phrase, it was clear that their work either encompassed multiple fields and/or used techniques and approaches that would not be considered traditional in civil and environmental engineering. One participant spoke of being situated "on the edge, outside" of civil engineering; another described research that fell between the boundaries of not only CEE but also of related fields.

Specific fields mentioned by these faculty members as being part of their research approach included: aerosol science, atmospheric chemistry, biology, computer science, economics, ecomorphology, electrical engineering, electronics, environmental science, exposure assessment, forestry, geochemistry, health sciences, materials science, mechanical engineering, microbiology, microfluidics, natural resources, nuclear engineering, physics, and public health.

In some cases, interdisciplinary researchers can be considered early pioneers in the particular combination of techniques and disciplines that they use. One early career researcher mentioned that his doctoral research was carried out in the lab that invented the field in which he currently works. Another senior researcher spoke of having been one of the first who worked at the intersection of microbiology and engineering, a combination that has now become more common. Yet another senior researcher, who likely would describe his work as traditional in comparison to these colleagues, spoke of incorporating new innovations that had not been available before. All of these fit the National Science Foundation's (NSF) description of the dynamic aspects of interdisciplinary research.[5]

Often, while the approaches are interdisciplinary, the research topics being addressed are squarely within the realm of traditional civil, construction, or environmental engineering. By using new approaches, new solutions are being developed to existing problems. One researcher commented that because of the wide scope of topics he was investigating, a large number of approaches was needed, but he also noted that these approaches needed to be integrated and not used independently. In his case, an "interdisciplinary approach helps tremendously." Another researcher commented how it is "more powerful" to combine disciplines and approaches. A common pairing observed among several participants was adding a microbiological or biological approach to engineering. In other cases, tools more common to electrical engineering or physics, such as robotics, sensors, and automation, were being used.

Another variation was the degree to which collaborators contributed to the interdisciplinary aspects of the research. In some cases, the study participants themselves were actively making use of novel techniques and approaches and/or whose own training were in areas outside of CEE. In other cases, they sought out collaborators who could provide the expertise and knowledge from other disciplines. In these latter cases, each collaborator contributed "traditional" domain expertise.

Challenges

Participants spoke of several challenges they encountered in conducting interdisciplinary research. One felt overextended due to the need to keep up with multiple fields, while several referred to the need to attend conferences in multiple areas. As one researcher put it:

> "I feel stretched a little thin that I need to understand or know what's happening in pretty diverse fields. That's partly just a function of how I've chosen to do research or the type of research I've chosen to do."

One participant expressed the wish to attend seminars in other departments on campus to help foster more connections and expand his knowledge in new areas but noted it was difficult to learn about these talks. Another researcher mentioned how his past experience at other institutions showed him the value of

[5] National Science Foundation. (n.d.) What is Interdisciplinary Research? Retrived from https://www.nsf.gov/od/oia/additional_resources/interdisciplinary_research/definition.jsp

physical collocation in fostering interdisciplinary connections. This will likely become easier in some respects when the CCEE department moves to its new building on Centennial Campus in ~2020, which will bring it in closer proximity with other departments in the College of Engineering (COE) and the College of Textiles (COT). However, this also will also move the department further away from other units on campus, such as the College of Sciences (COS) or the College of Agriculture and Life Sciences (CALS).

When looking ahead to the future of the field, several participants noted that in many ways, civil engineering was a “mature field” and had become “siloed” from other disciplines. However, continuing the path towards interdisciplinarity by improving connections and becoming better integrated with other disciplines would likely help the field to move forward and also help demonstrate how CEE researchers can contribute. One researcher noted that funders have been placing increased emphasis on interdisciplinary research, and so interdisciplinary collaboration is also becoming a necessity. Another participant noted that increased interdisciplinarity would also be beneficial as CEE researchers begin to work in research areas unrelated to traditional civil engineering topics.

Additional challenges related to interdisciplinary collaboration, publishing, and information discovery are discussed throughout the rest of this report.

Collaboration

Collaborators

The participants in this study chose their collaborators based on a variety of different factors, including point-of-need expertise, previous relationships, as well as the requirements outlined in Calls for Proposals. Their most common collaborators were researchers at NC State, particularly within CCEE specifically and COE broadly. NC State collaborators outside of CCEE included departments from COT, COS, CALS, the College of Veterinary Medicine, the College of Humanities and Social Sciences, as well as technicians at shared research facilities across campus. Many participants also had collaborators at other universities, whose expertise came from a variety of areas, including: computer science, computational fluid dynamics, coral biology, coral geomorphology, economics, electrical engineering, industrial and systems engineering, logistics, mathematics, management, mechanical engineering, microbiology, nuclear engineering, physics, plant sciences, policy, psychology, public health, social sciences, statistics, and urban planning. These collaborations often grew out of relationships that were started at previous institutions, whether during graduate school or previous places of employment.

In addition to these collaborations with other academics, participants in this study reported a number of other collaborators from outside of the academy. These included: Federal agencies, local and state governments, regulatory bodies, non-governmental organizations (NGOs), National Laboratories, as well as industry partners. These partnerships with non-academic groups took many forms, and reflected the needs of the researchers. Relationships with governments and NGOs often emerged as a need for access to sites for field work, whereas partnerships with regulatory groups and industry partners often emerged from consulting contracts or gift-in-kind donations.

Interview participants attributed their past successful collaborations to a number of different factors, some of which seem at odds with one another. Some of our participants raved about the progress made in web-based tools. They use platforms like Cisco WebEx, Skype, and Google Hangouts to have remote meetings; online editing tools like Google Docs and Overleaf to draft proposals; and cloud storage providers such as Box, DropBox, OneDrive, and Google Drive to host and share data. The researchers use these tools because they help overcome challenges of working with large or distant teams. Meanwhile, others noted that access to "shared physical spaces" was crucial and that "physical distance" creates real challenges to the progress of their collaborative endeavors.

Despite these occasional differences, a few themes repeatedly emerged as core features of successful collaborations. Participants noted that successful collaborations almost always had: 1) aligned, focused, and compatible research interests among the principal investigators; 2) clear expectations for the final products of the collaborations; and 3) well-defined roles for each member of the research team. Yet, even with these three conditions, some of the researchers interviewed cautioned that initially promising collaborations sometimes fail to thrive. As such, a few of respondents acknowledged that "luck" has an outsized influence on whether these partnerships are ultimately fruitful.

Challenges

When asked for barriers to collaborations, some of the most common responses were unsurprising: scheduling, logistics, and data sharing. Scheduling and logistics were particularly challenging for researchers with international collaborators. Not only do these global relationships create problems in terms of scheduling conference calls, they also often lead to challenges both mundane (accessing cloud-based tools at field sites) and unique (transporting research equipment through customs offices). Data sharing often proved challenging even for researchers with collaborators in their same building. For more on data sharing, please see our section titled "Data Practices."

Some of the other barriers to successful collaborations mentioned by our participants were less predictable. For example, a number of respondents cited "cultural differences" resulting from different research environments and methodologies proving insurmountable in previous collaborations. Others noted that "PI-to-PI" issues in terms of personality can derail otherwise promising collaborations. According to respondents, what separates productive from unproductive collaborations is often as much about aligning personalities among the principal investigators as it is about aligning expertise and research interests.

These potential cultural differences based on training become even more problematic for researchers looking to establish interdisciplinary collaborations. When working with researchers outside their discipline, an additional challenge to collaboration was learning a new set of technical terminology, or as one participant phrased it, "learning the language" of their collaborators. This "language barrier" creates a challenge in even locating potential collaborators – respondents were frustrated that a lack of shared understanding and descriptors for concepts between different disciplines prevented them from effectively searching the literature of other fields and finding experts to work with. Even once these relationships are formed, this issue remained a persistent challenge, especially for interdisciplinary work. Researchers who overcame these challenges noted that the only real solution for overcoming this barrier was for all parties to “commit to understanding each other deeply.”

Our researchers reported that a lack of alignment in priorities or expectations was the most common factor leading to collaborations failing. A lack of clarity on priorities can lead to missed deadlines, while differing expectations can lead to “misaligned standards of quality” in terms of data collection, data analysis, and article manuscripts. Our respondents shared a number of strategies they had learned for addressing these issues, and chief among these was the assertion that collaborative projects need to have a leader invested in driving the project forward. In addition to keeping the project moving forward, the leader also needs to establish norms for the group at the outset of the process, as well as set expectations for what the final results of the project should look like.

Locating Information for Research

Information Sources

When asked about the types of published information they relied on for their research, all of the participants identified journals as their primary source. Journal articles provided a way of finding information for specific research questions as well as a means of staying current within their fields. The scope and range of the articles that they used varied with their research topic and needs. One researcher mentioned that because he works in a mature field, he often looks at both recent publications and the original literature from twenty years ago, but seldom anything in between those two time frames. Another commented that seminal papers from different areas were especially important for interdisciplinary work.

A few of the participants also described the importance of data published in journal articles and how they used this data for comparison to their own data and/or to help confirm an analysis or model they had developed. They had confidence in this type of published data because the article itself had been peer-reviewed. Examples given included using numerical data in tables and data taken from plots and figures. One researcher also spoke of subsequently contacting authors to request their underlying raw data. In some cases, the data came from supplemental information included with the journal article. A couple of the participants noted the importance of the availability of supplemental data, with one stating that these were often more useful than the “money figure” within the article itself (i.e., the figure or plot that encapsulates the most important finding of the paper).

Conference proceedings articles, however, received a mixed response, where only half of the participants considered these publications as a useful source of information. In contrast, several others stated that conference proceedings were less important in their own subfields, while acknowledging that this was not the case in other areas. One major concern about conference articles was quality. One researcher said that it was difficult to trust the information because these articles were not peer-reviewed while another stated more bluntly that “there’s so much junk in conference proceedings” that one needed to approach them with caution. Yet another mentioned that “the majority of conference papers tend to be a little bit light on detail and content.” One participant also pointed out that conference papers are often a work in progress.

Two of the researchers also noted how the importance of conference papers had changed for them over time. One pointed out that while a lot of good work had been published in proceedings from the 1970s through the 1990s in their field, much of the seminal work is now published in journals. Another researcher noted that he has found a lot of recycled material in conference papers, and consequently, relies much less on proceedings now than he had in the past.

Another important resource mentioned by several of the researchers was textbooks, particularly when they needed to learn more about a new topic or to find very specific information. Similarly, one participant mentioned theses as a good supplement to journal articles, since a thesis tends to provide more details of the work. Other types of publications mentioned by the participants included standards and codes; technical reports; reports published by government agencies, NGOs, industry, and industry groups; regulatory reports; and government regulations.

Finding Literature and Keeping Current

When seeking articles for a specific topic, most of the researchers used Google and Google Scholar regularly, while a minority of participants used article and indexing databases such as Web of Science or Compendex/Engineering Village. Two of the current Google Scholar users previously had used Web of Science or Engineering Village but they found that Google Scholar now sufficed for their needs. The NCSU Libraries homepage search box was mentioned by one participant. Some researchers also supplemented database use with searching directly within specific journals in their field. Citation tracking was mentioned by some of the researchers as a means of working their way to more relevant and seminal works.

Most of the participants noted that their access to journals was through the NCSU Libraries. Several mentioned their use of the Libraries' Tripsaver (Interlibrary Loan/ILL) service to obtain books, journal articles, and conference proceedings not available through the Libraries' collections and subscriptions, expressing appreciation of this resource. Regarding conference papers, one participant stated, "I think amazingly we always get them...we haven't had a situation where we haven't found one yet." Another noted both the speed and fulfillment of requests: "Tripsaver is great. I love Tripsaver, I mean, it's one of the greatest things. I don't know how you guys find it...it always comes to me the same day, next day. So I feel like we have access to a lot of stuff."

While they had mixed views of conference papers, nearly all of the participants considered attending conferences as one of their primary means of keeping abreast of current research in their fields. The opportunity for face-to-face meetings and networking was also an important aspect of going to conferences.

Several researchers also discussed the ways they kept up with the literature. These included alerts from Google Scholar and ResearchGate, table of contents (TOC) alerts from specific journals, and browsing specific journals for their latest articles. Knowledge of the major researchers in the field provided another avenue, as some of the participants noted how they followed or searched for publications of specific authors from journals, databases, and the authors' own websites.

Experience can also play a role; one senior researcher noted how his involvement in many different groups has afforded him a greater awareness of what is happening in the field, and his connections have made it easier to request reports or documents directly from others. Aside from experience, some of the researchers mentioned keeping in touch regularly with friends and colleagues in the field.

Challenges

Several challenges were mentioned by participants regarding information discovery and access. Particularly for researchers engaged in interdisciplinary research, finding existing literature in other fields could be difficult, due to not knowing the right keywords or jargon to use. Another difficulty was "finding information on who does what" in other fields. For researchers working in areas that are not distinct disciplines, it could be difficult to identify journals in which to find relevant publications. It was also noted that it was challenging to find conference papers as well as regulatory and industry reports, since these publications are not always indexed in databases.

Being able to work efficiently with literature and information was important for the participants. For some, dealing with the volume of literature was difficult. One participant noted that the challenge did not lie in finding information, "but it's finding too much and then parsing and managing it effectively." Not being able to directly access journals the Libraries does not subscribe to was a frustration voiced by a few participants, even when they were aware of and used ILL services. For those instances where a journal article has accompanying supplemental information, one researcher said he would like to be able to download both the article PDF and supplemental information at the same time with one click.

Managing Information for Research

Organizing Information

When asked how they managed, organized, and stored the articles found in their literature searches, several approaches were mentioned. A folder system on a personal computer, DropBox, or Google Drive was one common way. Cloud-based options such as DropBox and Google Drive were often chosen to allow the researcher to easily share articles with the rest of the research group.

Half of the researchers used a specific citation management system such as Mendeley, BibTeX, or Zotero to store and organize the articles they rely on for their research, with Mendeley mentioned most frequently. Often the tool they prefer is the tool they were taught to use in graduate school. They also expressed a strong resistance to learning new tools. One professor noted that, "but I'm just used to Zotero and I pay for a Cloud storage for all the PDFs and stuff, so students can use that, too." Another researcher who did not use a citation manager mentioned that the group's graduate students used RefWorks. In this case, the RefWorks culture stemmed from an initial set of students learning RefWorks through the NCSU Libraries and then passing on the knowledge to the rest of the group.

Challenges

The researchers spoke of several challenges with organizing information. Participants who did not use a citation manager with a sharing feature or a cloud-based storage system spoke of needing a way where they could easily share articles with their students. Another was finding an effective file-naming and organization method. Participants who used a folder system often spoke of the challenge of locating a specific article again after it had been filed away. Yet another frustration was with citation management systems that required a paid subscription or had simply become obsolete – two former EndNote users now used Mendeley. On the other hand, another researcher was not fully invested in using Mendeley due to multiple experiences of adopting tools that no longer existed, each representing a significant investment of time in the past.

Data Practices

When asked about their data practices, our respondents talked about a wide variety of processes: their planning, collection, storage, sharing, visualization, values, and challenges. Many participants expressed that though they had no codified plans, they did have strong customs surrounding data storage and preservation.

Data Planning and Procedures

The study participants uniformly stated they had either no plan for data storage and use or that their practices were inadequate. One stated when asked about how he stored data, "I have a lab hard drive that supposedly everybody should be backing up to it regularly. I don't know where it is now." Another researcher, when asked if they had plans or procedures for data, stated, "No… So sometimes a student just doesn't do a good job of putting information in there…" Despite their lack of a codified plan, most labs do have customs built around creating and preserving meaningful data. Many are adopting cloud based data storage platforms like Dropbox, Google Drive, and Box. One researcher described his lab's practices, "Every student creates his own repository and creates a description of what file is what, for what scenario. And that's it. That's sitting in Google Drive."

Physical lab notebooks are a primary method of data capture in some labs. One researcher mentioned the importance of maintaining appropriate physical lab notebooks for data collection, "I don't care if the lab notebook is dirty, I just care about the completeness." He went on to express frustration that students often will not maintain perfect records in their notebooks unless they are working toward publishing, "One grad student I had was very good at lab notebooks because he knew that the sponsor wanted the lab notebook. And that made it happen." It often took external pressures to encourage students to follow best practices with their lab notebooks.

Our respondents described treating data generated at other labs or by other research efforts differently: it is often not stored locally. One professor said about data generated elsewhere, "We wouldn't store it. We would only store what we needed." Even when their research relied on other lab's data, they only stored the part they needed to continue their work.

Visualization as Analysis

While experimental data has the highest value, multiple researchers reported that they use that data as a basis to generate visualizations and graphs. One researcher said, "The nature of our data is very large so we have to… reduce it into mainly graphical form, then we can see it." Seeing the data allows them to understand it and make guidelines based on it, "after we finished up the research lab, writing the recommendations for the findings. We have to justify that if we come out with a recommendation to a certain design specification."

Data Reuse

Some disciplines and sections of civil and environmental engineering use data generated in other labs or by other groups. In particular, environmental engineers who focus on pollution and transportation engineers rely on data generated elsewhere. One transportation engineering faculty member said in reference to data, "We try to consume and get our hands on as much as we can."

Researchers acquire this external data in a few ways. The most common way they get data is by request. One researcher described his method of requesting data from other labs as, "I would contact the PIs and ask what they could provide." Other researchers discussed getting it from government reports, public datasets or other published sources. One engineer remarked, "We rely on published data because most of the published data are well screened." Still others talked about getting data from collaborators in the field. In particular one environmental engineer stated about his data sources, "it's [data] that collaborators have generated."

The majority of civil and environmental engineering faculty, however, emphasized the primacy of their own data and data sourced locally versus that gathered elsewhere. One researcher stated, "It is very hard to use data from other labs because it depends about the kind of boundary conditions." Another researcher said when asked if he used data generated by others, "Very rarely. Very rarely. No."

Some ways that some researchers use other people's data are to validate their results or train their graduate students. One engineer noted, "One of the things that I recommend to my students is that when they are learning something new, they need to reproduce someone else's work to make sure they can do it." This shows that while they might not always trust other's results, they can still use that data as a training set.

Challenges

Some professors mentioned a rise of proprietary data as a challenge they experience now and expect to become worse over time. In particular, in transportation engineering, TomTom and other data brokers collect and process the data and then sell it back to the cities or researchers. To combat this challenge, cities are increasingly rolling data collection into new infrastructure.

Obtaining data from other researchers is another challenge. One participant said he does not always receive data when he requests it directly from a researcher, describing it as "sometimes you can get it, sometimes you can’t.” Another participanrt mentioned that while he welcomes data sharing mandates from federal funding agencies, it is still a challenge to obtain that data, particularly in terms of timely access since researchers tend not to release data until after they have published their own papers: “It’s a good start, but getting that information across is really a challenge. And even if there are data repositories, the meat of the data makes it there in the very end. But sometimes it is too late.”

Another challenge these disciplines face in terms of data is size and sharing. Some research groups are generating terabytes of data and need to share that data at a long distance. Some solve this problem by paying for unlimited data storage on cloud platforms. Some have to work with campus IT to get remote researchers access to our network infrastructure. Some researchers resort to building their own networked storage server. One researcher explained, “That’s about 150 terabytes, and I have it right here in this building in our computer server room.” Another researcher highlighted the time-cost of transferring data this size: “anytime you have something larger than about 15, 20 megabytes, how [do] you share that between collaborators, especially if they're at different institutions? And what will end up happening still is people will just mail you a hard drive.”

Tools

Researchers rely on two main categories of tools to support their data practices: data storage tools (see above in “Collaboration”), and data gathering and processing tools. Data processing tools are very dependent on research discipline and methods. Many researchers use methods and tools from other disciplines in concert with their own, while others use new methods in core civil engineering disciplines. One researcher described gathering data on structural failure, “in a given test we can have 100 or 200 data [points] from different locations along the span, along the deflection, and everywhere, and collected electronically with a very fast speed. We're talking a reading could be at 10,000 readings a second.”

Most work with some form of CSV or Excel compatible files and report that their first pass is often in Excel. One researcher remarked succinctly, “Excel is still the backbone of a lot of things.” Those that work with large data often use other processing programs or languages to extract usable slices of their data. One participant mentioned using MATLAB to “try to slice the data into things that make it easier.”

Finally, many are turning to open source to help them find new scripts for data analysis. One researcher noted, “We get open-source software that are on the Internet. And then we have to modify it.” Several talked about the difficulty of contributing to open source efforts, remarking on the long tail of supporting something long term or the concern that their code does not look professional enough.

Publishing

The consensus from our respondents for where they share their work was peer-reviewed journals. Many respondents indicated that the typical publication workflow was for one of their students to present their results first as a conference paper or at a conference poster session, and then to follow-up on that initial presentation with an article manuscript very quickly afterwards. Conference presentations were viewed as valuable because they often allowed the research team to share more data than would be possible in a single journal article. While a few respondents noted that they sometimes share their work in other venues, including government agency reports and trade publications, journal articles were the consensus gold standard.

Publishing Criteria

When selecting which journals to publish their results in, most of our respondents used similar criteria for making their decisions. Researchers in one way or another described the importance of choosing “good” journals that had “prestige.” When asked to define these terms, researchers generally agreed that “good” and “prestigious” journals tended to publish good science and featured the work of prominent experts in their field. In terms of deciding which “good journal” to publish in, these decisions tended to be dependent upon a manuscript’s given topic. In order to ensure that the article would be discovered by the relevant audience, our respondents time and again mentioned the importance of finding the right “fit.” Respondents explained that they determined “fit” by looking at what types of articles the journal publishes, where their peers publish, as well as the official “scope” listed on the journal’s website.

While most respondents acknowledged that journal impact analytics were an item of consideration in this vetting process, very rarely were they listed as a top priority. Rather, it was most important that they find a journal where the work would be “read and cited.” While these journals may often have “good” impact metrics, for most of the researchers in our sample, these impact metrics were not a driving factor. Moreover, a handful of respondents had derisive comments about these journal metrics, dismissing their utility and accuracy for evaluating the quality of scholarship. Rather than seeking out metrics, it was most important to promote the “visibility” of the work, or as one respondent put it, going “where the readers are.” Other criteria included processing and review time, quality of reviews, and journal continuity for multi-part research studies. There was a noticeable difference in responses between junior and senior faculty, as well. While junior faculty may mention phrases like “focusing on a few key journals that I need for tenure,” some senior faculty had shifted priorities towards different areas of emphasis, such as “filling in gaps in my student’s CV.”

Challenges

Respondents noted that the peer review and editorial processes of traditional publishing seemed to be deteriorating; “bad reviewers” was the most common response when we asked about barriers to publishing the results of their work. A number of respondents pointed out the complete lack of incentives provided to individual scientists for creating honest and thoughtful reviews, and suggested that this created opportunities for bad actors to engage in peer review fraud. Bad reviewers were also suggested as a cause for the interminable length of review time, which some respondents suggested was really harmful to both individual careers as well as the scientific enterprise writ large. Editors could also create barriers as well – a number of respondents noted that they frequently encountered vague and unclear author’s guidelines that led to frustrating formatting issues throughout the review process. Editorial turnover could also create issues – one respondent shared a particularly painful memory of a new Editor-in-Chief inheriting their manuscript that was already months into the review, and deciding that it no longer fit the new scope of the journal.

Several of our respondents described how publishing interdisciplinary work both exacerbated these typical challenges while also introducing novel issues. Multiple respondents noted that the structure of scholarly publishing did not reflect the cross-disciplinary methods and approaches used by contemporary researchers, with one stating pointedly that "the structure of these journals was developed 50, 60, 70 years ago." Another respondent suggested that this archaic system of scholarly publishing had led to the creation of “too many journals with too narrow a focus.” These narrowly defined journals feature scopes and editorial boards that are at best ambivalent towards interdisciplinary work; as one respondent explained, “doing interdisciplinary work keeps you out of the club.” This quote encapsulated the feelings of several of our respondents, many of whom described the frustrating and isolating experience of receiving repeated rejections to well-executed interdisciplinary research. For more on the challenges associated with designing and conducting interdisciplinary research projects, please see our “Interdisciplinarity” section.

Working with Students

One additional challenge was publishing the work of students. One of the major tensions our respondents noted was balancing their lab’s output versus providing opportunities for the students to learn, and nowhere was this more evident than the publishing process. Many of the respondents acknowledged that their students would benefit from having access to technical editors or even scientific writing staff, which could drastically increase their research group’s productivity. However, others noted that this approach, while fruitful in the short-term, could ultimately hurt their students’ long-term development as scientists. Students need to learn how to deal with the frustration of formatting images, how to comply with inscrutable author’s guidelines, and how to respond to less than helpful reviewer comments so that they could run their own labs later in their careers. That being said, students also needed to be given guidance, and their progress and productivity needed to be monitored – numerous respondents expressed exasperation at trying to publish an article based on the work of students that had already left.

Open Access

Our respondents’ experiences with open access publishing models varied greatly. While the majority of the respondents had not published in open access journals, a sizeable portion of respondents indicated that they had previously made at least some of their publications available via some form of open access. These efforts included posting article manuscripts as PDFs to their personal websites and university profiles, as well as using services like ResearchGate. Nearly every respondent indicated that they shared PDF copies of their own articles when contacted directly by other researchers, as well. However, a number of researchers noted that publishers’ rules on sharing copies of their own articles seemed intentionally vague, and many of these respondents expressed some anxiety over whether “sharing articles this way is legit.”

The barriers discouraging investment in open access publications fell into two categories; the fiscal burden of paying for article processing charges (APCs), and perceptions of the quality of open access scholarship. Nearly every researcher who had even considered publishing open access articles noted that a number of open access journals had exorbitantly expensive APCs, and several admitted that they were unsure “whether [APCs] would be covered by [their] grants.” For these researchers, cost created a real barrier against “gold” OA journals.

APCs also created the perception of a “pay-to-play” model of scholarship that some researchers viewed as “very problematic.” These perceptions often led to the conclusion that open access publications “do not have the same level of scholarship” as closed access journals, with one respondent suggesting that open access publications were where research groups publish their “not best work.” Tenure and promotion processes also weighed heavily in this discussion. Open access journals were viewed by some respondents as “traditionally having low impact factors,” which for junior faculty meant that open access publishing would have to wait “until after tenure.”

In spite of these barriers, a substantial number of respondents had very positive things to say about more open forms of scholarship. Not only did a number of respondents express generally positive opinions towards their research being made available this way, a few indicated that their preference would be to always publish open “if [an] APC is included in the budget” they listed on their grant applications. Others went even further, asserting that openly publishing the results of their work is an “ethical mandate when doing international field work.” A few of our respondents expressed awareness of and were interested in learning more about some of the emerging trends of open scholarship, specifically preprints, pre-registration of experimental protocols, and open peer review.

Authoring Tools and Processes

Most of our researchers use one main tool to draft articles and reports: Microsoft Word. Some had experimented with online platforms like Google Docs and Overleaf but prefer Word’s change tracking features and ability to tailor the format of a document. One researcher described their authoring practices as, “someone drafts it up [in] Microsoft Word, it's track changes, goes to one person, you see the comments and you go down that road.” They also mentioned that final touches and typesetting are often done in LaTeX saying when they “typically submit manuscripts…[they] put it in LaTeX.”

Social Media

By and large, the researchers in this study were not active users of social media. Most of them had a university website where they listed summaries of their research and/or publications, but the extent of their social media accounts was limited largely to ResearchGate and/or LinkedIn. When asked about other social media outlets, such as Twitter or Facebook, many mentioned a lack of time or interest. Interestingly, multiple researchers referred to themselves as “old school” or being a “social media Luddite,” including early-career faculty. One researcher pointed out that civil engineering itself is “very conservative” which probably has made it more difficult to generate momentum of social media use within the field. Others were not opposed to exploring the use of social media for their professional work in the future, and even felt this was something they should learn how to use. In fact, several respondents mentioned seeing other researchers use these tools effectively to promote their science to broader audiences. However, even these researchers who saw its value noted they lacked the time to get started, with one describing it pointedly as “a big time sink.”

Recommendations

Our respondents within the Department of Civil, Construction, and Environmental Engineering identified a number of overlapping needs that cut across domain expertise. While some of these needs overlap with existing services already available at NC State, several of these challenges point to gaps. Some of these areas will necessitate strategic and long-term planning; however, many can be addressed more immediately. In Table II below, we outline ten areas where the NCSU Libraries could highlight existing services and develop new initiatives to address these researchers' needs. By designing solutions to these challenges, the NCSU Libraries has the opportunity to take a leadership role in setting the culture of information and data practices at NC State.

Table II. Challenges and recommendations

Challenge	**Recommendation**
Finding collaborators for interdisciplinary work (pp. 6, 8)	Host events featuring interdisciplinary research projects at NC State, including seminars, networking sessions, and workshops; explore creation of a knowledge base of researchers on campus who are interested in interdisciplinary work
Finding journals that will publishing interdisciplinary research (p. 16)	Provide researchers with tools for identifying journals that welcome interdisciplinary research; work with publishers and editorial boards to broaden the scope of narrowly defined journals
Expanding knowledge outside of domain/home department (pp. 6-7)	Aggregate and disseminate information about campus and departmental seminars to enable researchers to foster connections in other disciplines
Finding information and literature in other disciplines (pp. 8, 11)	Provide expert searching support for literature discovery in other fields
Managing and sharing published information with collaborators (pp. 11-12)	Raise awareness of and provide training on reference management software
Optimizing processes for managing research data (p. 12)	Provide training related to research data management; highlight Libraries' data management planning review service; share best practices related to data storage available at NC State
Sharing data with off-site collaborators (p. 14)	Raise awareness of need for access to campus IT infrastructure for off-site collaborators
Visualizing research data (p. 13)	Provide training related to data science and data visualization; expand opportunities for researchers to share their data visualization techniques with the NC State community

Challenge	Recommendation
Overcoming barriers to open access publishing (pp. 16-17)	Raise awareness of APC-free open access publishing options (e.g., preprints, postprints, APC-free journals); advocate for APCs to be included in grant applications; clarify misunderstandings surrounding open access scholarship
Leveraging social media for research (p. 17)	Share best practices for using social media to promote researchers' work; highlight social media exemplars in the field and host workshops

Appendix A

Semi-Structured Interview Guide

Research focus and methods

- Describe your current research focus and projects.
- How is your research situated within the field of Civil and/or Environmental Engineering?
    - Does your work engage with any other fields or disciplines?
- What research methods do you typically use to conduct your research?
    - How do your methods relate to work done by others in Civil and/or Environmental Engineering [and, if, relevant in the other fields you engage with]?

Working with others

- Do you regularly work with, consult or collaborate with any others as part of your research process?
    - If so, who have you worked with and how?
        - Lab or on-campus research group
        - Other scholars or researchers [e.g. faculty at the university or other universities, student assistants, independent researchers]
        - Research support professionals: e.g. librarians, technologists
        - Other individuals or communities beyond the academy
        - Others not captured here?
- Have you encountered any challenges in the process of working with others? [focus on information-related challenges, e.g. finding information, data management, process of writing up results]
- Are there any resources, services or other supports that would help you more effectively develop and maintain these relationships?

Working with Data

- Does your research typically produce data? If so,
    - What kinds of data does your research typically produce? [prompt: describe the processes in which the data is produced over the course of the research]
    - How do you analyze the data? [e.g. using a pre-existing software package, designing own software, create models]
    - How do you manage and store data for your current use?
    - Do you use any other tools to record your research data? [e.g. electronic lab notebooks]. If so, describe.
    - What are your plans for managing the data and associated information beyond your current use? [e.g. protocols for sharing, destruction schedule, plans for depositing in a closed or open repository]
    - Have you encountered any challenges in the process of working with the data your research produces? If so, describe.
    - Are there any resources, services or other supports that would help you more effectively work with the data your research produces?

- Does your research involve working with data produced by others? If so,
  - What kinds of data produced by others do you typically work with?
  - How do you find that data?
  - How do you incorporate the data into your final research outputs? [e.g. included in the appendices, visually expressed as a table or figure]
  - How do you manage and store data for your current use?
  - How do you manage and store this data for your current use?
  - What are your plans for managing the data beyond your current use?
  - Have you encountered any challenges working with this kind of information?
  - Are there any resources, services or other supports that would help you more effectively work with the data produced by others?

Working with Published Information

- What kinds of published information do you rely on to do your research? [e.g. pre-prints, peer-reviewed articles, textbooks]
  - How do you locate this information? [Prompt for where and how they search for information and whether they receive any help from others in the process]
  - How do you manage and store this information for your ongoing use?
  - What are your plans for managing this information in the long-term?
  - Have you experienced any challenges working with this kind of information?
  - Are there any resources, services or other supports that would help you more effectively work with this kind of information?

Publishing Practices

- Where do you typically publish your scholarly research?
  - What are your key considerations in determining where to publish?
  - Have you ever made your scholarly publications available through open access? [e.g. pre-print archive; institutional repository, open access journal or journal option]. If yes, describe which venues.
    - Describe your considerations when determining whether or not to do so.
- Do you disseminate your research beyond scholarly publications? [If so, probe for where they publish and why they publish in these venues]
- Do you use social networking or other digital media platforms to communicate about your work [e.g. ResearchGate, Twitter, YouTube]?
  - If yes, describe which venues and your experiences using them.
  - If no, explain your level of familiarity and reasons for not choosing to engage with these kinds of platforms.
- How do your publishing practices relate to those typical in your discipline?
- Have you encountered any challenges in the process of publishing your work?
- Are there any resources, services or other supports that would help you in the process of publishing?

State of the Field and Wrapping Up

- How do you connect with your colleagues and/or keep up with trends in your field more broadly? [e.g. conferences, social networking]

- What future challenges and opportunities do you see for the broader field?
- Is there anything else about your experiences or needs as a scholar that you think it is important for me to know that was not covered in the previous questions?

Appendix B

Demographics of NC State CCEE study participants and departmental faculty

Table B1. Demographics of study participants (n=14)

	Assistant Professor	Associate Professor	Full Professor	**Total**
Civil and Construction Engineering	4	2	3	**9**
Environmental Engineering	3	0	2	**5**
Total (n)	**7**	**2**	**5**	**14**
Percentage of all participants	**50%**	**5.9%**	**36%**	

Table B2. Demographics of CCEE departmental faculty engaged in research, November 2017 (n=51)

	Assistant Professor	Associate Professor	Full Professor	**Total**
Civil and Construction Engineering	8	3	16	**27**
Environmental Engineering	9	3	12	**24**
Total	**17**	**6**	**28**	**51**
Percentage of all faculty	**33%**	**12%**	**55%**	

Appendix C

Study Methodology

The research team consisted of three librarians from the NCSU Libraries. A qualitative study approach was used, consisting of semi-structured interviews with CCEE faculty about: research topics and methods; working with others; working with data; working with published information; publishing practices; and future challenges and opportunities. A copy of the interview questionnaire is provided in Appendix A. The study protocol was submitted to North Carolina State University's Institutional Review Board (IRB) and approved as exempt from the policy as outlined in the Code of Federal Regulations (Exemption: 46.101. Exempt b.2).

Participants for the study were recruited from 51 CCEE faculty members who we identified from the department’s website as being actively engaged in research activities. Email invitations were sent out in mid-November 2017 after informing the department head about the study. From the initial set of email invitations, 11 faculty members agreed to be interviewed. Interviews were arranged with nine of these researchers, while scheduling difficulties prevented us from interviewing the other two. We then chose additional faculty members to contact based on their research areas in order to have all seven departmental research areas represented. An additional five agreed to participate, giving a total of 14 faculty members for the study. Demographics of the study sample can be found in Appendix B.

The interviews took place between November 2017 and February 2018. Each faculty member was scheduled for an hour-long meeting in their office with one of the team members. The interviews were digitally recorded with the consent of the participants, and lasted between 30 and 71 minutes, with an average length of 53 minutes.

The audio recordings were then transcribed and anonymized. The transcripts were manually analyzed using grounded theory methodology, i.e., codes were developed as the transcripts were read instead of starting with pre-existing codes. Each team member independently coded all 14 transcripts. We then met to discuss the themes that had been identified during the coding process and chose six to focus on for a second round of coding. The identities of all faculty participants were kept anonymous throughout the analysis process and in all subsequent reports.