Yahriel's 4A's: An Independent Interdisciplinary Field

1. Aerospace-Aeronautical Systems

2. Anthropology-Engineering

3. Applied Science, Technology, and Society (STS)

4. Anatomy and Artificial Intelligence

By Yahriel Salinas-Reyes

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i.

DEDICATION

I dedicate my thesis primarily to the two most important people in my life - my nurturing mentor known as The Cyclone of Education, and my to my lifelong supporter, and companion, Don Yahriel Salinas-Reyes - An embodiment of Chaos, Order, Logic, and Madness. I miss you both incredibly, and I promise to make good on my word to make you both proud.

I am deeply grateful to my family in the United States, Mexico, and El Salvador for bearing with me patiently as I worked on my thesis. I dedicate this work to all of you. Your unconditional love and strong show of support are the only things that kept me going every time I wanted to give up. To my parents, Sonia Reyes-Alvarenga and Oscar Salinas-Millan, your daily phone calls and pep talks kept me grounded and pushed me closer to the finish line. To my sister Lizbeth Salinas-Reyes, who would chide me every week and guilt trip me for being away from home - your prayers and love have kept me safe here. To my family Abigail Salinas-Reyes, Samuel Salinas-Reyes, Delmy Salinas-Reyes, and La Raza - thank you for seeing the best in me. You have never failed to cheer me up.

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Anthroengineering: an independent interdisciplinary field

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In recent decades, funding agencies, institutes and professional bodies have recognized the profound benefits of transdisciplinarity in tackling targeted research questions. However, once questions are answered, the previously abundant support often dissolves. As such, the long-term benefits of these transdisciplinary approaches are never fully achieved. Over the last several decades, the integration of anthropology and engineering through inter- and multidisciplinary work has led to advances in fields such as design, human evolution and medical technologies. The lack of formal recognition, however, of this transdisciplinary approach as a unique entity rather than a useful tool or a subfield makes it difficult for researchers to establish laboratories, secure permanent jobs, fund long-term research programmes and train students in this approach. To facilitate the growth and development and witness the long-term benefits of this approach, we propose the integration of anthropology and engineering be recognized as a new, independent field known as *anthroengineering*. We present a working definition for anthroengineering and examples of how anthroengineering has been used. We discuss the necessity of recognizing anthroengineering as a unique field and explore potential novel applications. Finally, we discuss the future of anthroengineering, highlighting avenues for moving the field forward.

1. Introduction

Transdisciplinarity forms a common axiom that transcends the disciplines, creating an overarching synthesis [1] (figure 1). As these syntheses combine previously isolated thoughts and ideas, the knowledge created by their integration is greater than anything that can be created by a single discipline on its own. Simply put, the whole is greater than the sum of its parts (Aristotle). Here we propose a new field that transcends existing disciplines: anthroengineering.

A recent transdisciplinary trend combining anthropology and engineering—anthroengineering—has become increasingly popular over the last few decades. It has played a crucial role in the development of fields such as biomechanics [2,3], ergonomics [4,5] and functional morphology [6–9]. Anthropology—the science and study of human and societal culture, language and biology—and engineering—the application of science to create machines and implement technologies and tangible solutions to societal problems—are unique and distinct disciplines that infrequently share curricular overlap. When the transdisciplinary approach has been applied to anthropology and engineering, it has often leveraged methods or data from one discipline to address a question from the other (figure 2). This focus on specific problem-solving rather than a united theoretical foundation limits the impact of any innovations created by the collaboration. Thus, the power of the transdisciplinary approach is not fully realized. By leveraging both disciplines to address issues that transcend each discipline (i.e. transdisciplinary issues), syntheses can be created that are of interest not only to members of both disciplines, but also to individuals outside of either.

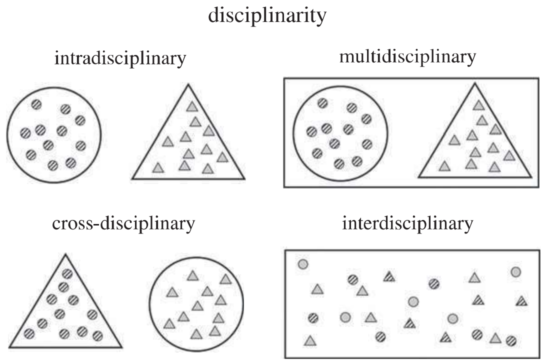

Figure 1. Types of disciplinarity that combine anthropology (circles) and engineering (triangles). Intradisciplinary: anthropologists (striped circles) and engineers (grey triangles) work within their respective fields (large circle and triangle). Multidisciplinary: anthropologists and engineers work within their respective fields to address a larger issue (rectangle). Cross-disciplinary: anthropologists investigate issues within engineering, and engineers investigate issues within anthropology. Interdisciplinary: anthropologists, engineers, anthropologists turned engineers (striped triangles) and engineers turned anthropologists (grey circles) seamlessly use both disciplines, simultaneously, to address larger issues.

The uniqueness and distinctiveness of the two disciplines means that, if a Venn diagram were to be drawn, little overlap would be apparent. Thus, it is difficult for researchers to identify issues that simultaneously leverage both disciplines. Yet, such issues exist, and many of them are crucial for the success of people and planet. Examples of such issues include the United Nations (UN) 17 Sustainable Development Goals (SDGs). These goals set forth a blueprint for how to achieve a more sustainable future for all by addressing problems ranging from poor health to inequality, environmental degradation, and peace and justice [15–17]. Because anthropologists and engineers are trained to approach these problems in discipline-unique ways, their perspectives will be distinct along a multitude of axes, and the fusion of the two disciplines will be difficult. But, ultimately, the insights gained will lead to solutions that neither discipline could achieve independently.

Despite the presence of significant overlapping issues and great benefits that could be achieved by leveraging both anthropology and engineering to address these issues, this transdisciplinary approach is rare, because no generalized framework that incorporates anthropology and engineering currently exists. Instead, frameworks are constructed for targeted projects which are often abandoned when the project is completed. Establishment of these frameworks requires an extraordinary amount of effort, and their specificity and frequent abandonment prevents them from being used for novel applications. A generalized framework is needed.

Such a framework would require, among other attributes, a common language where anthropologists and engineers can communicate effectively. It would require acknowledgement, respect and integration of expertise to develop new syntheses and a new cohort of students who are trained to think as both anthropologists and engineers simultaneously. But before a framework can be developed, this transdisciplinary approach requires a name. Without a name, the approach remains unknown, ill-defined and abstract. But with a name, this approach has identity and carries with it symbolism beyond its meaning. We suggest, therefore, that the transdisciplinary approach, combining both anthropology and engineering, be recognized as its own, independent field called *anthroengineering*.

2. What is anthroengineering

Anthroengineering is an approach that uses theories, methods and/or data from both anthropology and engineering to address questions within and beyond both disciplines. The result is the development of new knowledge, which can take a multitude of forms (e.g. data, technologies, viewpoints, axioms, syntheses). While the true power of such an approach would lie in leveraging it to address transdisciplinary issues, anthroengineering can also be used to address questions within anthropology and engineering and to advance each field individually (figure 2).

Providing anthroengineering with a name, describing it and recognizing it as distinct entity allows for researchers to succinctly define their work and, more importantly, provides them with identity as anthroengineers. It also acts to provide a common thread and search term that can tie together all future work that uses a transdisciplinary approach to combine both anthropology and engineering. Doing so will provide those interested in anthroengineering with a direct way to learn about it and what frameworks, data and methods exist to leverage anthroengineering effectively in their own work.

3. Examples of anthroengineering

As previously discussed, examples of anthroengineering already exist, and some have existed for decades. Given our expertise, we discuss some examples largely through the lens of biological anthropology and engineering mechanics.

3.1. Classic anthropology meets classic engineering

Anthropologists have studied dental wear patterns on the micro-, meso- and macro-levels for over a century [18] to address a myriad of questions in such topics as taxonomy [19], palaeoecology [20], environmental reconstruction [21] and behaviour [22,23]. Similarly, mechanical failure analyses—and, in this situation, tribology and fracture mechanics—have been a major focus of engineering since the birth of the field as all machines experience wear [24–26]. It is, therefore, unsurprising that anthropologists and engineers have teamed up to understand better how teeth wear and fracture.

Using techniques such as nano-indentation, researchers have been able to investigate the role that microscopic particles (e.g. phytoliths, grit) play in the wear of dental enamel [27,28]. Additionally, through physical experimentation, modelling and comparative anatomy [29–32], researchers have been able to investigate the role of enamel thickness and schmelzmusters (enamel microstructure) in force and energy in failure resistance. Although researchers may not always agree on interpretations of experimental results [33–35], this research has led to advances in understanding dental wear and the factors that influence it [36], understanding functional adaptations of teeth [37,38] and the creation of bioinspired materials [39].

Similarly, principles from material science and solid mechanics (engineering) and musculoskeletal biology

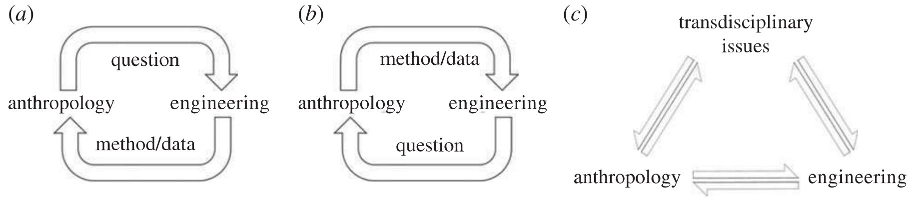

Figure 2. Transdisciplinary approaches to anthroengineering. (*a*) Engineering method(s)/data being leveraged to address anthropological question(s). Through an iterative process, question(s)/method(s) are refined and a synthesis is reached (e.g. the application of FE modelling to human evolution [10–13]). (*b*) Anthropological method(s)/data being leveraged to address engineering question(s). Through an iterative process, question(s)/method(s) are refined and a synthesis is reached (e.g. the application of ethnography to engineering design [14]). (*c*) Engineering and anthropological questions, methods and data are used to address transdisciplinary issues (e.g. design and/or manufacture of culturally relevant, sustainable medical devices for low- and middle-income countries).

(anthropology) have been used to understand how skeletal form (shape + size) and skeletal and ecological mechanical properties affect the way loads are transferred to the skeleton and how the skeleton responds to internal and external loads. Bone (re)models in response to mechanical strain [40–43]: this in turn affects bone's mechanical properties (remodelling) and form (modelling) (e.g. [44,45]). Bone strains have been measured experimentally using *in vivo* [46,47] and *in vitro* [48,49] techniques using strain gauges and digital image/volume correlation (DIC, DVC). However, this only delivers information on bone strain at a limited number of sites. By constructing finite-element (FE) models and validating them using experimental strains [50,51], we can obtain three-dimensional strain maps across the entire structure.

FE models require several inputs, including geometry, constraints and mechanical properties [8,52–54]. Advances in three-dimensional scanning techniques, computer science and statistical shape modelling (e.g. geometric morphometrics [55], dental topography [56]) have made it possible to not only (re)construct three-dimensional digital representations of such models [9,57–61], but also quantify complex shapes for statistical analyses [55,62–64]. Constraints come from muscles, joints and/or the external environment. Muscle force can be estimated by multiplying maximum force generation—originally estimated using physiological cross-sectional area [65–67] but now relying on muscle activation/strength [68] and often validated using electromyography [69–71]. Joint constraints are estimated using anatomical knowledge and skeletal collections. Although constraints from the external environment are often modelled as reaction forces, the mechanical properties of the environment (e.g. ground substrate composition during locomotion [72] or dietary mechanical properties during mastication [73,74]) affect the rate and manner in which the load is transmitted. Finally, mechanical properties are difficult to obtain, as bone is a hierarchical, composite structure, but techniques such as tension/compression tests, bending, indentation and ultrasound are used to estimate static and dynamic (bulk) properties [75–82]. Sensitivity studies are useful in understanding how parameter estimates affect the results, but not in validating the model [49,83–86], which requires data from empirical studies (e.g. [53,83]).

Using an extensive array of theories and methods from anthropology and engineering, we have learned more about musculoskeletal biomechanics than can be listed here. Some major findings include:

(1) Over a lifetime, an individual will engage in actions that will load their skeleton. In turn, their bones will generate a set of mechanical properties and forms to properly resist the *in vivo* strains brought on by those loads [42,87–89]. But it can be difficult or impossible to determine what actions occurred in the lifetime of an individual given only a set of bone mechanical properties and forms, as multiple behaviours can yield similar loading regimes. This is further complicated with inter-populational or among-species comparisons, as genetics and neutral selection play a significant role in bone form [90].
(2) Skeletal morphologies particular to specific hominin species have focused attention on the relationships among form, function and behaviour [91]. For instance, the lower limb and pelvic morphology of *Australopithecus afarensis* (e.g. [92]), *Australopithecus sediba* (e.g. [93]) and *Homo neanderthalensis* (e.g. [94]) has led to long-term debates regarding their forms of terrestrial locomotion. Geometric morphometrics and other traditional statistical analyses have led to important insights (e.g. [95]), although they quantify skeletal form and not biomechanical function, and many questions remain. Inverse dynamic simulation of walking in extinct hominins offers the opportunity to expand our understanding of this critical behaviour (e.g. [92,96]), but the integration of musculoskeletal models offers the best opportunity for future insights [68].
(3) Masticatory loads cause mechanical strains in the skull, which significantly affect its mechanical properties and form [44,45,97]. However, the debate about the relationship between feeding mechanics and diet has led to major questions: is it possible, over an individual's lifetime, to develop a skull that is over- or under-designed for the masticatory loads it experiences [98,99]? Does a skull's ability to resist masticatory loads dictate or limit an animal's or species' diet? Does natural selection select for skull form based on its ability to resist masticatory loads [10–13,100–102]?
(4) Primate tooth shape is undoubtedly correlated with diet [56,103], likely because teeth have evolved to break down foods consumed more efficiently [56,104,105]. However, the interactions between multicusped teeth and food items are so complex that we lack an efficient model for describing these relationships and, thereby, predicting food item breakdown from tooth shape [64,106,107].

Although it may seem that these lines of research have created more questions than answers, the independent syntheses of anthropology and engineering have led to important insights not only for the fields of anthropology and bioengineering but also anatomy, evolution, medicine and dentistry, to name a few. Further, the crucial questions generated would not exist if not for this transdisciplinary anthroengineering approach, and researchers would be ignorant of their ignorance.

3.2. Addressing intradisciplinary questions

Anthroengineering has also contributed in addressing more targeted questions within the disciplines of anthropology and engineering. Owing to decades of research in relatively independent fields, anthropology can provide insights into the Universe that engineering does not have, and vice versa.

Because anthropology is a discipline dominated by questions, while engineering a discipline that focuses on methods and applications, it is easy to see how the tools of engineering can be used to address anthropological questions. For example, using methods initially developed in engineering, virtual anthropology [108] has made it possible to quantitatively reconstruct palaeoarchaeological material and statistically quantify the accuracy of these reconstructions [59–61,109,110]. Two important examples of this are the reconstruction of the skull of *Ardipithecus ramidus*, which provided crucial, previously missing information about the evolution of hominin social structure, bipedalism and brain structure in hominin evolution during the Pliocene [110]. Additionally, the reconstruction of the mandible of *Homo habilis* not only showed a decoupling of brain and tooth size, but also allowed the development of a hypothesis regarding a much earlier origin of the genus *Homo* [109]. While that paper was under review, a new fossil (the Ledi-Geraru mandible) was discovered, confirming the authors' hypothesis [111].

Two additional common engineering methods—FE analysis and tension/compression tests—have been used extensively in palaeoanthropology to quantify the biomechanical performance of hard skeletal tissues and address questions concerning the evolution of primate diets [12,46,58,112–114]. The ability to print three-dimensional fossils further allows for the mechanical testing of previously inaccessible material [115–117]. These *in silico* and *in vitro* models and experiments carry with them several assumptions about the loading conditions and mechanical properties of the structure being analysed but provide valuable information about the biomechanical limits of the structure.

Given the plethora of methods in engineering, it may be more difficult to see how anthropology can benefit engineering. Nonetheless, engineering focuses on the application of science to solve problems for people, and anthropology is uniquely situated to provide the context to those problems. For instance, anthropology has improved engineering through the incorporation of anthropological methods. For example, the incorporation of ethnography into design to form the fields of design/techno-anthropology [14] and conferences like EPIC (Ethnographic Praxis in Industry Conference; www.epicpeople.org). End-user design focuses on the user's needs when designing products. By using anthropological techniques like ethnography, engineers can gather information about the wants and needs of the user that is inaccessible through focus groups developed from marketing perspectives. A classic example is in the design of the MP3 player, which was meant as an affordable alternative to the iPod to be used in the gym. Focus groups thought they wanted a device with many options and, therefore, many buttons. The product was designed, sent to market and failed. It was only by teaming up with ethnographers that designers and engineers realized that people's hands got sweaty in gyms and that gyms were social places. Ultimately, people actually wanted devices with fewer buttons and a quick on/off switch—they just did not realize it when they were in focus groups because the questions were not asked in the proper framework [118].

Anthropologists bring with them techniques that can be used to design for the future [119] and understand the consequences of technological advances. Engineers make design decisions to help today, but rarely think about the long-term effects on societies and communities in the future: this is because many work for companies which are on a deadline and, once one project is complete, they move on to the next. A classic example of the desire to solve the problem at hand without considering the potential longer-term societal consequences has been documented [120]. Engineers working through an international development organization created a solution to a chronic water shortage by developing a 140 km gravity-driven water pipeline that supplied water taps in local settings. Before the project, local women had carried water from natural sources, at times a journey of 3 h. The water distribution system worked well, but two unintended consequences occurred: the decrease in energy expenditure due to no longer needing to carry water increased the women's fertility and, because nutritional resources remained the same, increased child malnutrition [120]. These consequences are predictable through the lens of human reproductive ecology, a key body of knowledge in biological anthropology.

Anthropologists are trained to investigate long-term societal and community trends and are in a much better position not only to understand but also to address these problems. By working together, anthropologists and engineers who are interested in finding more socially connected solutions can do more to address crippling human problems. An example of how this can work came forth at the 'Why the World Needs Anthropologists: Powering the Planet' conference at Durham University, UK, in 2018. The conference focused on the problems facing energy (e.g. production, dissemination, storage) and explored how energy professionals and anthropologists can work together to create energy innovations that change the world for the better (https://www.dur.ac.uk/dei/events/?eventno=34503). In many cases, applied anthropology, which focuses on the external application of anthropology to current problems, could be used to extend and/or enhance the solutions to the problems engineers are regularly faced with.

Finally, although biomimicry is a field in itself, its application often falls short of its potential. Engineers who use biomimicry often look at the biological system in isolation and with overly simplified biological theories (e.g. assuming natural selection has caused a structure to be optimal for its function, without considering the evolutionary history of that element). Biological solutions typically must solve several simultaneous problems and have evolved within a set of allometric, phylogenetic and ontogenetic constraints [121]—a core understanding in biological anthropology—and the adaptationist programme frequently employed by engineers has been rejected by biologists for decades

[122,123]. Because of this, biomimetic engineering falls short of its goals.

Anthropologists are trained to consider biological context that could lead to more effective biomimicry solutions using primates and human biological systems (e.g. the hierarchical structure of bone [124]). Take, for example, the design of the human foot, a complex structure that can be rigid in some circumstances and compliant in others. The evolutionary history of the foot is complex and filled with gaps [125], but we know it has evolved to interact with various substrates [72]. When wearing a shoe, the substrate interacting with the foot is no longer the ground, but the shoe itself [126], but shoe design does not often take foot–substrate interactions into account. Many shoe designs lead to running biomechanics that the human skeleton has not evolved to handle (e.g. high-impact forces during heel striking [127]). Similar issues can be seen in prosthetic foot design, where the impact of foot stiffness on gait biomechanics is well documented for advanced prosthetic feet (e.g. [128]). But in situations with fewer opportunities for the use of advanced medical devices, 'one size fits all' becomes 'one stiffness fits all' and the negative consequences of such choices are not appreciated. Further, even advanced medical interventions select a specified, unchanging stiffness for the prosthetic foot, when the natural foot has an adaptive, continuously changing stiffness, dependent on substrate and loading. Using anthroengineering and biomimicry approaches, answers to questions like 'How can we use what we know about variation in Primates to make engineered products better?' are achievable.

4. Why recognize a formal field of anthroengineering?

If anthroengineering projects already exist, why is it necessary to provide the word 'anthroengineering' to describe them all? It is not as if the previously discussed anthroengineering examples would cease to exist should the term 'anthroengineering' not be coined. More importantly, why is it necessary to recognize anthroengineering as its own field?

First, as previously mentioned, names provide identity and symbolic meaning. Should it not be given a unifying name, anthroengineering will remain elusive and ill-defined. In a well-known paper on evolutionary theory, Gould & Vrba [129] present a new word—exaptation—to describe an evolutionary phenomenon. They argue that the existing word 'adaptation' is defined and recognized by two criteria and biologists fail to recognize potential confusion between these criteria. Part of the reason for this confusion, they go on to say, is that one of these criteria does not have a distinctive word to describe it. They then propose that the word 'exaptation', which had not previously existed, be used for this criterion [129]. By providing a phenomenon with a name, Gould and Vrba took a previously undefined concept and centred it, making it tangible and real. Similarly, while anthroengineering has existed for decades, it has remained abstract and ill-defined. By providing a word to describe this line of work, anthroengineering becomes tangible and real.

Second, providing the name anthroengineering allows for the field to be recognized. This provides a thread to unite researchers working at the intersection of anthropology and engineering, much as the word 'anthropology' ties together cultural, linguistic and biological anthropologists, or 'engineering' ties together chemical, mechanical and computer engineers. Anthropology and engineering intersect across so many areas of interest that researchers in one area are often ignorant of people working in another (e.g. design anthropologists versus palaeo-biomechanists). The word anthroengineering creates a unifying concept for these researchers and an umbrella under which those anthroengineers can meet with, learn from and work with each other.

Third, the creation of a word and field to describe this line of work creates with it a new way of thinking and new framework, but, unlike interdisciplinary projects, it also creates a permanency. This allows researchers to be trained in this novel way of thinking and apply it with a deeper understanding to new problems in the future. This will then open a new world of potential applications for anthroengineering and enable researchers to ask questions they previously would not have considered.

Once anthroengineering is established and researchers have become fully trained in the field, the questions researchers ask will change. Instead of asking how anthropology or engineering, individually, could address a problem, researchers will ask how anthroengineering can address the problem and—as such—be able to answer it in a more fully informed, comprehensive manner. New questions can be asked, such as:

— How can we leverage anthroengineering to address large problems in the world, such as the UN's SDGs?
— How can we use anthroengineering to better understand how humans have evolved and why modern human biological variation exists in the manner it does?
— How can we leverage that information to better understand how humans are currently evolving in light of technological and societal changes and to address problems associated with racism and other identity-based biases in our technology and societies [130]?
— How can we use advanced modelling techniques to address global problems associated with healthy human ageing?

4.1. Creation of a new field

Today, many of the problems facing anthroengineering are the same as those facing interdisciplinary research in general. We recognize the issues facing research and research projects can often be distinct from those facing fields, but, at the time of writing, anthroengineering has almost solely existed at the research level, so it has not yet developed (m)any unique 'field-level' problems. As the plights of interdisciplinary research are much discussed, we will provide an overview of some of the main problems facing interdisciplinary research that we have witnessed within anthroengineering. We will further discuss some issues specific to anthroengineering today.

4.1.1. Publishing

Publications are currency in academia. When academics try to demonstrate their impact as researchers, they often total their number of publications, h-index, i10 index and the like for good reason. Publications foster recognition and the institutionalization of research, which in turn feeds back on the infrastructure and capacity of centres and departments, resulting in increased support [1].

Anthroengineers are faced with several difficulties when it comes to publication that plague interdisciplinary research. When making the decision on where to publish, anthroengineers must choose between specialist and generalist journals [131]. Often, their manuscripts do not fit within the narrow remits of specialist journals and would have to change position from a truly transdisciplinary approach to one where the methods/theories from one field are being used to advance the other [132]. Until specialist anthroengineering journals are established, therefore, manuscripts must be published in generalist journals. The risk when publishing in generalist journals is that the paper will not have its desired impact, as the generalist journal may not be regularly read by anthropologists, engineers or fellow anthroengineers. The paper would then miss its target audience.

The most effective way of circumventing this issue is through publication in high-impact generalist journals with large readership bases. But herein lies two dilemmas: (i) high-impact generalist journals tend to have word/page limits, and there is often not enough space to fully explain or discuss the anthropological *and* engineering theories and methods, and (ii) these journals have many submissions and limited publication space. They are, therefore, likely only to publish material they believe will be of interest to a high percentage of their audience, meaning that they can be hesitant to accept and publish papers in untested areas that do not already have a demonstrated readership base.

Further, the editors handling the manuscripts are unlikely to be anthroengineers and are more likely to be either anthropologists or engineers, making it less likely they will be able to grasp fully the impact of the research as part of the work is outside their area of expertise. The same issue occurs when recruiting reviewers for the manuscript [133]. Often, few researchers exist with the expertise to comprehensively review the manuscript. Consequently, more reviewers must be recruited, and it is not uncommon for reviewers to provide conflicting reviews. When conflicting reviews are received by a high-impact journal, the manuscript is often rejected, as the lack of consistency among reviewers is believed to be indicative of an inferior manuscript.

As a result, researchers are required to spend years publishing high-impact research in lower impact generalist journals that may not reach their target audience, and/or moulding their research to reach the narrow remit of the specialist journals. As institutional and funding support are often hinged on the ability to publish in high-impact journals (as this is often used as a metric for the 'quality' of research), researchers in interdisciplinary fields must often work much harder to be recognized. Fortunately for anthroengineering, several well-respected journals have been receptive to the publication of anthroengineering manuscripts (e.g. those published by the Royal Society [106,107,134], *Proceedings of the National Academy of Sciences of the United States of America* [12] and *Nature* [58]), but more explicit definition of the field will extend this acceptance.

4.1.2. Funding bodies

Funding is almost as important as publishing in academia, but securing funding for interdisciplinary projects comes with many of the same problems [132,135]. Instead of choosing between specialist journals, researchers are forced to choose between specialist councils (e.g. the Engineering and Physical Sciences Research Council (EPSRC), Natural Environment Research Council (NERC) and Biotechnology and Biological Sciences Research Council (BBSRC) in UK Research and Innovation (UKRI)) or specialist research areas (Biological Sciences, Engineering, International Science and Engineering, and Social, Behavioral, and Economic Sciences in the National Science Foundation (NSF)).

At a time when inter-/multidisciplinary research is heralded as the future of academia [136–138], the narrow focus of councils/research areas makes it complicated to submit interdisciplinary proposals and receive funding. When proposals are submitted to a specific research council/area, the proposal's merit is judged within the expertise of that council/area. While submission of truly interdisciplinary proposals that transcends the boundaries of the research councils/areas can occur through cross-council submissions, councils need to be contacted prior to submission to determine if the proposal is of interest. It often takes months to answer interdisciplinary enquiries, as it requires cross-council conversations, which delay proposal submission.

Once submitted, it is consistently more difficult to be awarded funding for interdisciplinary projects [139], and it is easier to secure funding for projects that combine closely related disciplines than for disparate ones [132]. This, unfortunately, leads to a situation where the more groundbreaking the collaboration is, the harder it is to fund. Lower funding success rates are believed to originate from a bias against interdisciplinary projects. Firstly, interdisciplinary proposals are viewed as higher risk because they do not follow an established path [139]. Secondly, as with journal articles, proposals are often reviewed by reviewers and panels who are ill-equipped to evaluate all parts of the project, making it difficult for them to appreciate the scope and impact of the proposal. They instead only review the portion of the proposal for which they are an expert and are more likely to assign a mediocre or poor score to an interdisciplinary proposal than an intradisciplinary one owing to a poor understanding of the project or the foundational concepts. Having a mix of reviewers who do and do not fully appreciate or understand the project will lead to proposals being rejected, as a lack of consistency between the reviewers is viewed as a problem with the application and not the review process. Additionally, interdisciplinary proposals compete with intradisciplinary ones, which are easier to justify for the funding agent [139].

4.1.3. Institutional support

In the longer term, for anthroengineering—or any other interdisciplinary line of research—to succeed, it must have career-level institutional support. Once interdisciplinary grants are awarded, the resulting projects often include graduate students and/or postdoctoral research associates. While this training expands their knowledge in ways that we recommend, it also leads to the training of a cohort of interdisciplinary researchers who, in the case of anthroengineering, do not fit the classic definitions of anthropology or engineering. They are often not considered 'real' anthropologists or 'real' engineers. As a result, when it comes time for these individuals to obtain permanent posts, the more interdisciplinary they are, the more difficult it is to obtain a permanent position.

During faculty searches, departments/divisions look for individuals to fill gaps in programme teaching and/or research foci, often hiring candidates who best fit the discipline(s) in which the programme awards degrees. This makes it difficult for truly interdisciplinary researchers to obtain permanent posts: an anthropologist or engineer who has spent their entire career working within the boundaries of their traditional discipline is a much stronger candidate than an anthroengineer. For the long-term success of anthroengineering, high-level institutional support is needed.

4.1.4. Anthroengineering education

In terms of education, institutions need to go a step further than the current practice. To date, all anthroengineering training has been done on an individual level in the laboratory, which requires an inordinate amount of time and effort from the laboratory's principal investigator, and from the individuals independently seeking out formal educations in both anthropology and engineering. Given how different the two disciplines are, this often requires twice the time and money to be educated in anthroengineering, limiting the ability to study anthroengineering to the privileged. Owing to the clear benefits of interdisciplinary research, and the scientific leaps that have been made by anthroengineering research already, we believe that universities should support formally training students as anthroengineers.

The majority of these students will leave academia and enter the private sector. The students trained as anthroengineers will have immediately transferable skills that make them superior on the job market to other anthropologists/engineers seeking employment. For example, a major concern among engineering companies is how to be more socially responsible, while social responsibility is a central theme in anthropology. The anthroengineers entering the job market will have the skills not only to be practising engineers, but also to be more socially responsible than engineers who have not received this training—something that is direly needed [140]. The anthroengineering cohorts will be trained in both anthropology and engineering from the start of their higher education, and, thus, taught to think using interdisciplinary approaches from the start. These anthroengineers will have the ability to see new questions and novel, innovative answers that cannot be imagined by the current generation of anthroengineering.

5. Disciplinary culture

The last issue we would like to touch upon with anthroengineering is that of disciplinary culture. In the creation of a new field, we are in the unique position to create the academic culture for the field. A focus of many disciplines, today, is to address the realities of sexism, racism, homophobia, etc., that have become engrained within these disciplines and academia in general and to take the necessary steps to solve these problems [141]. In the establishment of a new field, we can attempt to create a more inclusive academic environment from its inception [142].

When applying to hold the first symposium on anthroengineering at the American Association of Physical Anthropology (AAPA) conference in Cleveland, Ohio, USA, 2019 (Symposium 13—Anthroengineering: a Biological Perspective), we were required to write a 300-word diversity statement. In it, we described our methods for recruiting symposium participants which reflect our vision of anthroengineering:

> In recruiting participants for this symposium, we focused on early career researchers and on members of groups frequently underrepresented in research. Consequently, about half of our participants are women, and others are ethnic minorities and members of the LGBTQA[+] community. By recruiting a diverse group of people at an early stage in their careers, we hope to foster an environment of inclusion that connects to and bolsters other such efforts at the AAPAs and in the discipline of biological anthropology generally… [Anthroengineering should value] the contributions of all people, regardless of sex, gender, ethnicity, or sexual orientation, and supports all types of research that combine anthropology and engineering.

In short, our vision for this new field is one of fairness and inclusivity, but anthroengineering will be housed in academic institutions and is born out of two fields which have their own problems. Fortunately, we are in a position where we can observe the issues present in other fields and strive to avoid those issues in this one.

6. Conclusion

In this paper, we have presented the concept of anthroengineering, provided examples of how anthroengineering has been used in the past and outline a plan for the future. Importantly, we have argued that anthroengineering should be recognized as its own, independent field: if you did not already believe this, we hope we have made converts out of you.

We cannot wait to see what the future has in store.

Data accessibility. This article has no additional data.

Authors' contributions. Both M.A.B. and P.A.K. conceived of and wrote the paper.

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References

1. Klein JT. 2008 Evaluation of interdisciplinary and transdisciplinary research: a literature review. *Am. J. Prev. Med.* **35**, S116–S123. (doi:10.1016/j.amepre.2008.05.010)
2. Kramer PA. 1999 Modelling the locomotor energetics of extinct hominids. *J. Exp. Biol.* **202**, 2807–2818. (doi:10.1242/jeb.202.20.2807)
3. Weber GW, Bookstein FL, Strait DS. 2011 Virtual anthropology meets biomechanics. *J. Biomech.* **44**, 1429–1432. (doi:10.1016/j.jbiomech.2011.02.079)
4. Wilson JR. 2000 Fundamentals of ergonomics in theory and practice. *Appl. Ergon.* **31**, 557–567. (doi:10.1016/S0003-6870(00)00034-X)
5. Hertzeberg HTE. 1955 Some contributions of applied physical anthropology to human engineering. *Ann. N. Y. Acad. Sci.* **63**, 616–629. (doi:10.1111/j.1749-6632.1955.tb32114.x)
6. Ruff CB, Hayes WC. 1983 Cross-sectional geometry of Pecos Pueblo femora and tibiae—a biomechanical investigation: I. Method and general patterns of variation. *Am. J. Phys. Anthropol.* **60**, 359–381. (doi:10.1002/ajpa.1330600308)
7. Ruff CB, Hayes WC. 1983 Cross-sectional geometry of Pecos Pueblo femora and tibiae—a biomechanical investigation: II. Sex, age, side differences. *Am. J. Phys. Anthropol.* **60**, 383–400. (doi:10.1002/ajpa.1330600309)
8. Richmond BG, Wright BW, Grosse I, Dechow PC, Ross CF, Spencer MA, Strait DS. 2005 Finite element analysis in functional morphology. *Anat. Rec.* **283**, 259–274. (doi:10.1002/ar.a.20169)
9. Rayfield EJ. 2007 Finite element analysis and understanding the biomechanics and evolution of living and fossil organisms. *Annu. Rev. Earth Planet. Sci.* **35**, 541–576. (doi:10.1146/annurev.earth.35.031306.140104)
10. Strait DSDSDS *et al.* 2013 Viewpoints: diet and dietary adaptations in early hominins: the hard food perspective. *Am. J. Phys. Anthropol.* **151**, 339–355. (doi:10.1002/ajpa.22285)
11. Daegling DJ, Judex S, Ozcivici E, Ravosa MJ, Taylor AB, Grine FE, Teaford MF, Ungar PS. 2013 Viewpoints: feeding mechanics, diet, and dietary adaptations in early hominins. *Am. J. Phys. Anthropol.* **151**, 356–371. (doi:10.1002/ajpa.22281)
12. Strait DS *et al.* 2009 The feeding biomechanics and dietary ecology of *Australopithecus africanus*. *Proc. Natl Acad. Sci. USA* **106**, 2124–2129. (doi:10.1073/pnas.0808730106)
13. Grine FE *et al.* 2010 Craniofacial biomechanics and functional and dietary inferences in hominin paleontology. *J. Hum. Evol.* **58**, 293–308. (doi:10.1016/j.jhevol.2009.12.001)
14. Gunn W, Otto T, Smith RC. 2013 *Design anthropology: theory and practice*. London, UK: Bloomsbury Academic.
15. Griggs D *et al.* 2013 Sustainable development goals for people and planet. *Nature* **495**, 305–307. (doi:10.1038/495305a)
16. Sachs JD. 2012 From millennium development goals to sustainable development goals. *Lancet* **379**, 2206–2211. (doi:10.1016/S0140-6736(12)60685-0)
17. UN. 2015 *Transforming our world: the 2030 agenda for sustainable development*. See https://sdgs.un.org/2030agenda.
18. Smith HB. 2020 Foreward. In *Dental wear in evolutionary and biocultural contexts* (eds C Schmidt, JT Watson), pp. xv–xxi. Cambridge, UK: Academic Press.
19. De Groote I *et al.* 2016 New genetic and morphological evidence suggests a single hoaxer created 'Piltdown man'. *R. Soc. Open Sci.* **3**. (doi:10.1098/rsos.160679)
20. Grine FE, Sponheimer M, Ungar PS, Lee-Thorp J, Teaford MF. 2012 Dental microwear and stable isotopes inform the paleoecology of extinct hominins. *Am. J. Phys. Anthropol.* **148**, 285–317. (doi:10.1002/ajpa.22086)
21. Ungar PS, Abella EF, Burgman JHE, Lazagabaster IA, Scott JR, Delezene LK, Manthi FK, Plavcan JM, Ward CV. 2017 Dental microwear and Pliocene paleocommunity ecology of bovids, primates, rodents, and suids at Kanapoi. *J. Hum. Evol.* **140**, 102315. (doi:10.1016/j.jhevol.2017.03.005)
22. Frayer DW, Clarke RJ, Fiore I, Blumenschine RJ, Pérez-Pérez A, Martinez LM, Estebaranz F, Holloway R, Bondioli L. 2016 OH-65: The earliest evidence for right-handedness in the fossil record. *J. Hum. Evol.* **100**, 65–72. (doi:10.1016/j.jhevol.2016.07.002)
23. Bermúdez de Castro J, Bromage TG, Jalvo YF. 1988 Buccal striations on fossil human anterior teeth: evidence of handedness in the middle and early Upper Pleistocene. *J. Hum. Evol.* **17**, 403–412. (doi:10.1016/0047-2484(88)90029-2)
24. Archard JF, Hirst W. 1956 The wear of metals under unlubricated conditions. *Proc. R. Soc. Lond. A* **236**, 397–410. (doi:10.1098/rspa.1956.0144)
25. Amini S, Miserez A. 2013 Wear and abrasion resistance selection maps of biological materials. *Acta Biomater.* **9**, 7895–7907. (doi:10.1016/J.ACTBIO.2013.04.042)
26. Põdra P, Andersson S. 1999 Simulating sliding wear with finite element method. *Tribol. Int.* **32**, 71–81. (doi:10.1016/S0301-679X(99)00012-2)
27. Lucas PW *et al.* 2013 Mechanisms and causes of wear in tooth enamel: implications for hominin diets. *J. R. Soc. Interface* **10**, 20120923. (doi:10.1098/rsif.2012.0923)
28. Xia J, Zheng J, Huang D, Tian ZR, Chen L, Zhou Z, Ungar PS, Qian L. 2015 New model to explain tooth wear with implications for microwear formation and diet reconstruction. *Proc. Natl Acad. Sci. USA* **112**, 10 669–10 672. (doi:10.1073/pnas.1509491112)
29. Lawn BR, Lee JJ-W, Chai H. 2010 Teeth: among nature's most durable biocomposites. *Annu. Rev. Mater. Res.* **40**, 55–75. (doi:10.1146/annurev-matsci-070909-104537)
30. Chai H, Lee JJ-W, Constantino PJ, Lucas PW, Lawn BR. 2009 Remarkable resilience of teeth. *Proc. Natl Acad. Sci USA* **106**, 7289–7293. (doi:10.1073/pnas.0902466106)
31. Ziscovici C, Lucas PW, Constantino PJ, Bromage TG, van Casteren A. 2014 Sea otter dental enamel is highly resistant to chipping due to its microstructure. *Biol. Lett.* **10**, 20140484. (doi:10.1098/rsbl.2014.0484)
32. Constantino PJ, Lee JJ-W, Chai H, Zipfel B, Ziscovici C, Lawn BR, Lucas PW. 2010 Tooth chipping can reveal the diet and bite forces of fossil hominins. *Biol. Lett.* **6**, 826–829. (doi:10.1098/rsbl.2010.0304)
33. van Casteren A *et al.* 2018 Evidence that metallic proxies are unsuitable for assessing the mechanics of microwear formation and a new theory of the meaning of microwear. *R. Soc. Open Sci.* **5**, 171699. (doi:10.1098/rsos.171699)
34. Xia J, Zhou Z, Qian L, Ungar PS. 2018 Comment on van Casteren *et al.* (2018): softer metallic spheres do abrade harder enamel. *R. Soc. Open Sci.* **5**, 181376. (doi:10.1098/rsos.181376)
35. Rabenold D, Pearson OM. 2014 Scratching the surface: a critique of Lucas *et al.* (2013)'s conclusion that phytoliths do not abrade enamel. *J. Hum. Evol.* **74**, 130–133. (doi:10.1016/j.jhevol.2014.02.001)
36. Lucas PW *et al.* 2014 The role of dust, grit and phytoliths in tooth wear. *Ann. Zool. Fennici* **51**, 143–152. (doi:10.5735/086.051.0215)
37. Constantino PJ, Borrero-Lopez O, Pajares A, Lawn BR. 2015 Simulation of enamel wear for reconstruction of diet and feeding behavior in fossil animals: a micromechanics approach. *Bioessays* **38**, 89–99. (doi:10.1002/bies.201500094)
38. Borrero-Lopez O, Pajares A, Constantino PJ, Lawn BR. 2015 Mechanics of microwear traces in tooth enamel. *Acta Biomater.* **14**, 146–153. (doi:10.1016/j.actbio.2014.11.047)

39. Sanchez-Gonzalez E, Rodriguez-Rojas F, Pinilla-Cienfuegos E, Borrero-Lopez O, Ortiz AL, Guiberteau F. 2020 Bioinspired design of triboceramics: learning from the anisotropic micro-fracture response of dental enamel under sliding contact. *Ceram. Int.* **46**, 27 983–27 989. (doi:10.1016/j.ceramint.2020.07.292)
40. Frost HM. 2003 Bone's mechanostat: a 2003 update. *Anat. Rec.* **275A**, 1081–1101. (doi:10.1002/ar.a.10119)
41. Frost HM. 1987 Bone 'mass' and the 'mechanostat': a proposal. *Anat. Rec.* **219**, 1–9. (doi:10.1002/ar.1092190104)
42. Ruff C, Holt B, Trinkaus E. 2006 Who's afraid of the big bad Wolff?: 'Wolff's law' and bone functional adaptation. *Am. J. Phys. Anthropol.* **129**, 484–498. (doi:10.1002/ajpa.20371)
43. Barak MM. 2020 Bone modeling or bone remodeling: that is the question. *Am. J. Phys. Anthropol.* **172**, 153–155. (doi:10.1002/ajpa.23966)
44. Schwartz-Dabney CL, Dechow PC. 2002 Edentulation alters material properties of cortical bone in the human mandible. *J. Dent. Res.* **81**, 613–617. (doi:10.1177/154405910208100907)
45. Dechow PC, Wang Q, Peterson J. 2010 Edentulation alters material properties of cortical bone in the human craniofacial skeleton: functional implications for craniofacial structure in primate evolution. *Anat. Rec.* **293**, 618–629. (doi:10.1002/ar.21124)
46. Ross CF, Berthaume MA, Dechow PC, Iriarte-Diaz J, Porro LB, Richmond BG, Spencer M, Strait D. 2011 In vivo bone strain and finite-element modeling of the craniofacial haft in catarrhine primates. *J. Anat.* **218**, 112–141. (doi:10.1111/j.1469-7580.2010.01322.x)
47. Hylander WL, Ravosa MJ, Ross CF, Johnson KR. 1998 Mandibular corpus strain in primates: further evidence for a functional link between symphyseal fusion and jaw-adductor muscle force. *Am. J. Phys. Anthropol.* **107**, 257–271. (doi:10.1002/(SICI)1096-8644(199811)107:3<257::AID-AJPA3>3.0.CO;2-6)
48. Ross CF, Hylander WL. 1996 In vivo and in vitro bone strain in the owl monkey circumorbital region and the function of the postorbital septum. *Am. J. Phys. Anthropol.* **101**, 183–215. (doi:10.1002/(SICI)1096-8644(199610)101:2<183::AID-AJPA6>3.0.CO;2-3)
49. Toro-Ibacache V, Fitton LC, Fagan MJ, O'Higgins P. 2016 Validity and sensitivity of a human cranial finite element model: implications for comparative studies of biting performance. *J. Anat.* **228**, 70–84. (doi:10.1111/joa.12384)
50. Strait DS, Wang Q, Dechow PC, Ross CF, Richmond BG, Spencer MA, Patel BA. 2005 Modeling elastic properties in finite-element analysis: how much precision is needed to produce an accurate model? *Anat. Rec.* **283**, 275–287. (doi:10.1002/ar.a.20172)
51. Prado FB, Freire AR, Rossi AC, Ledogar JA, Smith AL, Dechow PC, Strait DS, Voigt T, Ross CF. 2016 Review of in vivo bone strain studies and finite element models of the zygomatic complex in humans and nonhuman primates: implications for clinical research and practice. *Anat. Rec.* **299**, 1753–1778. (doi:10.1002/ar.23486)
52. Sylvester AD, Kramer PA. 2018 Young's modulus and load complexity: modeling their effects on proximal femur strain. *Bone Biol.* **301**, 1189–1202.
53. Kramer PA, Hammerberg AG, Sylvester AD. 2019 Modeling the spine using finite element models: considerations and cautions. In *Spinal evolution: morphology, function, and pathology of the spine in hominoid evolution* (eds E Been, A Gomez Olivencia, P Kramer), pp. 387–400. Cham, Switzerland: Springer.
54. Ross CF. 2005 Finite element analysis in vertebrate biomechanics. *Anat. Rec.* **283**, 253–258. (doi:10.1002/ar.a.20177)
55. O'Higgins P, Fitton LC, Phillips R, Shi J, Liu J, Gröning F, Cobb SN, Fagan MJ. 2012 Virtual functional morphology: novel approaches to the study of craniofacial form and function. *Evol. Biol.* **39**, 521–535. (doi:10.1007/s11692-012-9173-8)
56. Berthaume MA, Lazzari V, Guy F. 2020 The landscape of tooth shape: over 20 years of dental topography in primates. *Evol. Anthropol.* **29**, 245–262. (doi:10.1002/evan.21856)
57. Lautenschlager S. 2016 Reconstructing the past: methods and techniques for the digital restoration of fossils. *R. Soc. Open Sci.* **3**, 160342. (doi:10.1098/rsos.160342)
58. Ledogar JA *et al.* 2016 Mechanical evidence that *Australopithecus sediba* was limited in its ability to eat hard foods. *Nat. Commun.* **7**, 10596. (doi:10.1038/ncomms10596)
59. Benazzi S, Bookstein FL, Strait DS, Weber GW. 2011 A new OH5 reconstruction with an assessment of its uncertainty. *J. Hum. Evol.* **61**, 75–88. (doi:10.1016/J.JHEVOL.2011.02.005)
60. Benazzi S, Gruppioni G, Strait DS, Hublin J-J. 2014 Technical note: virtual reconstruction of KNM-ER 1813 *Homo habilis* cranium. *Am. J. Phys. Anthropol.* **153**, 154–160. (doi:10.1002/ajpa.22376)
61. Godinho RM, O'Higgins P. 2017 Virtual reconstruction of cranial remains. In *Human remains: another dimension*, pp. 135–147. Amsterdam, The Netherlands: Elsevier.
62. O'Higgins P, Fitton LC, Godinho RM. 2017 Geometric morphometrics and finite elements analysis: assessing the functional implications of differences in craniofacial form in the hominin fossil record. *J. Archaeol. Sci.* **101**, 159–168. (doi:10.1016/j.jas.2017.09.011)
63. O'Higgins P, Bastir M, Kupczik K. 2006 Shaping the human face. *Int. Congr. Ser.* **1296**, 55–73. (doi:10.1016/j.ics.2006.03.036)
64. Berthaume MA. 2016 On the relationship between tooth shape and masticatory efficiency: a finite element study. *Anat. Rec.* **299**, 679–687. (doi:10.1002/ar.23328)
65. Ward SR, Lieber RL. 2005 Density and hydration of fresh and fixed human skeletal muscle. *J. Biomech.* **38**, 2317–2320. (doi:10.1016/j.jbiomech.2004.10.001)
66. Dickinson E, Stark H, Kupczik K. 2018 Non-destructive determination of muscle architectural variables through the use of DiceCT. *Anat. Rec.* **301**, 363–377. (doi:10.1002/ar.23716)
67. Taylor AB, Vinyard CJ. 2009 Jaw-muscle fiber architecture in tufted capuchins favors generating relatively large muscle forces without compromising jaw gape. *J. Hum. Evol.* **57**, 710–720. (doi:10.1016/j.jhevol.2009.06.001)
68. Sylvester AD, Lautzenheiser SG, Kramer PA. 2021. A review of musculoskeletal modelling of human locomotion. *Interface Focus* **11**, 20200060. (doi:10.1098/rsfs.2020.0060)
69. Illyés Á, Kiss RM. 2005 Shoulder muscle activity during pushing, pulling, elevation and overhead throw. *J. Electromyogr. Kinesiol.* **15**, 282–289. (doi:10.1016/j.jelekin.2004.10.005)
70. Vinyard CJ, Wall CE, Williams SH, Johnson KR, Hylander WL. 2006 Masseter electromyography during chewing in ring-tailed lemurs (*Lemur catta*). *Am. J. Phys. Anthropol.* **130**, 85–95. (doi:10.1002/ajpa.20307)
71. Konrad P. 2006 *The ABC of EMG*. Scottsdale, AZ: Noraxon. See https://www.noraxon.com/wp-content/uploads/2014/12/ABC-EMG-ISBN.pdf.
72. Hatala KG, Perry DA, Gatesy SM. 2018 A biplanar X-ray approach for studying the 3D dynamics of human track formation. *J. Hum. Evol.* **121**, 104–118. (doi:10.1016/J.JHEVOL.2018.03.006)
73. Lucas PW. 2004 *Dental functional morphology: how teeth work*. Cambridge, UK: Cambridge University Press.
74. Berthaume MA. 2016 Food mechanical properties and dietary ecology. *Am. J. Phys. Anthropol.* **159**, 79–104. (doi:10.1002/ajpa.22903)
75. Peterson J, Dechow PC. 2002 Material properties of the inner and outer cortical tables of the human parietal bone. *Anat. Rec.* **268**, 7–15. (doi:10.1002/ar.10131)
76. Chung DH, Dechow PC. 2011 Elastic anisotropy and off-axis ultrasonic velocity distribution in human cortical bone. *J. Anat.* **218**, 26–39. (doi:10.1111/j.1469-7580.2010.01320.x)
77. Rho J-Y, Kuhn-Spearing L, Zioupos P. 1998 Mechanical properties and the hierarchical structure of bone. *Med. Eng. Phys.* **20**, 92–102. (doi:10.1016/S1350-4533(98)00007-1)
78. Boughton OR, Ma S, Zhao S, Arnold M, Lewis A, Hansen U, Cobb JP, Giuliani F, Abel RL. 2018 Measuring bone stiffness using spherical indentation. *PLoS ONE* **13**, e0200475. (doi:10.1371/journal.pone.0200475)
79. Pringle D, Koob TJ, Kim HKW. 2004 Indentation properties of growing femoral head following ischemic necrosis. *J. Orthop. Res.* **22**, 122–130. (doi:10.1016/S0736-0266(03)00135-9)
80. Currey JD. 2006 *Bones: structure and mechanics*. Princeton, NJ: Princeton University Press. See http://books.google.com/books?hl=en&lr=&id=2jYsJhxiNWQC&pgis=1.
81. Cuy JL, Mann AB, Livi KJ, Teaford MF, Weihs TP. 2002 Nanoindentation mapping of the mechanical properties of human molar tooth enamel. *Arch. Oral Biol.* **47**, 281–291. (doi:10.1016/S0003-9969(02)00006-7)
82. Coats B, Margulies SS. 2006 Material properties of human infant skull and suture at high rates.

J. Neurotrauma **23**, 1222–1232. (doi:10.1089/neu.2006.23.1222)

83. Berthaume MA, Dechow PC, Iriarte-Diaz J, Ross CF, Strait DS, Wang Q, Grosse IR. 2012 Probabilistic finite element analysis of a craniofacial finite element model. *J. Theor. Biol.* **300**, 242–253. (doi:10.1016/j.jtbi.2012.01.031)
84. Gröning F, Fagan M, O'Higgins P. 2012 Modeling the human mandible under masticatory loads: which input variables are important? *Anat. Rec.* **295**, 853–863. (doi:10.1002/ar.22455)
85. Fitton LC, Shi JF, Fagan MJ, O'Higgins P. 2012 Masticatory loadings and cranial deformation in *Macaca fascicularis*: a finite element analysis sensitivity study. *J. Anat.* **221**, 55–68. (doi:10.1111/j.1469-7580.2012.01516.x)
86. Godinho RM, Toro-Ibacache V, Fitton LC, O'Higgins P. 2017 Finite element analysis of the cranium: validity, sensitivity and future directions. *C. R. Palevol* **16**, 600–612. (doi:10.1016/j.crpv.2016.11.002)
87. Shaw CN, Stock JT. 2009 Habitual throwing and swimming correspond with upper limb diaphyseal strength and shape in modern human athletes. *Am. J. Phys. Anthropol.* **140**, 160–172. (doi:10.1002/ajpa.21063)
88. Shaw CN. 2011 Is 'hand preference' coded in the hominin skeleton? An in-vivo study of bilateral morphological variation. *J. Hum. Evol.* **61**, 480–487. (doi:10.1016/j.jhevol.2011.06.004)
89. Shaw CN, Stock JT. 2009 Intensity, repetitiveness, and directionality of habitual adolescent mobility patterns influence the tibial diaphysis morphology of athletes. *Am. J. Phys. Anthropol.* **140**, 149–159. (doi:10.1002/ajpa.21064)
90. Agostini G, Holt BM, Relethford JH. 2018 Bone functional adaptation does not erase neutral evolutionary information. *Am. J. Phys. Anthropol.* **166**, 708–729. (doi:10.1002/ajpa.23460)
91. Kramer PA, Sylvester AD. 2009 Bipedal form and locomotor function: understanding the effects of size and shape on velocity and energetics. *PaleoAnthropology* **2009**, 238–251. (doi:10.4207/PA.2009.ART32)
92. Wang W, Crompton RH, Carey TS, Günther MM, Li Y, Savage R, Sellers WI. 2004 Comparison of inverse-dynamics musculo-skeletal models of AL 288-1 *Australopithecus afarensis* and KNM-WT 15000 *Homo ergaster* to modern humans, with implications for the evolution of bipedalism. *J. Hum. Evol.* **47**, 453–478. (doi:10.1016/j.jhevol.2004.08.007)
93. DeSilva JM, Holt KG, Churchill SE, Carlson KJ, Walker CS, Zipfel B, Berger LR. 2013 The lower limb and mechanics of walking in *Australopithecus sediba*. *Science* **340**, 1232999. (doi:10.1126/science.1232999)
94. Raichlen DA, Armstrong H, Lieberman DE. 2011 Calcaneus length determines running economy: implications for endurance running performance in modern humans and Neandertals. *J. Hum. Evol.* **60**, 299–308. (doi:10.1016/j.jhevol.2010.11.002)
95. Sorrentino R *et al.* 2020 Morphometric analysis of the hominin talus: evolutionary and functional implications. *J. Hum. Evol.* **142**, 102717. (doi:10.1016/j.jhevol.2020.102747)
96. Sellers WI, Cain GM, Wang W, Crompton RH. 2005 Stride lengths, speed and energy costs in walking of *Australopithecus afarensis*: using evolutionary robotics to predict locomotion of early human ancestors. *J. R. Soc. Interface* **2**, 431–441. (doi:10.1098/rsif.2005.0060)
97. Lordkipanidze D, Ponce de Leon MS, Margvelashvili A, Rak Y, Rightmire GP, Vekua A, Zollikofer CPE. 2013 A complete skull from Dmanisi, Georgia, and the evolutionary biology of early homo. *Science* **342**, 326–331. (doi:10.1126/science.1238484)
98. Lieberman D. 2011 *The evolution of the human head*. Cambridge, MA: Harvard University Press. See https://books.google.com/books?hl=en&lr=&id=6d3DSdR7gIC&pgis=1.
99. Lieberman DE. 1996 How and why humans grow thin skulls: experimental evidence for systemic cortical robusticity. *Am. J. Phys. Anthropol.* **101**, 217–236. (doi:10.1002/(SICI)1096-8644(199610)101:2<217::AID-AJPA7>3.0.CO;2-Z)
100. McGraw WS, Daegling DJ. 2020 Diet, feeding behavior, and jaw architecture of Taï monkeys: congruence and chaos in the realm of functional morphology. *Evol. Anthropol.* **29**, 14–28. (doi:10.1002/evan.21799)
101. Grine FE, Daegling DJ. 2017 Functional morphology, biomechanics and the retrodiction of early hominin diets. *C. R. Palevol* **16**, 5. (doi:10.1016/j.crpv.2017.01.005)
102. Strait DS *et al.* 2012 Microwear, mechanics and the feeding adaptations of *Australopithecus africanus*. *J. Hum. Evol.* **62**, 165–168. (doi:10.1016/j.jhevol.2011.10.006)
103. Winchester JM, Boyer DM, St Clair EM, Gosselin-Ildari AD, Cooke SB, Ledogar JA. 2014 Dental topography of platyrrhines and prosimians: convergence and contrasts. *Am. J. Phys. Anthropol.* **153**, 29–44. (doi:10.1002/ajpa.22398)
104. Kay RF, Sheine WS. 1979 On the relationship between chitin particle size and digestibility in the primate *Galago senegalensis*. *Am. J. Phys. Anthropol.* **50**, 301–308. (doi:10.1002/ajpa.1330500303)
105. Sheine WS, Kay RR. 1982 A model for comparison of masticatory effectiveness in primates. *J. Morphol.* **172**, 139–149. (doi:10.1002/jmor.1051720202)
106. Berthaume MA, Dumont ER, Godfrey LR, Grosse IR. 2013 How does tooth cusp radius of curvature affect brittle food item processing? *J. R. Soc. Interface* **10**, 20130240. (doi:10.1098/rsif.2013.0240)
107. Constantino PJ, Bush MB, Barani A, Lawn BR. 2016 On the evolutionary advantage of multi-cusped teeth. *J. R. Soc. Interface* **13**, 20160374. (doi:10.1098/rsif.2016.0374)
108. Weber GW. 2001 Virtual anthropology (VA): a call for Glasnost in paleoanthropology. *Anat. Rec.* **265**, 193–201. (doi:10.1002/ar.1153)
109. Spoor F, Gunz P, Neubauer S, Stelzer S, Scott N, Kwekason A, Dean MC. 2015 Reconstructed *Homo habilis* type OH 7 suggests deep-rooted species diversity in early Homo. *Nature* **519**, 83–86. (doi:10.1038/nature14224)
110. Suwa G, Asfaw B, Kono RT, Kubo D, Lovejoy CO, White TD. 2009 The *Ardipithecus ramidus* skull and its implications for hominid origins. *Science* **326**, 1175825.
111. Villmoare B, Kimbel WH, Seyoum C, Campisano CJ, DiMaggio EN, Rowan J, Braun DR, Arrowsmith JR, Reed KE. 2015 Paleoanthropology. Early Homo at 2.8 Ma from Ledi-Geraru, Afar, Ethiopia. *Science* **347**, 1352–1355. (doi:10.1126/science.aaa1343)
112. Smith ALAL *et al.* 2015 The feeding biomechanics and dietary ecology of *Paranthropus boisei*. *Anat. Rec.* **298**, 145–167. (doi:10.1002/ar.23073)
113. Pampush JD, Daegling DJ. 2016 Symphyseal surface strain during in vitro human mandibular wishboning. *Am. J. Phys. Anthropol.* **159**, 256–266. (doi:10.1002/ajpa.22863)
114. Berthaume M, Grosse IR, Patel ND, Strait DS, Wood S, Richmond BG. 2010 The effect of early hominin occlusal morphology on the fracturing of hard food items. *Anat. Rec.* **293**, 594–606. (doi:10.1002/ar.21130)
115. Bastir M, Garcia-Martínez D, Torres-Tamayo N, Palancar CA, Fernández-Pérez FJ, Riesco-López A, Osborne-Márquez P, Ávila M, López-Gallo P. 2019 Workflows in a Virtual Morphology Lab: 3D scanning, measuring, and printing. *J. Archaeol. Sci.* **97**, 107–134.
116. Fiorenza L, Yong R, Ranjitkar S, Hughes T, Quayle MR, McMenamin PG, Kaidonis J, Townsend GC, Adams JW. 2018 Technical note: The use of 3D printing in dental anthropology collections. *Am. J. Phys. Anthropol.* **167**, 400–406. (doi:10.1002/ajpa.23640)
117. Berthaume MA, Kupczik K. 2021 Molar biomechanical function in South African hominins *Australopithecus africanus* and *Paranthropus robustus*. *Interface Focus* **11**, 20200085. (doi:10.1098/rsfs.2020.0085)
118. Brown AS. 2012 Designing for technology's unknown tribes. *Am. Soc. Mech. Eng.* **134**, 30–35. (doi:10.1115/1.2012-AUG-1)
119. Bell G, Blythe M, Sengers P. 2005 Making by making strange: defamiliarization and the design of domestic technologies. *ACM Trans. Comput. Interaction* **12**, 149–173. (doi:10.1145/1067860.1067862)
120. Gibson MA, Mace R. 2006 An energy-saving development initiative increases birth rate and childhood malnutrition in rural Ethiopia. *PLoS Med.* **3**, e87. (doi:10.1371/journal.pmed.0030087)
121. Gould SJ. 1966 Allometry and size in ontogeny and phylogeny. *Biol. Rev.* **41**, 587–640. (doi:10.1111/j.1469-185X.1966.tb01624.x)
122. Gould SJ, Lewontin R. 1979 The spandrels of San Marco and the Panglossian paradigm: a critique of the adaptationist programme. *Proc. R. Soc. Lond. B* **205**, 581–598. (doi:10.1098/rspb.1979.0086)
123. Sepkoski D. 2012 *Rereading the fossil record*. Chicago, IL: The University of Chicago Press.
124. Weiner S, Traub W, Wagner HD. 1999 Lamellar bone: structure–function relations. *J. Struct. Biol.* **126**, 241–255. (doi:10.1006/JSBI.1999.4107)

125. McNutt EJ, Zipfel B, DeSilva JM. 2018 The evolution of the human foot. *Evol. Anthropol.* **27**, 197–217. (doi:10.1002/evan.21713)
126. Addison BJ, Lieberman DE. 2015 Tradeoffs between impact loading rate, vertical impulse and effective mass for walkers and heel strike runners wearing footwear of varying stiffness. *J. Biomech.* **48**, 1318–1324. (doi:10.1016/j.jbiomech.2015.01.029)
127. Lieberman DE, Venkadesan M, Werbel WA, Daoud AI, D'Andrea S, Davis IS, Mang'Eni RO, Pitsiladis Y. 2010 Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature* **463**, 531–536. (doi:10.1038/nature08723)
128. Halsne EG, Czerniecki JM, Shofer JB, Morgenroth DC. 2020 The effect of prosthetic foot stiffness on foot-ankle biomechanics and relative foot stiffness perception in people with transtibial amputation. *Clin. Biomech.* **80**, 105141. (doi:10.1016/j.clinbiomech.2020.105141)
129. Gould SJ, Vrba ES. 1982 Exaptation—a missing term in the science of form. *Paleobiology* **8**, 4–15. (doi:10.1017/S0094837300004310)
130. Lasisi T, Smallcombe J, Shriver MD, Kenney WL, Havenith G, Jablonski NG. 2020 Hair fiber morphology and function: at the intersection of anthropology, physiology, and engineering. *Fed. Am. Soc. Exp. Biol.* **34**, 1.
131. Campbell LM. 2005 Overcoming obstacles to interdisciplinary research. *Conserv. Biol.* **19**, 574–577. (doi:10.1111/j.1523-1739.2005.00058.x)
132. Rylance R. 2015 Grant giving: global funders to focus on interdisciplinarity. *Nature* **525**, 313–315. (doi:10.1038/525313a)
133. Porter AL, Rossini FA. 1985 Peer review of interdisciplinary research proposals. *Sci. Technol. Hum. Values* **10**, 33–38. (doi:10.1177/016224398501000304)
134. Dominy NJ, Mills ST, Yakacki CM, Roscoe PB, Carpenter RD. 2018 New Guinea bone daggers were engineered to preserve social prestige. *R. Soc. Open Sci.* **5**, 172067. (doi:10.1098/rsos.172067)
135. Porter AL, Roessner JD, Cohen AS, Perreault M. 2006 Interdisciplinary research: meaning, metrics and nurture. *Res. Eval.* **15**, 187–196. (doi:10.3152/147154406781775841)
136. Rhoten D, Parker A. 2004 Risks and rewards of an interdisciplinary research path. *Science* **306**, 1103628. (doi:10.1126/science.1103628)
137. Rhoten D. 2004 Interdisciplinary research: trend or transition. *Items Issues* **5**, 6–11.
138. Van Noorden R. 2015 Interdisciplinary research by the numbers. An analysis reveals the extent and impact of research that bridges disciplines. *Nature* **525**, 306–307. (doi:10.1038/525306a)
139. Bromham L, Dinnage R, Hua X. 2016 Interdisciplinary research has consistently lower funding success. *Nature* **534**, 684–687. (doi:10.1038/nature18315)
140. Viseu A. 2015 Integration of social science into research is crucial. *Nature* **525**, 291. (doi:10.1038/525291a)
141. Seron C, Silbey SS, Cech E, Rubineau B. 2016 Persistence is cultural: professional socialization and the reproduction of sex segregation. *Work Occup.* **42**, 178–214. (doi:10.1177/0730888415618728)
142. Mitchneck B, Smith JL, Latimer M. 2016 A recipe for change: creating a more inclusive academy. *Science* **352**, 148–149. (doi:10.1126/science.aad8493)

The Hourglass Structure of a Typical Scientific Research Paper

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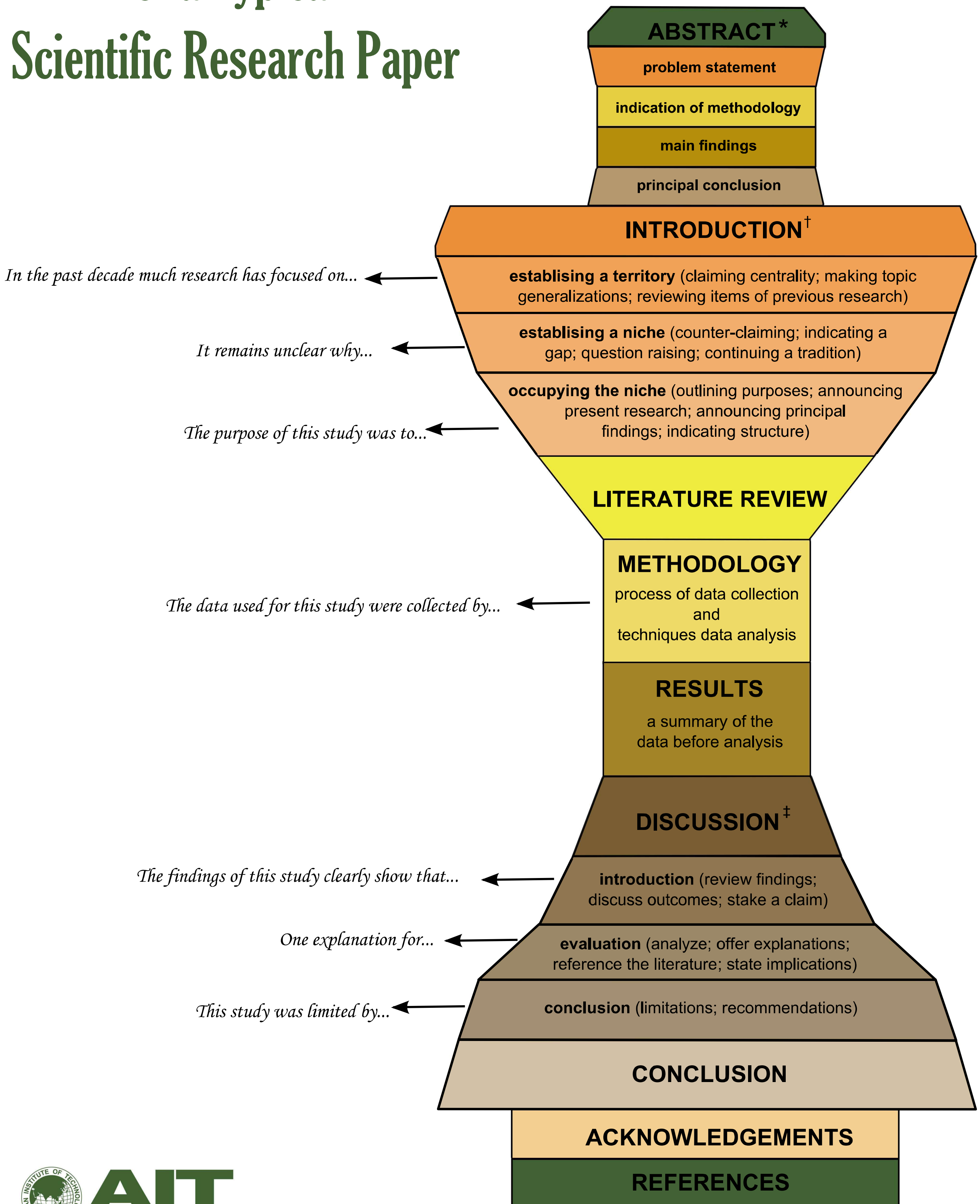

Asian Institute of Technology

* Bhatia, V.K. (1993). *Analysing genre: Language use in professional settings.* New York; Longman.

Derntl, M. (2003). Basics of research paper writing and publishing, Technical report, Department of Computer Science and Business Informatics, University of Vienna.

Gustavii, B. (2008). *How to write and illustrate a scientific paper* (2nd ed.). Cambridge: Cambridge University Press.

Shaw, M. (2003). Writing good software engineering research papers: minitutorial. In *ICSE '03: Proceedings of the 25th International Conference on Software Engineering,* 726-736, Washington, DC, USA. IEEE Computer Society.

† Swales, J.M. (1990). *Genre analysis: English in academic and research settings.* Cambridge: Cambridge University Press.

‡ Day, R.A. (1988). *How to write and publish a scientific paper* (3rd ed.). Cambridge: Cambridge University Press.

Goldbort, R. (2006). *Writing for science.* London: Yale University Press.

Katz, M.J. (2006). *From research to manuscript: A guide to scientific writing.* Dordrecht, The Netherlands: Springer.

Peacock, M. (2002). Communicative moves in the discussion section of research articles. *System, 30*(4): 479-497. Retrieved on October 25, 2010, from doi: 10.1016/S0346-251X(02)00050-7.

Yang, J.T. (1995). *An outline of scientific writing: For researchers with English as a foreign language*. Singapore: World Scientific.

Damping mechanisms in a tip-mass piezoelectric cantilever system

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(Dated:)

Here we characterize the damping response from a commercial piezoelectric transducer when it is subjected to free-vibrations. The problem under study is an electromechanical problem and hence a combination of dimensionless parameters including the natural frequency of the system, are used to study and understand the damping characteristics of the tip-mass-piezoelectric system. Rectangular prisms with varying aspect ratios(0.5-3.0) are loaded onto two flexible piezoelectric transducers rendering the setup to resemble a cantilever tip-mass system.To directly visualize the effect of tip displacement on the voltage generated, high-speed imaging studies of the cantilever are performed in addition to separate measurements of the voltage response using an oscilloscope. In this paper, we will discuss how these results can further studies into the development of efficient energy harvesters.

PACS numbers:

In this manuscript we present experimental and computational data for the free vibrations of a tip-mass piezoelectric cantilever system. Here we are interested in developing robust dynamic models that may be used as a test bed for understanding control of dynamic behavior that arises in these types of complex systems [1–7]. The Euler-Bernoulli equations with coupled linear piezoelectric deformation equations govern the cantilever's displacement in the small amplitude vibration limit. These equations were developed in other publications for the purpose of single mode vibration analysis [1]. Here, we utilize those equations through a slight modification to study the small amplitude vibration of a damped cantilever with a mass at the tip undergoing free-vibration. The system yields fully-transient dynamics, and understanding the role that damping can play in generating power from these piezo-electric systems is of interests. It has been shown that adding a mass (vibration inducing body) at the tip of piezoelectric cantilevers results in a tremendous increase in the efficiency of energy harvesters [8].

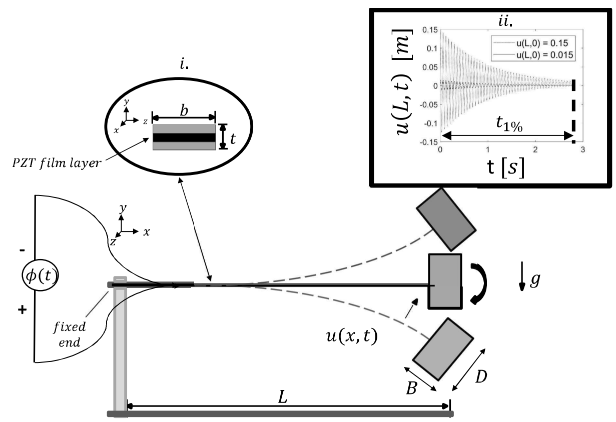


FIG. 1: Problem schematic. *i* PZT layer cross section. *ii* Plot of displacement versus time for 2 initial displacements of a damped Euler-Bernoulli cantilever with $\pi_4 = 4$. Both attenuate to 1% of that initial displacement at the same elapsed time.

Consider a flexible cantilever made of laminated polymer piezo-electric material such that the piezo-electric material lies along the cantilever's neutral axis. We seek to study unsteady motion of this cantilever along its transverse axis assuming displacements with the generic form $u(x,t)$. The other variables are cantilever composite density, ρ, composite cross sectional area, $A = t_c L$, composite elastic modulus, E, and composite area moment of inertia, I. We include net external (linear viscous, μ_1), and internal (Kelvin-Voigt, μ_2) damping [9] for a homogeneous cantilever. The relevant electrical properties are the piezoelectric film capacitance C_f, the film resistance R_f, and the electro-mechanical coupling term $\alpha = d_{31} E_p h_{pc} b$ where d_{31} is the strain per electric field coincident with the direction of axial strain (1) and polarization (3); E_p is the piezoelectric elastic modulus; h_{pc} is the distance of piezoelectric center to the neutral axis and b is the beam width. Attached to the cantilever's tip is a mass m_T with cross-section long dimension B and height D. The cantilever with tip-mass natural frequency is denoted ω_N, and natural frequency (first mode vibration) in the absence of the tip-mass $m_T = 0$ is denoted ω_{N_0}. Figure 1 shows a schematic of the problem proposed in this study where the neutral axis is positioned with its length along the x-axis.

In Ref. [1] the authors develop equations of motion for a piezoelectric material placed along the neutral axis of a cantilever for the problem of base excitation (forced vibration). The equation set consisted of coupled Euler-Bernoulli beam equation and an integrated electric displacement equation that results in a two component current conservation equation. Coupling was achieved by considering the composite cantilever's total internal moment as the sum of a bending stiffness moment, and a moment generated from the product of an induced voltage potential, ϕ, and the E-M coupling term α. An unsteady voltage was considered uniform over the length spanning the piezoelectric material, therefore the coupling appears through boundary conditions (although the authors in Ref. [1] use Heaviside functions to include the E-M coupling moment in the main equation in order to perform a modal analysis through separation of variables).

Here, the same equations of motion are made dimensionless by scaling lengths with the non-deformed cantilever length L and time with the frequency $\omega = \sqrt{EI/\rho AL^4}$ (note that ω_{N_0} is proportional to ω [10, 11]). The resulting dimensionless independent and dependent variables are $u^* = u/L$, $x^* = x/L$, $v^* = v/(\omega L)$, $\phi^* = \phi C_f/\alpha$ and $t^* = \omega t$; and the dimensionless form of the coupled Euler-Bernoulli and electric current conservation equations are

$$\frac{\partial u^*}{\partial t^*} = v^* \tag{1}$$

$$\frac{\partial v^*}{\partial t^*} = -\pi_1 v^* - \pi_2 \frac{\partial^4 v^*}{\partial x^{4*}} - \frac{\partial^4 u^*}{\partial x^{4*}} \tag{2}$$

$$\frac{\partial \phi^*}{\partial t^*} = \pi_3 \phi^* - \int_0^1 \frac{\partial^2 v^*}{\partial x^{2*}} dx^{\cdot} \tag{3}$$

Solutions for the linear PDE can be found by using the boundary conditions for a cantilever with E-M coupling and a tip-mass [9], where at $x^* = 0$ we apply a fixed and symmetry condition:

$$u^*(0, t^*) = 0 \tag{4a}$$

$$\frac{\partial u^*}{\partial x^*} = 0 \tag{4b}$$

and at $x^* = 1$ we apply conservation of moments and force, respectively,

$$\frac{\partial^2 u^*}{\partial x^{2*}} + \pi_2 \frac{\partial^2 v^*}{\partial x^{2*}} = \pi_4 \frac{\partial^2 v^*}{\partial t^* \partial x^*} - \pi_5 \phi^* \tag{5a}$$

$$\frac{\partial^3 u^*}{\partial x^{3*}} + \pi_2 \frac{\partial^3 v^*}{\partial x^{3*}} = \pi_4 \frac{\partial v^*}{\partial t^*}. \tag{5b}$$

Notice we include the rotatory inertia term in the tip-moment conservation equation. The dimensionless variables are defined

$$\pi_1 = \frac{\mu_1}{\rho A \omega}, \quad \pi_2 = \frac{\mu_2 \omega}{E}, \quad \pi_3 = \frac{1}{C_f R_f \omega}, \tag{6}$$

$$\pi_4 = \frac{m_T}{m}, \quad \text{and} \quad \pi_5 = \frac{\alpha^2 L}{C_f EI}. \tag{7}$$

The dimensionless parameters represent: dimensionless viscous μ_1 and Kelvin-Voigt μ_2 damping coefficients, dimensionless inverse piezoelectric film resistance R_f, dimensionless tip-mass m_T and a dimensionless E-M coupling α.

Spatial derivatives in (1)-(3) and first derivative boundary condition in (5) were discretized using 4^{th} order accurate finite differences [12]. The tip-momentum and force conservation boundary conditions required much higher order accuracy (7^{th} order accuracy) to ensure unique solutions for the 5^{th} order spatial derivatives that appear after substitution of Eq. (2) into (6). The integral in (3) was computed using a trapezoidal rule. The equations were advanced in time using an adaptive 4^{th} order accurate Runge-Kutta-Merson (RKM) time stepping algorithm [13]. There were $n = 50$ interior grid points. The precision was set to 1×10^{-8} for all of the data presented here. The algorithm was written and implemented using an in-house code written in Fortran programming language.

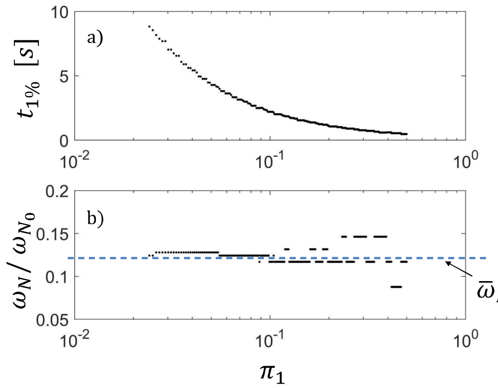


FIG. 2: Plot of a) $t_{1\%}$ and, b) natural frequency ω_N normalized by natural frequency for $\pi_4 = 0$ i.e. ω_{N_0}, with both plotted versus dimensionless viscous damping coefficient π_1 ($\pi_2 = 0$). A value of $\pi_4 = 4$ and $\omega \approx 120$ Hz was used for these calculations.

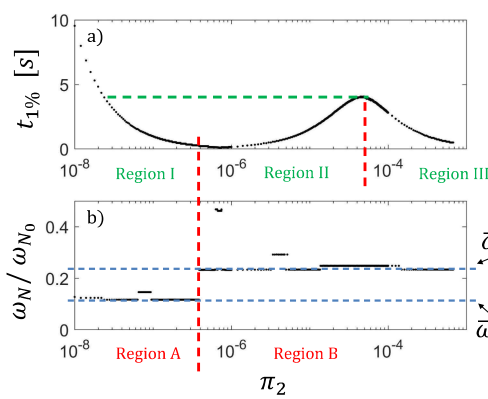


FIG. 3: Plot of a) $t_{1\%}$ and, b) natural frequency ω_N normalized by natural frequency for $\pi_4 = 0$ i.e. ω_{N_0}, with both plotted versus dimensionless viscous damping coefficient π_2 ($\pi_1 = 0$). A value of $\pi_4 = 4$ and $\omega \approx 120$ Hz was used for these calculations.

Solutions to the set of equations can be used to estimate the unknown damping coefficients μ_1 or μ_2 for a cantilever undergoing free-vibration [14]. We are assuming that the damping coefficient is independent of any external forcing and does not vary with time. To estimate the coefficients we keep in mind that any displacement of the beam from its initial position should result in an underdamped system. In Fig. 1, with $\pi_4 = 4$ and $\pi_2 = 0.0001$ we show a solution to the governing equations for the problem of free-vibration that resulted in an underdamped system. Notice that for 2 different initial conditions, $u(L, 0) = 0.15$ and 0.015 m, and with all other parameters being equal (including dimensionless frequency $\omega = 120$ Hz), that the two underdamped systems reach 1% of their initial displacement at the same time, denoted $t_{1\%}$. The value 1% is not unique, and any fraction below 40% appears to follow the same trend; though, there was noticeable difference in the normalized natural frequency that is measured as we computed the 1% times. Here, in Figs. 2(a)-3(a) we show the computed normalized $t_{1\%}$ for $0.02 < \pi_1 < 0.5$ with $\pi_2 = 0$ and $1 \times 10^{-8} < \pi_2 < 7 \times 10^{-4}$ with $\pi_1 = 0$, respectively. In Fig. 2(a) the data asymptotes to zero as the dimensionless damping coefficient is increased, but in Fig. 3(a) the initial $t_{1\%}$ values asymptote to zero then increase to a local maximum before another asymptote to zero, forming 3 regions I, II and III. This computational result suggests for systems where internal damping is present at least 3 values of π_2 can exist if $t_{1\%}$ is less than the value of the local maximum (horizontal dashed line). In

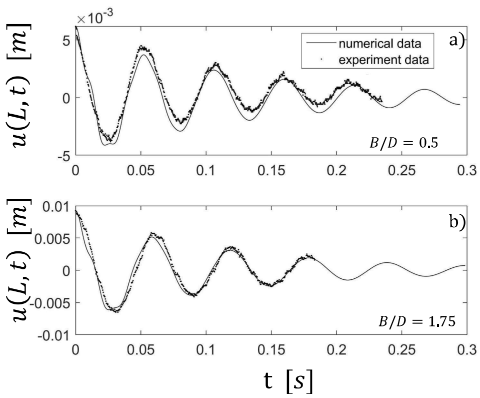


FIG. 4: Plots of free-vibration tip displacement of a PZT cantilever and tip-mass system. The experiment parameters were a) $B/D = 0.5$, $\pi_4 = 3.0$, and b) $B/D = 1.75$, $\pi_4 = 2.45$ with measured natural frequencies $\omega_N =$ a) 20.2 and b) 18.8 Hz. Also shown in each plot are results from computation using the same parameters with $\pi_1 = 0$, $\pi_2 =$ a) 8.33×10^{-8} and b) 1.1×10^{-7}.

Figs. 2(b)-3(b) we show the corresponding normalized natural frequencies for the same range of dimensionless damping coefficients as in 2(a)-3(a). In Fig. 2(b) there is a narrow range of values that span the data with the average $\bar{\omega}_N \approx 0.12$. In Fig. 3(b) there are 2 average values: the first is computed for π_2 values less than the first asymptotes minimum (Region A), and the second for the values greater than this first asymptote where the normalized frequency shifts to a higher value (Region B). Now we can estimate the damping coefficient by comparing the transient maximum displacement of the cantilever $u^*(1, t^*)$ between numerical and experimental data for a given value of dimensionless μ_1 and/or μ_2, along with similar dimensionless tip-mass π_4, and dimensionless E-M terms π_3 and π_5.

Piezoelectric cantilevers (TE Connectivity) with dimension of $41 \times 17 \times 0.2$ mm^3 (i.e. $w = 17$ mm, $t = 0.2$ mm), resistance $R_f = 1\times10^{-7}$ Ohms, capacitance $C_f = 1.38\times10^{-9}$ F and $\alpha = 1.7\times10^{-8}$ N/V (Newtons per Volt) were used for experiments. The other properties, for the composite structure, we estimated as $E = 3\times10^{-9}$ (an average value) and $\rho = 1800$ kg/m^3. The experimental setup consisted of two acrylic bridges made of 60 mm high and 12 mm thick vertical posts supported by a 19.0 mm thick base, erected inside an open circuit wind tunnel. The distance between the two bridges was 115 mm. Two piezoelectric strips were mounted individually on an acrylic cube ($13 \times 13 \times 13$ mm^3), and the cube was bolted to the vertical posts. Thus, the piezoelectric cantilevers possess 1-DOF and vibrate along their transverse direction. The approximate cantilever length measured from acrylic cube to mass-free tip that was free to vibrate was $L = 25$ mm, although this length may need to be adjusted when computing natural frequency since the attached tip-mass can reduce this value. With this length the corresponding electrical dimensionless parameter are $\pi_3 \approx 0.31$ with $\omega \approx 120$ Hz and $\pi_5 \approx 1.5 \times 10^{-4}$. A decrease in the vibration length L results in an increased ω and smaller π_3 and slightly larger π_5.

We used tip masses in the form of rectangular prisms made of dense tear-resistant foam sheet (McMaster-Carr) loaded onto the piezoelectric films. Two thicknesses, 12.7 mm and 19.0 mm, were used for the models. To attach the prisms onto the PZT cantilevers, slits 16 mm wide with negligible thickness were laser cut (Epilog) on the test pieces. However, for a select few, a razor blade was used to make slits on the rectangle's short face because the short face was prone to laser burns. A total of 11 test pieces with B-by-D (B/D) ratios ranging from 0.5 to 3.0 were made and were loaded onto the piezoelectric cantilevers, resulting in dimensionless mass ratios $2 < \pi_4 < 5$. In a separate set of experiments, an oscilloscope (Model DSO1024A, Keysight Technologies) was used to record the piezo films' voltage-time data. The oscilloscope possesses a maximum bandwidth of 200 MHz and a sampling size of 2 GSa/s.

The natural frequency was found experimentally for all the B/D ratios by exciting the tip-mass cantilever systems with small displacements. Vibrations of the cantilever tip were captured by a fast camera (Hotshot) at roughly 2000 frames per second, fit with a macro lens (Computar), and in a 500×500 pixels window (pixel window and frames per second were subject to change for specific experiments as needed). A fluorescent lamp in line with the camera was placed behind the setup. The experiments were carried out in air at standard ambient temperature and pressure. An in-house MATLAB code extracted frame by frame displacement versus time data. Figure 4 shows a plot comparing the experimental

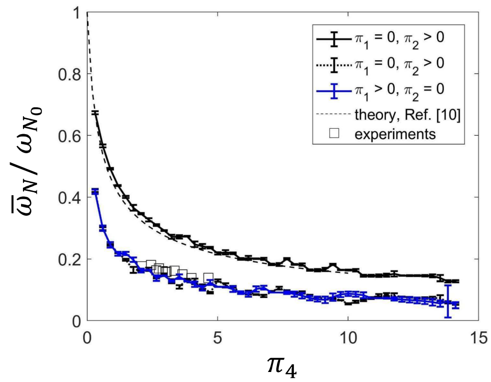


FIG. 5: Plot of normalized averaged natural frequency $\bar{\omega}_N/\omega_{N_0}$ versus dimensionless tip-mass π_4. Data is shown for $\pi_1 = 0$ and $\pi_2 > 0$ averaged at high and low values; $\pi_1 > 0$ with $\pi_2 = 0$; theoretical results for no damping and no rotatory motion of the tip-mass [10]; and measured values from experiments.

and numerical free-end underdamped vibrations of the flexible PZT cantilever tip-mass system versus elapsed time. Similar plots were utilized to estimate the appropriate damping coefficient of a particular system. First, the length L was slightly adjusted until the computed and experimentally measured natural frequency values matched, which resulted in peaks and troughs that were in near-perfect alignment. This required adjustment is not surprising for data where $B/D > 1$ since the reduced length from attaching the tip-mass should affect the natural frequency (See Supplemental Material for more information). A plot of the computed normalized averaged natural frequency $\bar{\omega}_N/\omega_{N_0}$ versus dimensionless tip-mass π_4 appears in Fig. 5. Data is shown for $\pi_1 = 0$ and $\pi_2 > 0$ averaged at high and low values (See Fig. 3), $\pi_1 > 0$ with $\pi_2 = 0$, theoretical results for no damping and no rotatory tip-mass [10], and measured values from experiments. The experiments all fall along the line corresponding to results for viscous and low frequency Kelvin-Voigt damping.

A comparison between maximum voltage $\max|\phi|$ versus initial cantilever displacement appears in Fig. 6. Data is shown comparing values for maximum voltage measured with the oscilloscope and computed. The vertical line corresponds to approximate maximum displacement where computation with Euler-Bernoulli equation is not valid. Although the data is not exact the trends appear similar between the two data sets. This seems to confirm that there is good agreement between the computation and experiments for the range of parameters where the experiments should overlap with the computation. Overall, the results provide a means to estimate damping coefficients that are present in these type of systems.

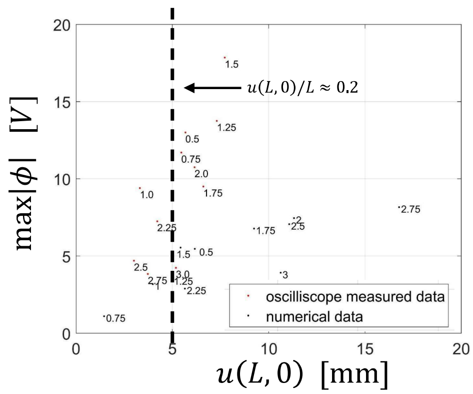


FIG. 6: Plot of maximum voltage $\max|\phi|$ versus initial cantilever displacement. Data is shown for both measured values (oscilloscope) and computed (solutions to governing equations). Note: initial conditions used for computation were randomly selected. Vertical line corresponds to approximate maximum displacement where computation with Euler-Bernoulli equation is not valid.

[1] A. Erturk, D. J. Inman, J. Vibr. Acoust. 130 041002 (2008).
[2] D. Zhu, M. J. Tudor, S. P. Beeby, Meas. Sci. Technol. 21 022001 (2010).
[3] I. Mehdipour, A. Barari, G. Domairry, Computational Materials Science 50, 1830–1833 (2011).
[4] L. Zhao, L. Tang, Y. Yang, Smart Mater. Struct. 22, 125003 (2003).
[5] H. Wang, Q. Meng, Mechanical Systems and Signal Processing 36, 193–209 (2013).
[6] R. L. Harne, C. Zhang, B. Li, K. W. Wang, J. Sound Vib. 373, 206–222 (2016).
[7] M. Zhang, J. Wang, Journal of Sensors 2016, 2673292 (2016).
[8] H. D. Akaydin, N. Elvin, Y. Andreopoulos, Smart Mater. Struct. 21(2), 025007 (2012).
[9] H. T. Banks, D. J. Inman, Trans. ASME 58, 716–723 (1991).
[10] P. A. A. Laura, J. L. Pombo, E. A. Susemihl, J. Sound Vib. 37(2), 161–168 (1974).
[11] S. Lenci, F. Clementi, J. Sound Vib. 331 5247–5267 (2012)
[12] S. Madanu, T. Ward, Chaos 26(6) 063113 (2016).
[13] J. H. Ferziger, *Numerical Methods for Engineering Application*, 2nd ed. (Wiley, New York, 1998).
[14] V. Sajjanapu, T. Ward, J. Fluid Struct. 102, 100290 (2021).

Strategies for writing a research paper

Estratégias para escrever um artigo de investigação

1. Introduction

Writing and publishing good research papers is essential for many reasons: not only advancing researchers' academic careers but above all for disseminating research findings and advancing the state of empirical knowledge. In addition, publications are a measure of the academic productivity needed for promotion. Another reason is that most researchers become experts in a given research area, and they are recognised as such by their peers when they contribute actively to the literature, helping to advance the state of empirical knowledge (El-Serag, 2006).

Research is not complete until results have been published, especially in the case of publicly funded research (Audisio et al., 2009; Davidson & Delbridge, 2011). Conversely, a track record of prior publications is essential for any competitive grant application (El-Serag, 2006).

Publishing the best possible research papers is also the main goal of journal editors, who value papers of interest to their readership that show originality, importance, clear research questions, correct methods and excellent style (Johnson, 2008). When evaluating your research, editors consider whether your paper, if published in their journal, is likely to be heavily cited, thus enhancing the standing and reputation of their journal (Davidson & Delbridge, 2011). Editors and reviewers spend hours reading manuscripts and greatly appreciate receiving papers that are easy to read and edit. They dislike long, wordy papers in a poor style with conclusions not justified by data, showing an inability to follow the 'authors' guidelines' and containing careless, sloppy mistakes (Johnson, 2008).

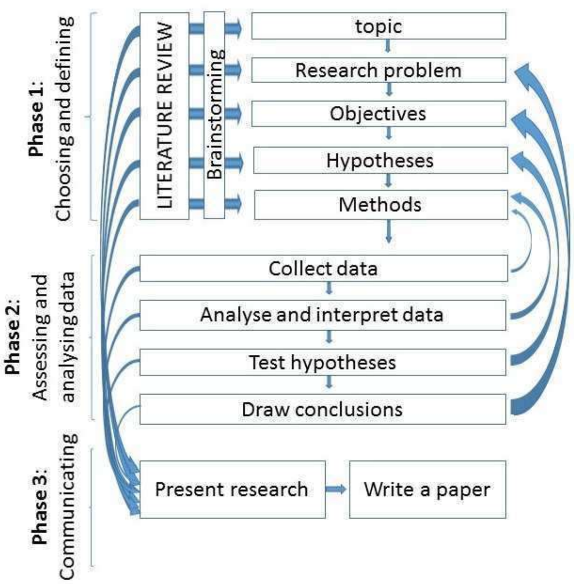
In point of fact, most submitted papers need substantial improvements before they can be published, and, unfortunately, many of them get rejected because they do not fulfil basic conditions for publication. Therefore, this paper seeks to provide some basic strategies for writing research papers and help especially novel researchers to improve papers before submitting them to journals. Sharing thoughts and experiences is the very essence of academic activities, and this can be quite rewarding if it substantially contributes to improving researchers' chances of publishing results.

2. The research process

A paper is the outcome of three different processes: research, writing and publication. Although this paper focuses on the writing process, it is important to understand the processes that you need to follow before and after writing. A good paper is the outcome of well-conducted research, careful writing and successful publication processes.

The research process is, in most cases, the implementation of a previously designed research plan. As shown in Figure 1, the research process is divided into three phases, each one comprising several steps. Phase one, choosing and defining, is theoretical or conceptual and based on a literature review. In this phase, you choose and define the fundamentals of your research: topic, research problem, objectives, hypotheses and methods. Much search, brainstorming and adaptation may be necessary during this phase. Regardless, you should not go on to the next phase – for instance, collecting data – before making the right decisions regarding research problem, objectives, hypotheses and methods.

Figure 1 - The research process



Source: Own elaboration.

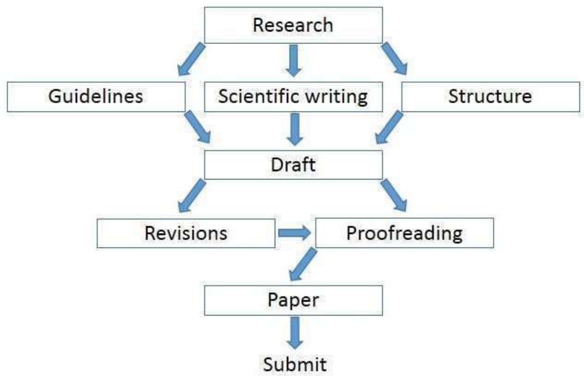
Phase two, assessing and analysing data, is empirical, as well as analytical, and it deals with data collection, processing, analysis and interpretation. Hypotheses are tested, and conclusions are drawn in order to address the research problem and objectives of the study.

Phase three deals with 'communicating' your research. This is the time to communicate your findings to the research community. There are several ways of doing this, including writing a report, making a presentation in a conference or writing a paper.

3. The writing process

Ideally, you should start the writing process as a logical consequence of the research process. As a matter of course, during the research process, you produce drafts of your research methodology and findings that you now need to transform into a paper. The following sections provide some strategies that may help you to convert your research into a well-written and appropriately structured paper. Figure 2 shows a chart of this process.

Figure 2 - The writing process



Source: Own elaboration.

3.1 Follow the journal's guidelines

It is strongly advised that, before you start writing your paper, you decide which is your target journal (Rosenfeldt, Dowling, Pepe & Fullerton, 2000; Johnson, 2011; Saper, 2014). Then read carefully the 'journal guidelines' or 'authors' guidelines' provided by that journal (Chiswick, 2004; Johnson, 2008; Davidson & Delbridge, 2011). The reason for this is that you need to adapt your paper to the journal guidelines from the very beginning because these deal with content and form, therefore affecting the entire paper and making it a difficult task to adapt to the journal's norms after the paper is written. By following guidelines appropriate to your type of study, you are likely to improve your paper and thus increase your chances of being published (Davidson & Delbridge, 2011). On the contrary, submitting papers without following journal guidelines dramatically increases the possibility of rejection.

Besides following the guidelines closely, reading some papers in your target journal also gives you an idea of the structure, norms and general organisation of papers approved for that journal. Another advantage is to identify the research interests of editors and the research areas of recently approved papers (Saper, 2014).

In the case of the *Tourism & Management Studies* journal the guidelines provide information about length of papers (6,000 words), abstracts (150 words) and keywords (5 words), as well as structure (introduction, methodology, results, discussion, conclusions and references), citation style and organisation of the list of references (APA style).

3.2 Use an adequate paper structure

An appropriate paper structure is a fundamental tool for developing and presenting research, and it makes it easier for readers to understand the content of papers. This can vary in small ways depending on the research field and journal guidelines, but it is commonly accepted that research papers should have a title, abstract and keywords and be divided into sections, including introduction, methods, results and discussion, conclusions and references (Rosenfeldt et al., 2000; Chiswick, 2004; Børresen, 2013). *Tourism & Management Studies*' editors prefer to include results and discussion in the same section. There must be a logical and understandable link between sections (Chiswick, 2004; Andonie & Dzitac, 2010) in such a way that all sections – as indispensable parts of the whole – communicate with each other and contribute to the unity and internal consistency of the paper. A logical flow must exist not only from section to section but also from paragraph to paragraph and from sentence to sentence (Andonie & Dzitac, 2010). Each element of a paper's structure is analysed and discussed below.

3.2.1 Title

According to El-Serag (2006), 'The title should be informative and specific to the study, and should contain key elements that advertise the paper's contents. The use of subtitles allows the insertion of additional information' (p. 20). Choosing a good title and subtitle is fundamental for a paper's success, as they are the first elements to catch the attention of editors and readers, and they tell them what the paper is all about. This first contact with the topic of the paper determines if the paper falls within the scope of the journal or the readers' interests, and it is decisive in their immediate decision to dedicate some time to exploring or reading it. Through the title and subtitle, it is also possible to deduce what type of paper it is and whether its topic is attractive to a broad audience, for instance, if it is a theoretical paper, an empirical or theoretical and empirical paper or a case study. Purely theoretical papers have a higher rejection rate, unless the authors truly innovate and firmly ground their theories. Quite often, case studies have an extremely high rejection rate because they have validity only within restricted contexts, and they are not attractive enough to reach a broad, international audience.

Titles (and subtitles) should address the content of the paper and be short, simple, easy to understand and attractive to the paper's audience. It is important that titles contain some strong keywords dealing with the content of the papers, to ensure that the titles are detected by fellow researchers searching literature databases (Davidson & Delbridge, 2011).

3.2.2 Affiliation

Next follows the affiliation of all authors. Journals have different requirements regarding the affiliation, but authors' names, universities and faculties or schools, countries and e-mails are common. Some journals also demand degrees and telephone and fax numbers of authors. In the case of the *Tourism & Management Studies* journal, the information regarding affiliation should be as follows for each author: name, university, faculty or school, department/research centre, postal code, city, country and e-mail address. In the case of the corresponding author, the complete mail address must be added.

The inclusion of this information is extremely important for the indexation process of the SciELO Citation Index/Web of Science, including the attribution of empirical production to the correct institutions, research centres and countries of publication. For publication purposes, authors need to use always exactly the same name without any variations from paper to paper, otherwise the indexing machines will treat these as different names (even with the slightest variation) belonging to different authors. The same applies to the names of institutions.

Authors should submit two versions of their paper: a DV version (director version) with the full affiliation of authors and an RV version (review version) without the affiliation or any other information regarding the authors. Make sure that direct identifiers are removed from the data (Davidson & Delbridge, 2011) and properties of the Word document. This is important for the implementation of blind refereeing, which obviously means the authors must be kept anonymous.

Concerning research, teamwork is preferable to individual work, and journals usually prefer papers with multiple authors, especially teams involving different nationalities.

3.2.3 Abstract

The function of the abstract is to give a quick overview of the contents of the paper. The abstract is the only part of the manuscript read by the vast majority of readers (El-Serag, 2006; Audisio et al., 2009; Shidham, Path, Pitman & DeMay, 2012), and, through it, the reader decides if it is worth reading the entire paper. According to Andonie and Dzitac (2010), an abstract should be concise and include motivation, problem statement, approach, results and conclusions. In the *Tourism & Management Studies* editors' view, objectives also need to be stated clearly, and all key information must be included. For Johnson (2008), an abstract should be structured per the specific journal's format within the word limit, without acronyms and abbreviations. The word limit for abstracts varies from journal to journal, usually from 150 to 250 words, so it is important to adapt the abstract to the target journal's guidelines for structure and length.

Together with the title and keywords, the abstract should be written last to make sure that it includes the most important aspects of the study. These three parts of the paper are strongly interconnected, and they reflect the ability of the researchers to concentrate the key aspects of their study into a limited number of words.

3.2.4 Keywords

Keywords are usually limited to five basic pieces of information containing one or more words, and they need to be carefully chosen in order to include the very essence of the paper. Keywords are fundamental elements for the dissemination of your research, as strong keywords enhance the likelihood that your paper will be retrieved by a search engine out of the huge number of published papers, when someone searches for a specific topic using a keyword (Audisio et al., 2009).

3.2.5 Introduction

Some authors write the introduction at an early stage as a guideline to the further development of the paper. In this case, they need to review this section and make all necessary changes when the rest of the paper is ready. Others prefer to write the introduction in the final stages of the paper. Davidson and Delbridge (2011) succinctly explain some of the most important aspects of this section:

> The purpose of the introduction is to explain to the reader what the research question is, how it is original, how it is important and succinctly outline how the study intends to answer it. It is critical that the paper starts with a brief introduction to the topic, which clearly describes how and why the research question has arisen. Provide adequate background information using relevant literature to acquaint readers with the topic but do not include a detailed literature review. Explicitly state the importance of your research as the reader may not necessarily make the leap in logic that is obvious to you. The introduction should end with the aims being clearly stated. If the study is addressing a hypothesis, then the hypothesis should be stated here too (pp. 62–63).

This quotation contains all the basic elements of the introduction, of which the most important are contextualisation, originality, research question, importance of research, objectives and hypotheses. The originality, or 'How does your research add to the literature?' (Audisio et al., 2009), is fundamental, as in most cases it determines if your paper is worth sending on to be reviewed or not. It can be seen as the added value that your paper brings to the stock of knowledge in a given research field. The research question – which, in the opinion of Davidson and Delbridge (2011), constitutes the core of the paper – needs to be formulated in the introduction and must be robust and well defined (Davidson & Delbridge, 2011).

As the introduction is critical to attracting the readers' attention, it should consist of short sentences (Shidham et al., 2012) and be brief, coherent, logical and stimulating – but not confusing to the reader – as well as creating a receptive mood (Chiswick, 2004). Concerning length, a typical introduction does not exceed one or two pages.

3.2.6 Literature review

Reviewing what others have written on your topic is a fundamental step in any research, and it serves a number of purposes:

- Identifying what has already been done and has contributed significantly to your topic;
- Identifying what still needs to be done in order to justify the originality and importance of your research;
- Establishing links between your research and the most relevant research on the topic (i.e. by comparing your study to previous research, you can point out similarities and contradictions);
- Defining relevant concepts for your study;
- Identifying relevant theories, research designs, approaches and methods used in the study of similar research problems that can be appropriate for your study.

The literature review needs to be the first step of your research because, without it, you cannot prove the originality and appropriateness of your study. However, one thing is reviewing the literature for an academic dissertation and another is presenting a literature review in a paper. In the latter case, it must be brief and contain only the most relevant references, especially the most updated ones – to satisfy some or all purposes mentioned above.

Sometimes a paper is based on a research project (for instance a dissertation) finished some years ago, and it does not use references from the last three or four years. Of course, depending on the research area, references thus are outdated, which is a possible reason for rejection. To avoid this situation, you must update your references before submitting your paper.

3.2.7 Methods

This is the most important section of any research paper because it determines the empirical validity of the study. Methodologies need to explain how results were obtained, and they should allow a researcher in that field to repeat the study (Saper, 2014).

Editors or reviewers reject papers when they consider that the research methods used are not appropriate or not strong enough. For the *Tourism & Management Studies* journal, methodologies are given first-class status, and any paper is rejected that does not use proper methods (at least in the reviewers and editors' opinion) in answering the research question and accomplishing its objectives. While there may be an opportunity to re-analyse the results, perhaps using more appropriate statistical tests, the methods cannot be changed without re-doing the research: what is done is done (Chiswick, 2004). You need to write about the methods in the past tense with adequate detail to repeat the study design and validate results (Johnson, 2008). Provide details of the selection and description of study participants, data collection processes and methods used in analyses. When in doubt, provide more (rather than fewer) details (El-Serag, 2006).

Any research problem to be solved needs appropriate methods, depending on the topic and research field. In some cases, qualitative research methods may be adequate, while in other cases, quantitative methods are required. Another possibility is to use a combination of methods.

Qualitative research methods are traditionally used in social sciences, and they use smaller samples aimed at achieving an in-depth understanding of human behaviour. The most common is interviews, which can be structured, semi-structured or unstructured. These data samples do not allow extrapolation to entire populations, but they can be important in formulating hypotheses that can be tested in another step using quantitative data. In fact, qualitative and quantitative methods are quite compatible, and they can be used in mixed-method approaches. Triangulation is the use of a combination of two or more research methods in the study of the same phenomenon in order to validate data through cross verification and to enhance confidence in results. In most cases, this is the preferred methodology in social sciences.

When using quantitative methods, you need to explain the size of the sample of the statistical population under study and the procedures for selecting this sample. Specify if the sample is statistically representative, allowing inferences from the sample to the general population. You should use appropriate methods to calculate ideal sample sizes. When you cannot work with a random sample, you need to work with a sample that is as representative as possible: the more representative, the better. One strong reason for rejecting a paper is if editors or reviewers consider that the sample used is not ideal. In this case, the validity of the study is restricted to the group of individuals who constitute the sample.

A pilot test is quite important for evaluating feasibility and making all necessary corrections or improvements to surveys, before you carry out any large-scale quantitative research. At least one of the authors needs to have an in-depth knowledge of research methods and statistics. When applicable, it is important to enlist the help of a statistician at the outset to determine sample size, power analysis and appropriate statistical methods (Johnson, 2008).

3.2.8 Discussion of results (or findings)

The results section is a critical part of the manuscript (Shidham et al., 2012). The presentation of results is the outcome of the application of methods to primary or secondary research resources. Some basic rules can help you to present your results in the best possible way:

- Interpret results and their implications, instead of simply presenting them in a descriptive way;
- Use primary data, which is more relevant than secondary data;
- Use a combination of text and visual aids such as graphs, tables or figures – these need to be well designed in order to make sure the reader understands the results more easily. Presenting the data in graphs has the advantage of clarity and impact, and it can bring out relationships between various parameters (Rosenfeldt et al., 2000);
- Keep graphs (or other visual aids) simple (Rosenfeldt et al., 2000);
- Do not repeat information presented in tables and figures in the text (El-Serag, 2006); instead, analyse data in qualitative terms without being repetitive (Davidson & Delbridge, 2011);
- Check that tables, graphs and figures are correctly labelled with numbers and titles and that they are cited in the previous paragraph; make sure that you indicate the source of your data;
- Write results in the past tense, in a logical sequence (Johnson, 2008);
- Match the arrangement of data to the methodology and communicate as much information as is relevant (Shidham et al., 2012);
- Do not omit unexpected results or results that do not satisfy your hypotheses; report them and discuss your analysis (Davidson & Delbridge, 2011);
- Avoid abbreviations if possible, but define them if used (Shidham et al., 2012);
- When using quantitative methods, first present results of descriptive analyses, followed by results of inferential analyses (Fortin, 1999).

3.2.9 Conclusions

The conclusions section is the most important part of your paper and the one that readers remember best. You have the chance to say the last word on your subject and leave a good final impression of your research.

Here are important rules to follow in the conclusions section:

- Link your conclusions with the introduction – conclusions must have a direct relationship to the objectives stated in the beginning of the paper and answer the research question(s) and objectives, as well as confirm or refute hypotheses;
- Compare your conclusions to previous research and point out implications and contributions of your paper to advancing knowledge in your field of research;
- Avoid any repetition of results presented in the previous section and any ambiguity or speculation;
- Make your conclusions solid, synthetic, brief, clear and convincing;
- Explain study limitations and make recommendations for future research.

3.2.10 References

You need to structure the list of references according to your target journal's guidelines. This is one of the sections that require the most attention and control by editors and the one that usually presents the highest number of inaccuracies. Authors and journals cannot publish papers with missing or incomplete references without compromising their reputation.

There are different styles for organising and presenting references. The most common in social sciences is probably the APA style. If you cannot afford to buy the Publication Manual of the American Psychological Association (the most accurate and complete document on the subject), it is advisable to check out materials on APA style guides that are available on the Internet. In organising your list of references, here are some important rules to follow:

- Follow journal guidelines;
- Include only references cited within the text;
- Double-check references for accuracy:
- Ensure that all information in the references list is complete and accurate (Davidson & Delbridge, 2011);

4. Style matters: Use adequate academic writing

Writing a paper using adequate academic writing involves many rules, and it is an extremely challenging task. To start with, you need to ensure you have relevant findings to communicate to readers. In fact, it is with the readers in mind that you have to find the best possible way of communicating your findings and arguments. Readers should be able to read and understand your paper without much effort (Gerstein, 2013). The following guidelines from different authors can help you to find the most adequate academic writing style for your paper:

- Use sentences that are short, clear and direct; use formal and carefully structured wording and make sure the subject of each sentence appears early in the sentence (Fahy, 2008);
- Do not insert large chunks of information between subjects and verbs (Chiswick, 2004);
- Make your ideas clear and your arguments easy to follow (Fahy, 2008);
- Ensure that the information you wish to emphasise comes at the end of each sentence or clause (Chiswick, 2004);
- Avoid repetition, wordiness, long sentences and excessive adverbs and adjectives (Johnson, 2008);
- Select, in general, for 'active' rather than 'passive voice' in verbs (Fahy, 2008) since the active voice is more concise and crisp (Johnson, 2008);
- Utilise the spell-check function in your word processing programme (Davidson & Delbridge, 2011);
- Write to enhance the elements of careful word choice: clarity, simplicity and accuracy – clarity means choosing the simplest and most accurate word to express each idea; accuracy means choosing the precise word to express what you mean; clarity is improved if, once having chosen a precise word, you use the same word consistently throughout and do not substitute inexact synonyms (Fahy, 2008);
- Double-check grammar, style, spelling and references; shorten and cut down your paper at every chance, editing for crispness, with a focus on accuracy, clarity and brevity (Johnson, 2008);
- Ensure you use research terminology correctly; do not confuse or misuse terms (Davidson & Delbridge, 2011);
- Turn long paragraphs into short paragraphs, long sentences into short sentences and long words into short words (Davidson & Delbridge, 2011).

5. Revision and proofreading

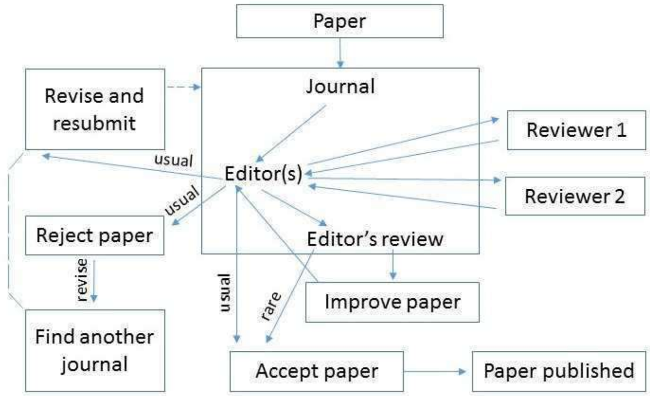
When your paper is complete, revise it thoroughly and make all necessary changes. If multiple authors sign the work, all of them should revise the entire paper and not only their contributions. A complete paper needs to be subjected to multiple revisions before submission.

If English is the intended language of your paper and it is not your mother tongue, you will need translation or proofreading services provided by a native speaker with skills in academic writing (Børresen, 2013). In this situation, some journals demand a proofreading certificate.

6. The submission process

Having a good research paper that complies with your target journal's guidelines is only the first step of the submission process, as shown in Figure 3.

Figure 3 - The submission process



Source: Own elaboration.

Most journals require a confirmation that your paper is original and that it has not been submitted to other journals at the same time. As mentioned earlier, in order to implement the double-blind review process, journals need an RV version without identification of the authors. After submission, the editors make a first evaluation of if the paper fits in the scope of the journal and complies with journal rules. If this is not the case or if the editors find any other obvious reason to refuse publication, the paper is immediately rejected. Otherwise, the editors send the RV version to two reviewers who are experts in the paper's topic. If the paper has a strong statistical component, at least one of the reviewers must be an expert in the methods used. Each reviewer evaluates the paper according to different parameters and sends a report back to the editors. To give an example from the *Tourism & Management Studies* journal, the parameters evaluated by the reviewers on a scale from 1 (very weak) to 5 (excellent) include importance of the topic and innovativeness of the research, objectives, literature review, methods, results, structure, academic writing and contributions to the field. If the editors decide to reject the paper, it cannot be submitted later to the same journal. If the decision is 'revise and resubmit', you can revise the paper according to the suggestions of the reviewers and resubmit it to the same journal. Another option is for you to use the feedback of the reviewers to improve your paper and submit it to another journal. Any paper selected for publication needs to be reviewed by the editors after receiving the peer reviewers' evaluations. Acceptance without suggestions for improvements by the reviewers and editors is nearly impossible. The most usual process is that the editors send the reviewers' suggestions and their own suggestions for improving the paper to the authors. In this case, the authors need to revise the paper along the lines suggested by the editors and reviewers and send the paper back to the editors along with an improvements report. Normally, the editors accept the paper for publication if suggestions have been successfully implemented.

7. Concluding remarks

Preparing a research paper for publication requires methodical work that involves three processes, each one with exact rules and steps. Provided you have done solid research, it is quite important to adopt strategies that will increase the likelihood that your paper gets accepted for publication. Our main purpose was to explain these strategies in order to help authors to write good research papers.

Many authors have addressed the topic of writing good papers. However, we believe this paper contributes to the literature by:

- Presenting strategies based on a combination of our experience as journal editors and the existing literature
- Integrating the writing process into a broader context together with the research and publication processes
- Developing our own models of these processes to represent the processes in charts

Writing a paper can be a wonderful and rewarding experience, especially when you see your first, or next, paper published.

References

Andonie, R. & Dzitac I. (2010). How to write a good paper in computer science and how will it be measured by ISI Web of Knowledge. *International Journal of Computers, Communications & Control*, *5*(4), 432–446.

Audisio, R. A., Rolf, A., Stahel, R. A., Matti, S., Aapro, M. S., Costa, A., Pandey, M. & Pavlidis, N. (2009). Successful publishing: How to get your paper accepted. *Surgical Oncology*, *18*, 350–356.

Børresen, T. (2013). How to write a good scientific paper. *Journal of Aquatic Food Product Technology*, *22*, 435–435. doi: 10.1080/10498850.2013.827558

Chiswick, M. (2004). Writing a research paper. *Current Paediatrics*, *14*, 513–518.

Davidson, A. & Delbridge, E. (2011). How to write a research paper. *Paediatrics and Child Health*, *22*(2), 61–65.

El-Serag, H. B. (2006). Scientific manuscripts: The fun of writing and submitting. *Gastrointestinal Endoscopy*, *64*(6), 19–22.

Fahy, K. (2008). Writing for publication: the basics. *Women and Birth*, *21*, 86–91.

Fortin, M.-F. (1999). *O processo de investigação: da concepção à realização*. Loures: Lusociência.

Gerstein, H. (2013). Writing science that your colleagues can read. *Journal of Diabetes and Its Complications*, *28*, 4–5.

Johnson, T. M. (2008). Tips on how to write a paper. *Journal of the American Academy of Dermatology*, *59*(6), 1064–1069. doi:10.1016/j.jaad.2008.07.007

Rosenfeldt, F. L., Dowling, J. T., Pepe, S. & Fullerton, M. J. (2000). How to write a paper for publication. *Heart, Lung and Circulation*, *9*, 82–87.

Saper, C. B. (2014). Academic publishing, part III: how to write a research paper (so that it will be accepted) in a high-quality journal. *Annals of Neurology*, *77*(1), 8–12.

Shidham, V. B., Path, F. R. C., Pitman, M. B. & DeMay, R. M (2012). How to write an article: Preparing a publishable manuscript! *CytoJournal*, *9*(1), 1–12. doi: 10.4103/1742-6413.92545.

The editors

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