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LETTER

Multidisciplinary biophotonics, open science, and … plug & pray deep learning?

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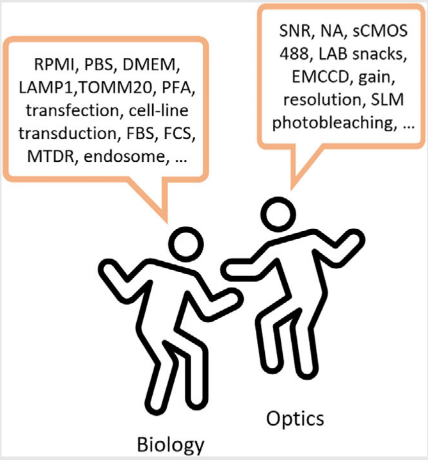
Abstract

Due to its great creative potential for innovation and scientific discovery, inter- and multidisciplinary collaboration is being increasingly encouraged by institutions and funding agencies. The increased opportunities in the multidisciplinary arena also come with significant challenges like the added experimental, analytical and logistical complexity, blended with a high likelihood of miscommunications. When is multidisciplinarity worth the effort, and how can we be better collaborators? With a focus on cross-disciplinary collaborative work to answer burning questions in biology and biomedicine, this paper discusses both large challenges and opportunities with multidisciplinary biophotonics, how we can better navigate the arena of big data and artificial intelligence combined with open, reproducible science and biological discoveries.



KEYWORDS
artificial intelligence, bioimage analysis, multidisciplinary collaboration, open science, team building

1 | INTRODUCTION

The pillars of traditional scientific disciplines are morphing and merging. Both the importance and challenges of inter- and multidisciplinary work endeavors have been recognized in many different fields, for example, natural resource management [1], rehabilitation [2] and establishing research environments [3]. The vastness of today's knowledge requires field and sub-field specialization. This alone can have a limiting effect on cross-discipline collaborations by pushing researchers to ignore other fields—with their possible application areas—in their quest for expert knowledge in one particular field of science [4]. While this can be seen as a paradox, the solution for efficient multidisciplinary research must lie in the construction and appropriate management of strong teams. But how do we construct and become a good team, and how can we communicate when lacking knowledge about each other's

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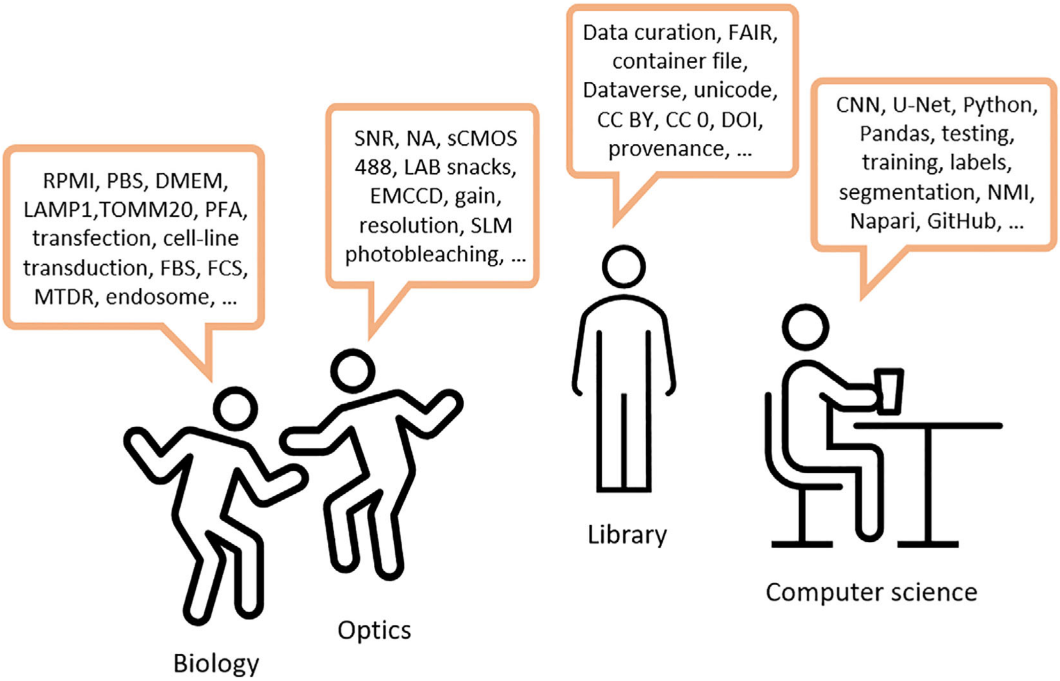

FIGURE 1 Multidisciplinary communication requires some thought and training. Terms obvious in one discipline are often not understandable to people from other disciplines. A good collaboration starting point can be to point out and explain the most important concepts in one's discipline and avoid unnecessary use of jargon

disciplines including basic concepts and vocabulary (Figure 1)? To help others become better collaborators and more reflected concerning—sometimes subtle—challenges in multidisciplinary projects, I have in this article shared my reflections and recommendations concerning multidisciplinary biophotonics projects after more than 6 years of experience working on the interface between biologists, computer scientists, microscopy developers, and, finally, librarians for the publishing of open and reusable datasets.

2 | BUILDING A STRONG TEAM ACROSS DISCIPLINES AND RESEARCH GROUPS

Great ideas can appear by chance in lucky encounters or emerge over time where people work together and exchange ideas. The decision to form a multidisciplinary team can form from, for example, the need or desire to better understand—and possibly even solve—complex societal or environmental issues like cardiovascular disease, disappearing fish stocks, or pollution. Governmental incentives with call for research proposals can be an important inspiration and decisive if the team formation with the desired research endeavors becomes possible through successful funding applications. For example, the largest funders in 2013 were the National Institutes of Health

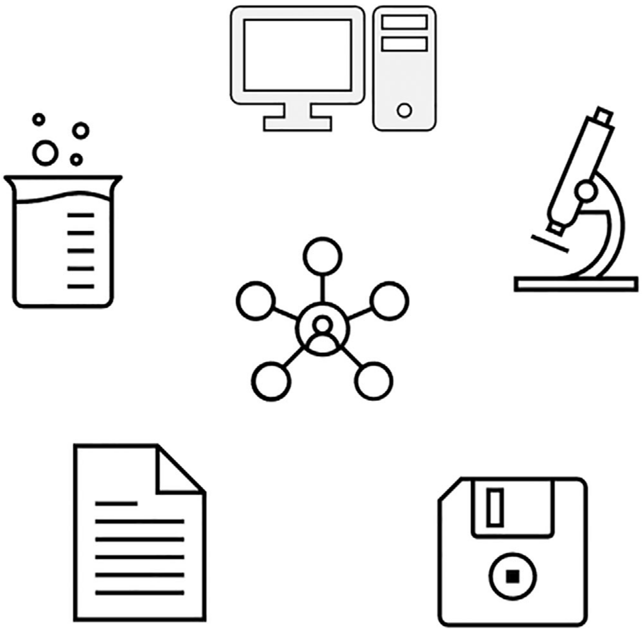

FIGURE 2 The successful execution of a multidisciplinary biophotonics project requires the availability of different facilities and resources like wet labs, instruments/microscopes, computational resources and data storage. Sufficient documentation for data archiving and the reuse of research data should also be in place. The different facilities and subfield experts must be sufficiently connected and coordinated to make the project run smoothly

(USA) with USD 26 081.3 million and the European Commission with USD 3717.7 million in total health research expenditures [5]. In particular to the field of biophotonics, one can in the same research project need experts in biology, biomedicine, microscopy, instrumentation and data analysis. There might be a need to develop a particular piece of instrument to enable the capture of data to elucidate a particular knowledge gap in biology to again develop a treatment for societal health issues. Not unlikely, that the data will come along with a need for analyzing the new type of data for the particular application. The growing demands for open science [6] add additional expectations and needs for data storage, data sharing and extensive documentation (Figure 2).

Assuming we are in a position to form our own research group, we will probably—as far as possible—try to recruit team members who in sum have all the necessary skills and knowledge to successfully carry out the project at hand. The perfect match for a position might not exist or be available at the right time, so retraining and/or reaching far and wide to get suitable team members are not unlikely. Each has to define their own success, but for a research team, success (or goals) can be, for example, to generate new knowledge, develop new tools, publish good articles and/or attract new funding and new team members.

Considering a research institution like a university accommodating many established research groups, many will have a team built to investigate something related to a particular discipline and faculty, for example, within biomedicine, computer science, photonics, aquaculture and so on. But inter- and multidisciplinary research is tempting as it could potentially solve significant challenges faced by the individual disciplines, attract funding, and is known to spark innovation. But what are the costs, and how can we ensure and maximize the gain of our multifaceted collaborations? Surely this depends on the particular collaboration, but from my personal experience in conducting multidisciplinary research in (and around) the biophotonics laboratory, I find that the points presented below are crucial for a good multidisciplinary research project which also complies with new standards for open and reproducible science.

2.1 | Recommendations for open and reproducible science in multidisciplinary collaborations

2.1.1 | A clear and shared objective of the collaboration

Everyone involved should benefit from the collaboration and have sufficient interest and dedication to the project to carry it to the end. This objective can be much broader than the particular research hypotheses or questions to be addressed in research articles.

2.1.2 | Research questions

Within the shared objective for the collaboration, several more specific research questions can be formulated. A good research question should address a particular knowledge gap, have a clear intention, and be specific enough to be of interest to the target audience [7, 8]. The knowledge gap to be addressed, the intention, the research methods as well as the target audiences can all be different for the different disciplines involved in the collaboration. It might therefore be necessary to formulate several discipline-specific research questions within the collaboration to satisfy the interests and career objectives of all involved.

2.1.3 | Publication avenues and authorship

Scientists from different disciplines are accustomed to different publication venues and often have very different target journals for their publications. Early planning of how to distribute different work components into different manuscripts and publications together with an open discussion of authorship can avoid later conflicts.

2.1.4 | A good team learning environment

It is important to develop a shared understanding of the research to be conducted, discipline-specific differences, developments to be made and dedicated time and resources, including an approximate timeline.

2.1.5 | Sufficient expertise in all (sub-)fields

Sufficient expertise in all (sub-)fields to be involved in the project, for example, branch of biology, photonics/bioimage acquisition, data management, image analysis and artificial intelligence. Expertise not present at the beginning can be acquired by team members through appropriate training.

2.1.6 | Translator/communicator and project manager

Communication between disciplines can be challenging and require both a significant amount of time and talent.

If none of the participants with particular field expertise has the necessary prerequisite or time to properly coordinate and understand all sides of the multidisciplinary project, maybe a new person can be identified who can? As the fourth industrial revolution is requiring different and additional skills compared to traditional project managers, there might be a need for a similarly skilled person to manage the more complex and dynamic multidisciplinary research projects in modern academia [9].

2.1.7 | Data acquisition plan

Much time can be saved by having an early discussion and agreement on what data in particular is needed for the desired analysis and investigations. Discuss the particular experimental parameters with an imaging expert and make sure the experimental settings are documented and consistent for the conditions to be compared. Agree on a file naming convention appropriate both for automated analysis and data archiving/publishing.

2.1.8 | Data management plan

Are the necessary infrastructure and resources available to support the acquisition, storage, processing and archiving of terabytes of data? Who will dedicate their time to appropriate documentation, curation and storage of the data in an open research data archive?

2.1.9 | Research documentation and reproducibility

Sample preparation, data acquisition, image processing and computational analysis: all should be well documented and as reproducible as possible. Each subfield has its challenges of reproducibility, and these challenges multiply in multidisciplinary projects.

2.1.10 | Sharing of software and classifiers

What research data, trained classifiers and code/programs are worth sharing, and what code is worth developing further into, for example, community Fiji plugins? This is an open question that must be considered and decided by the creators and, to some extent, by the funders of such research-related activities.

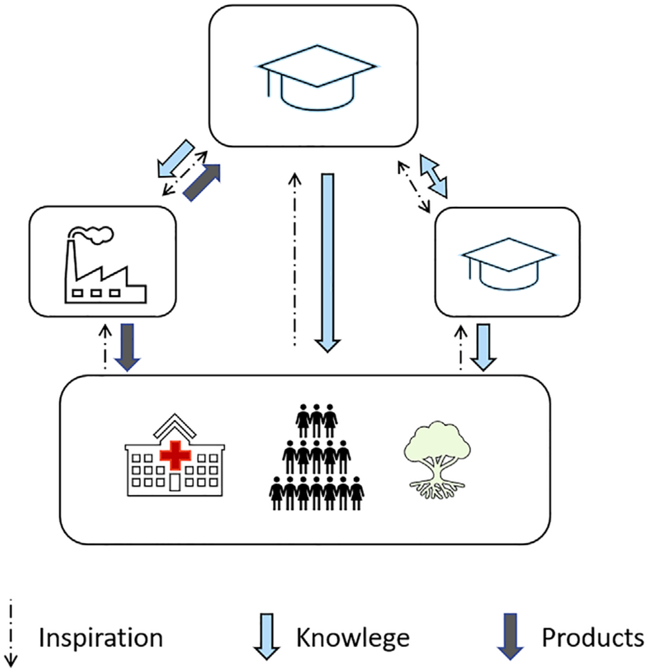

FIGURE 3 The knowledge of an open research ecosystem can spread and benefit society, industry or other research/educational institutions. The inspiration for research projects can come from, for example, the natural environment or population health issues. The products from industry-based research can benefit both society and open research institutions, but the findings are likely to be kept as trade secrets

2.1.11 | Research dissemination

If your research is well communicated across disciplines, it is likely to get more citations, spark new collaborations and research projects that can boost the impact of your work. The first steps in establishing new collaborations are in my experience learning about each other's work and interests, finding mutual benefits of joining forces, and considering what resources are available or could be made available through, for example, successful research grant applications. Sharing of research results can benefit old or initiate new research projects, but is not always desirable due to conflict of interests related to trade secrets or patenting if inventions are intended to be commercialized. The flow of research inspiration, knowledge and products are illustrated in Figure 3.

The current simultaneous movements of both "open science" and "entrepreneurial universities" have some conflicting ideas and values important to consider in the shaping of current and future educational institutions. Getting academic researchers better informed about the opportunities and potential conflicts concerning commercialization processes and industry partners can both help academics make more informed career choices and contribute to making a significant better use of university funds for startups and commercialization project [10].

2.2 | Joint workshops and training

Whether you are looking for the right collaborators in the first place or want to make the best out of the ones you already have, joint workshops and training can be a great tool and starting point for future success. There might not be anything externally organized fitting your team and project, so be prepared to organize it yourself or engage someone to get it going. In my experience, a physical workshop with presentations from experts in the most relevant disciplines can be a very useful arena to get together to know both the other teammates and the different disciplines better. A digital learning arena is of course also possible, but might feel less personal with a higher likelihood of losing focus on the workshop topic and disconnecting from the other team members. Especially for attracting new team members and attention to one's research activities, a conference (physical or digital) or educational videos on YouTube can be a good option. Whatever format is chosen for the multidisciplinary interaction, clear goals and strategies on how to reach them are likely to significantly increase the gain from the meeting.

Goals for joint meetings and personal aspirations can be:

1. Get to know each other and identify crucial communication points. This can be communicated within the same or between different research groups. Be aware of the different backgrounds of people and find strategies to reach a common understanding of the project at hand and how to avoid miscommunications. Identify and communicate the key aspects of your own research that are most crucial for the collaborators to understand. Be open about what is not clear.
2. Identify similarities and differences in work style, procedures and preferences (e.g., computational, experimental, bio lab, work hours). What experimental parameters are easily changed, and which ones are not? What are quick fixes and what takes a long time or simply too much time?
3. Plan way ahead but also with short-term goals. Avoid cramming before deadlines, especially on activities requiring multiple people. Not everyone is able or willing to set aside everything else right before your important deadline.
4. Forgive mistakes and learn from them. Have enough time and resources allocated to try again.
5. Be patient. Multidisciplinary collaboration is better done to go far than to go fast.

3 | OPEN SCIENCE, REUSABILITY, AND … PLUG & PRAY DEEP LEARNING?

Several of the recommendations listed in Section 2.1 are related to the movement of Open Science [6]. One should not only organize the storage of the research data for one's own use but strive (as much as seems reasonable) to make it available in an open repository for long-term storage and in a format with long-term readability. The archived data should be with sufficient description to make it reusable for anyone across the globe potentially wanting to reuse the data. Standards and guidelines for the sharing of research data [11], hardware design [12] together with quality control management of instruments and images [13] have been developed.

Scientifically, reproducibility of the data is of course desirable as much as possible, but sometimes data can simply be unique. Research data is also often produced using advanced and expensive equipment in practice accessible to only a few exclusive users, limiting reproducibility no matter how carefully the experiments are performed and documented. Significant initiatives addressing this issue, by "making microscopy open and available to everyone," are the Foldscope (ultralow-cost, origami-based paper microscope) [14, 15], the OpenFlexure microscope (an open-source, 3D-printed and fully-automated laboratory microscope) [16] and UC2 (a low-cost, 3D-printed, open-source, modular microscopy toolbox) [17].

Reusability of code and computational methods—together with their potential research impact—are greatly promoted by the adaptation of developed software into popular and open-source image analysis tools like ImageJ/Fiji [18], napari (image viewer for complex data in Python) [19] or ilastik [20] (interactive machine-learning-based bioimage analysis). The active communities of these platforms strive to facilitate scientific image analysis and to make it accessible to everyone.

We have arrived at a stage where advanced deep learning methods for image analysis are open and usable by basically everyone [21, 22]. As for commonplace plug-and-play devices [23] like Universal Serial Bus (USB) [24] or High-Definition Multimedia Interface (HDMI) [25], one could imagine a similarly simple interface for advanced deep learning-based image analysis methods. However, the current deep-learning-based classifiers for image analysis—although made accessible and user-friendly—require at the very least performance testing, but also very likely re-training (using application-specific and suitable training data) before the program is ready for new tasks. One can plug and pray that a pre-trained classifier will work for a different dataset, but this is known to yield poor reproducibility.

Considering these limitations, is there a point in adapting deep learning classifiers for non-expert end-users? Who are the potential end-users of advanced image analysis tools? On the one hand, a quick and easy-to-use interface is also appreciated by expert users, as it is possible to get far more done in less time. On the other hand, the knowledge gap to make use of new algorithms for image analysis is significantly reduced upon such an adaption, enabling end-users in other disciplines to far quicker acquire sufficient know-how to apply the new tools themselves in new branches of, for example, biology or biomedicine. And, if another expertise is needed for your most burning research question, why not start a new multidisciplinary collaboration?

4 | SUMMARY AND FINAL NOTES

Multidisciplinary research can be extremely rewarding but also brings along many challenges and potential pitfalls. As scientific methods are getting increasingly complex, so do the coordination and project management. As in industry, I suggested the inclusion of an additional project manager (beyond the traditional PI) to ensure smooth coordination and help communicate especially between the disciplines. By allowing for flexible choices of subjects together with an increased focus on interdisciplinary understanding and communication during research education, one can expect the challenge in general to be more manageable for individual researchers, but also to develop more talents for multidisciplinary project management. As universities are directing themselves according to a more entrepreneurial path, it will be beneficial to also facilitate the communication with stakeholders in industry and make students and staff more aware of potential conflicts of interest in industry-oriented research. Researchers will need to be informed to appropriately navigate the current movements of open science and entrepreneurial universities.

Communication skills in or across different arenas are extremely valuable and come with practice. It is therefore important to take the time to also learn this asset when educating coming scientists and continue the practice early on in new complex projects. This, in my opinion, will improve the quality and impact of all scientific disciplines and even increase the revenue in industry-directed projects.

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CONFLICT OF INTEREST

The author declares no potential conflict of interest.

DATA AVAILABILITY STATEMENT

Data sharing not applicable—no new data generated.

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