Notes on Research-Based Education

What research is, and why and how we conduct it

Prof. Makoto Chikaraishi

About These Notes

These short notes were written for all students in the lab. The first sets out what research is, how it differs from learning and from practice, and what makes it good. The second explains why undergraduate, master's, and PhD students conduct research and write academic papers. The third describes how we should go about conducting research, from reviewing the literature to establishing a research objective and carrying the work through.

1 What Is Research?

It is important to have a clear understanding of what research is. Research aims to expand society's collective knowledge, not simply our own personal knowledge. Learning something you did not know before is valuable, but research goes a step further: it contributes something new to what is already known.

For example, reading a textbook to understand why traffic jams occur is learning. Research might begin when you notice that traffic jams repeatedly occur at a location where existing explanations suggest they should not. You would then investigate possible explanations and test them against evidence. If your findings reveal something that existing knowledge cannot adequately explain, they can contribute to research. The key question is not simply "What did I learn?" but "What can others learn from my work that was not already known?"

What, then, makes research good? One hallmark of good research is that it inspires others to investigate further. It opens up new questions, offers new perspectives, and provides a foundation on which others can build. Its value lies not only in the answers it provides, but also in the further discoveries it makes possible.

I would also like to distinguish between research and practice. Both can ultimately contribute to a better society, but their immediate goals often differ. Practice focuses on addressing the problem at hand, whereas research focuses on generating knowledge that extends beyond that particular problem. Taking the shortest route to a solution may be appropriate in practice, but it is not necessarily the most valuable approach in research.

For example, suppose a city wants to increase bus use. Changing a bus route and checking whether ridership increases may be enough for a practical decision. A research study would go further by asking why the change worked or did not work, for whom, and under what conditions. Did more people use the bus because walking distances became shorter, or because the new route served different destinations? What could these findings tell us about other cities? The same project can therefore contribute to both practice and research if it addresses a local problem while also producing knowledge that others can build on: For a practical decision, the main

question may be whether the route change increased ridership enough to justify keeping it. For research, the key question is what this case adds to existing knowledge about how route changes affect bus use.

We cannot know exactly what challenges society will face twenty years from now. Knowledge that seems to have little practical value today may become essential when we encounter problems we have never faced before. Our ability to respond will depend partly on the breadth and depth of the knowledge we have accumulated, including knowledge that was not developed with those problems in mind. Research should therefore look beyond immediate usefulness and help build the foundations for addressing future challenges. To use a metaphor, research is not just about harvesting fruit today. It is about enriching the soil so that a wider variety of seeds can take root and flourish in the future, even if we do not yet know which seeds will grow.

I think the above understanding is very important for practitioners as well. A society that only harvests the fruits of knowledge produced elsewhere, without enriching its own soil, limits its ability to respond to future challenges. We should strive to build a society that contributes to the growth of knowledge, rather than simply relying on others to produce it.

Research can also change how we think. It asks us to examine evidence that challenges our expectations, take alternative explanations seriously, and engage carefully with ideas we may disagree with. This does not mean treating all ideas as equally valid. It means judging them by the quality of the evidence and reasoning that support them, and being willing to revise our own views. Practicing these habits can help us become more thoughtful researchers and contribute to a society that is better able to question assumptions, discuss disagreements, and learn from evidence.

You do not need to make a major discovery for your work to count as research. A small, well-supported contribution matters. Start by understanding what is already known, identifying a clear question that remains unanswered, and collecting and analyzing evidence to address it.

2 Why Do We Conduct Research?

It is easy to understand why PhD students are expected to conduct research and learn how to write academic papers. But why do undergraduate and master's students also need to do so? I believe that understanding the reasons behind this is essential for making the most of your time in the research lab. Here, I will use the term *research-based education* to refer to the process of learning through conducting research and writing academic papers.

To understand the value of research-based education, we first need to consider what knowledge is, how it is produced, and how it is used in society. Knowledge is the accumulated collection of ideas, ways of thinking, and principles about how the world and society work, developed by humanity throughout history. Some knowledge is systematically organized into academic disciplines, while other knowledge exists as practical experience and tacit knowledge passed down within companies and organizations. This accumulated knowledge forms an essential foundation of modern society. Financial institutions operate based on knowledge of finance. The construction industry relies on knowledge of soil mechanics, structural engineering, and architectural design to create safe and comfortable environments. Urban and transportation planning draws on a wide range of disciplines, including operations research, economics, transportation engineering, psychology, political science, and philosophy. In short, society functions by making use of the

knowledge accumulated by previous generations.

Let me briefly make a related point. Knowledge is continuously accumulated, but it is also revised and reorganized. Over time, the overall amount and complexity of knowledge tend to increase. As a result, the knowledge required to carry out professional work also becomes more extensive and complex. Although we try to organize knowledge systematically to make learning more efficient, it is becoming increasingly difficult to acquire all the necessary knowledge during undergraduate education alone, particularly in engineering.

Now, to improve our work and build a better society, we must continue to update our knowledge. This happens through academic research, but it also takes place within companies and other organizations. The important point is that many problems facing society cannot be solved using our existing knowledge alone. We need to develop new knowledge and improve what we already know. For example, we still cannot fully explain, in a systematic way, how increasing mobility has transformed society. Even the behavior of soil under applied loads is not yet completely understood. By improving our understanding of such phenomena, we can develop better disaster prevention measures and better transportation systems.

This is precisely why universities conduct research: to update the knowledge shared by society. We write academic papers not only to communicate new knowledge but also to make it available for others to examine, criticize, and build upon. This is different from updating our own individual knowledge. When we learn something, we are often simply acquiring knowledge that others have already developed. Most of the education you have received over the past 15 years, up to your third year of undergraduate study, has focused on this kind of individual learning. The next step is different. It is to contribute to updating the knowledge that society collectively possesses. In other words, it is the shift from being a *consumer* of knowledge to becoming a *producer* of knowledge. I believe that one of the major missions of universities is to help each student make this transition and, through it, contribute to building a better society.

After this rather long introduction, we can now return to research-based education. Research-based education is a practical way to help students make the shift from consuming knowledge to producing it. Humanity has accumulated a tremendous amount of useful knowledge and passed it down from generation to generation. However, we have also passed down knowledge that later turns out to be incorrect or incomplete. We therefore need to question existing knowledge, identify its limitations, and consider how it can be improved. By participating in the production of knowledge, rather than simply receiving it, I hope you will develop this way of thinking. One could even argue that universities exist to help create a society in which people across all fields and professions can critically examine existing knowledge and improve it when necessary. In this sense, I believe that research is one of the most fundamental parts of university education.

From this perspective, research at universities has two important roles. The first is to update society's knowledge. The second is to develop the ability and attitude to question the status quo and bring about change, not by forcing society to change, but by improving the knowledge on which our decisions and actions are based. I therefore encourage you to engage actively in research and write academic papers. Aim to produce solid research findings, even if they are small, and to present them at national and international conferences and publish them in academic journals. Through these experiences, I hope you will not only contribute new knowledge to society but also develop the skills and mindset needed to continue producing new knowledge throughout your life.

With this understanding, I hope you can see why I do not particularly like the question, "What should I do next?" Of course, I strongly encourage you to ask questions whenever you need help. However, if you simply wait for instructions without thinking for yourself, you may still contribute to producing new knowledge, but you will miss the opportunity to develop the ability and attitude to do so independently. I would like you to first think about what you believe should be done next, and then come to discuss your ideas with me.

Finally, for PhD students, my expectations are higher. I expect you to produce significant research contributions that demonstrate your ability to become independent researchers whom society can trust to continue advancing knowledge in your field.

3 How Should We Conduct Research?

Building on our previous discussion of research-based education, I believe that reviewing the existing literature serves two important purposes. The first is to acquire knowledge from previous studies and learn to read academic papers critically. The second is to position your own research within the broader body of existing knowledge. You cannot properly achieve the second without first working on the first. As you deepen your understanding of existing research, you will gradually identify what needs to be studied next. This will naturally help you understand where your own research fits into the broader field.

For undergraduate students in particular, it is extremely important to acquire knowledge by carefully reading academic papers and continuously practicing critical reading. Whenever you encounter something you do not understand, keep studying until you understand it, even if that means going back to the basics. You are also very welcome to discuss difficult points in our seminars. Remember that you are trying to identify problems in knowledge developed by researchers who came before you. You should therefore approach their work with humility, a solid understanding, and careful reasoning before making specific criticisms.

A literature review is not simply a way to justify your research topic. It is an essential process for building your own knowledge and learning to identify the limitations of existing research accurately. I encourage you to devote sufficient time to this process, especially during your first six months.

Personally, I recommend what I call the "**100-paper challenge**." Select 100 papers related to a topic that interests you, and continuously read, review, and organize them. The number 100 itself is not important. What matters is developing a systematic understanding of the field and becoming able to explain existing knowledge and its limitations in your own words.

You may use AI to help identify relevant papers, but you must read and understand their content yourself. Your goal is to make that knowledge part of your own understanding, not simply to collect information. If some parts are genuinely too difficult to understand, make sure you at least recognize and remember exactly what you do not yet understand. The main purpose of a literature review is to build a well-organized body of knowledge in your own mind. If you encounter too many things you cannot understand, narrow your focus and study a smaller topic in greater depth.

As you develop a solid understanding of previous research, you should gradually realize three important things. First, much of our existing knowledge is more uncertain and provisional than you might initially expect. Second, different researchers often identify different problems and

propose different approaches to solving them. Third, your supervisor is also just one researcher who has adopted a particular perspective or approach. Your supervisor is not always right.

In other words, knowledge at the research frontier is far from settled. It is constantly evolving, and future research may take it in very different directions. Once you truly understand this through your own experience, you will have reached an important milestone. You should then be able to critically and logically evaluate even what your supervisor says.

For undergraduate students, it is perfectly fine to start with a very narrow topic. Your first goal should be to reach this level of understanding in one specific area. As you progress through master's and PhD studies, gradually broaden the scope of your knowledge and your ability to critically evaluate existing research. If you can identify a genuine limitation in existing knowledge and come up with a promising way to address it, you already have the foundation of a strong research objective.

However, turning an identified problem into a concrete research objective is not easy. Many problems that remain unsolved are already well recognized by researchers. The difficulty is not identifying the problem, but finding a way to solve it. This is similar to an unsolved mathematical problem: we know what needs to be proved, but we do not yet know how to prove it.

At this stage, active discussion with your supervisor and other lab members becomes particularly important. Could this idea work? Could we apply a method developed in another field? Could a new survey or a different analysis help us find an answer? We should discuss such possibilities openly, examine different approaches, choose the best solution available to us, and give it a try.

There is absolutely nothing wrong with trying something and failing. Research allows us to fail. However, we should not jump to conclusions without thinking carefully, discussing our ideas, and examining the evidence. If we have made our best effort, even an unsuccessful attempt can produce findings worth sharing. Such results can also have academic value.

Once we have selected what we believe is the best approach and established a clear research objective, we move forward with the actual research. From this point on, success depends on how much effort we put into the work, how honestly we interpret our results, and how flexibly we adjust our approach in response to what we find. We must also have the persistence to complete demanding tasks, whether they involve programming, mathematical proofs, data analysis, or other challenging work.

By reaching this stage, I hope you will begin to appreciate not only how difficult it is to produce new knowledge, but also how exciting and rewarding the process can be. Ideally, I would like undergraduate students to discover this excitement while working on their graduation theses.

If your efforts eventually lead to new knowledge that you can share with society, the sense of achievement can be tremendous. I believe this is one of the greatest rewards of making the shift from being a consumer of knowledge to becoming a producer of knowledge.

More importantly, I hope that through this entire process, you will develop a lasting commitment to questioning existing knowledge, improving it, and continuing to contribute to the production of new knowledge throughout your life.

— Makoto Chikaraishi