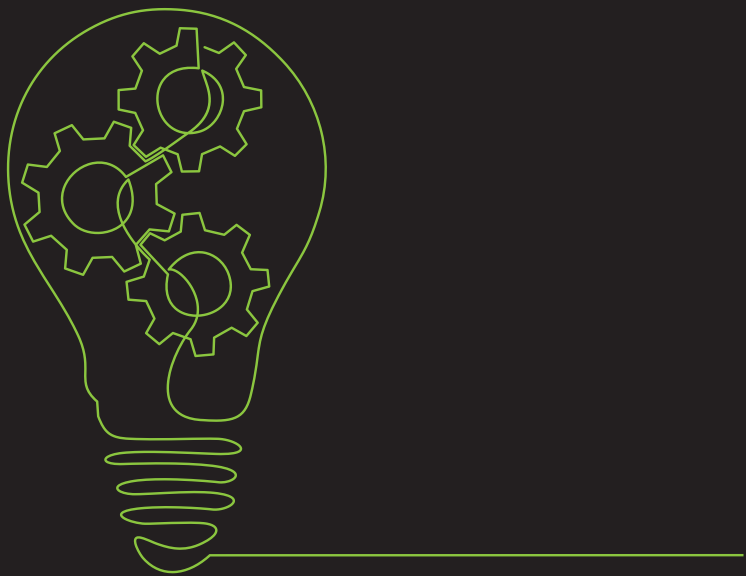
Effective Reading Practices for Engineering Research Articles

An Engineer's Guide to Reading, Critiquing, and Evaluating Primary Literature



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UPCGRAU 82

UNIVERSITAT POLITÈCNICA DE CATALUNYA
BARCELONATECH

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Preface

This book presents an easy and effective approach to reading scientific articles and honing analytical skills through critical examination of their content. It provides a valuable academic resource to facilitate engineering education and learning.

Primarily aimed at undergraduate students, the book serves as a guide for studying and assessing primary scientific literature as research information, not only in their academic pursuits but also as an essential skill for their future careers. It outlines the key components of research articles, their organisation, and the objectives they fulfil. Furthermore, it delves into the intricate process of writing a paper, from conception to publication, providing valuable insights for aspiring researchers. Therefore, to foster increased motivation and a sense of belonging, the book also offers practical recommendations.

Additionally, this resource is also tailored for instructors of engineering courses seeking to enhance their teaching methodologies. Drawing from a real-world case study in an undergraduate Fluid Technology course, the book outlines a teaching intervention designed to integrate primary literature into the curriculum. This approach, which emphasises active learning, has proven to be more effective in fostering comprehension compared to traditional textbook- and lecture-based methods. Given the abundance of information and knowledge available today, active learning as a pedagogical strategy is demonstrably superior to traditional methods.

This book is structured into two main parts:

Part 1 (Chapters 1 through 7) is tailored to students, providing comprehensive guidance on the essential practices for effectively reading, critiquing, and evaluating research articles.

Part 2 (Chapters 8 through 11) is geared towards instructors, aiming to enhance student motivation by contextualizing the benefits of these practices in engineering education.

Chapter 8, in particular, outlines a teaching intervention framework for engaging students in the reading of primary literature. Drawing from practical experience in an undergraduate course, this chapter provides a detailed case study focused on integrating scientific articles into the engineering research process, thus providing students with an immersive experience. Specifically, it explores the incorporation of primary literature within the curriculum of a one-semester Fluid Technology course for fourth-year undergraduates.

Contents

1 Introduction

1.1 Abstract

The significant role played by engineering education in serving society drives continuous efforts to improve its pedagogy. One academic tool employed is reading scientific articles. Proficiency in this skill proves invaluable for students, not only academically but also professionally. This book, derived from collecting and analysing multiple research studies and practical experiences, presents a straightforward and effective approach to reading scientific articles and developing analytical skills through critical assessment of their content. To guide undergraduate students' comprehension and evaluation of primary scientific literature, which is fundamental in forming their research knowledge, it delineates the fundamental components and structure of research articles, along with their interconnected roles. Furthermore, it outlines a teaching intervention framework for engaging students in primary literature reading, drawing from practical experience in an undergraduate Fluid Technology course. Because writing research papers improves reading skills, information acquisition, and critical analysis, this book delves into the intricacies of the paper-writing process and the progression of a research project, from conception to publication. Additionally, it provides guidance on responding to referees' comments. Given that the reading of primary scientific literature is not a typical practice in high school science curricula, fostering motivation is critical to research-based learning in engineering courses. To this end, this study offers some recommendations for increasing motivation in research-based education, informed by insights from neuroscience while further reinforcing students' sense of belonging.

1.2 Aim

This book comprises guides and notes intended to provide **students with the necessary skills to navigate research articles** and integrate their use into coursework. Reading research articles constitutes a major activity in studying a subject, and it prepares students for graduate school, should they choose to pursue a master's or doctoral degree.

1.3 Motivation

Given the sudden proliferation of information and knowledge in our modern era, **incorporating primary literature into coursework as part of active learning** promises to be more effective than traditional methods that rely solely on lectures and textbooks for content transmission.

1.4 Justification

When encountering primary literature for the first time, the experience can be rather daunting and provoke stress and anxiety. However, with proper guidance, **students can overcome these initial challenges and gain confidence in engaging with scientific articles**.

1.5 Rationale

The depth of knowledge inherent in primary literature renders it a suitable educational resource for students. **Active learning proves more efficacious than traditional approaches alone**.

1.6 Keywords

primary literature, reading skills, academic articles, engineering education, educational research, student motivation, student development.

1.7 List of abbreviations

ASSIST	Approaches to Study Skills Inventory for Students
C.R.E.A.T.E.	Consider, Read, Elucidate hypotheses, Analyse and interpret data, Think of the next Experiment
CUREs	Course-based Undergraduate Research Experiences
DBER	Discipline-Based Education Research
ILO	Internationalised Learning Outcomes
IMRaD	Introduction, Methods, Results, and Discussion
RPL	Reading Primary Literature
SAM	Scientific Argumentation Model
SEEQ	Student Evaluation of Educational Quality
STEM	Science, Technology, Engineering, and Mathematics
TOSLS	Test of Scientific Literacy Skills
TPCK	Technological Pedagogical Content Knowledge
UPC	Universitat Politècnica de Catalunya
UREs	Undergraduate Research Experiences

2
Primary literature

Primary literature comprises official documents utilized by scientists to disseminate their research findings (Guillen 2007). An article, also known as a paper, constitutes a written discourse presenting and discussing original research results or reviewing existing knowledge within a specific field of study. Typically disseminated through academic or scientific journals, these articles constitute a cornerstone of communication and discourse within the scientific and academic communities. The globally published scientific literature is often termed "archival literature" due to its permanent storage and enduring value for future generations of researchers (Thiel 2014).

Descriptor	Journal articles	Conference papers	Secondary sources	Standards	Patents	Text-books	Websites (in general)
Archival literature	O	O	X	O	O	O	X
Peer review (sign & process)	O	?	X	O	O	X	X
Author's affiliation	O	O	O	O	O	O	X
Publication date	O	O	O	O	O	O	X
Title (more than ten words)	O	O	X	O	O	X	X
Abstract	O	O	?	O	O	?	X
Keywords	O	O	X	?	O	X	X
Results (critique & discuss)	O	?	X	O	?	X	X
References	O	O	?	X	X	O	X

Table 1. Types and main characteristics of publications (adapted from Thiel 2014). The symbol "O" indicates a valid descriptor; the symbol "X" indicates a non-valid descriptor; and the symbol "?" indicates that the descriptor is sometimes valid.

Novice researchers should discern between the different types of publications grounded in the scientific method. Table 1 summarizes these types along their main characteristics. The scientific method rests upon observations, experiments, theories, calculations, and models derived from the existing body of scientific knowledge, independently verified by field experts through peer review. Engineering research operates under the same scientific method.

2.1 Reading primary literature in undergraduate education

According to the aforementioned definition, primary literature encompasses any written work utilized by scientists, researchers, and academics to share their findings. However, it's crucial that primary literature also considers the general public, taking into account its societal impact.

All stakeholders in society play varying roles in the research and innovation process. Research endeavours aim to generate new knowledge. Thus, while innovation activities focus on social economics, exploitation, and dissemination, it is also essential to assess the socio-economic impact of the knowledge and technology produced. Additionally, factors influencing their exploitation and dissemination must be analysed comprehensively.

Given that research knowledge and primary literature form the foundation of the academic community's work, a substantial body of research has been conducted on how teachers and researchers read this literature and the different ways in which they integrate information from articles into their professional knowledge (Bartels 2003). This research extends to considering secondary sources and explores how teachers of scientific literature might use popular texts and genres (Parkinson and Adendorff 2004).

Additionally, when focusing the survey of this body of research on undergraduate science education, the prevailing consensus underscores the importance of actively engaging students in the practice of scientific exploration and communication. Undergraduate research training offers a comprehensive foundation in various engineering techniques. For instance, Kozeracki et al. evaluated a primary-literature-based teaching program spanning from 1999 to 2005 (Kozeracki et al. 2006). Their assessment concluded that "the program increases student confidence and scientific literacy during their undergraduate years and facilitates their transition to postgraduate study". Students reported enhancements in their ability to comprehend and present primary scientific research, granting them an advantage over their peers. Notably, even in the first year of an undergraduate course, an advantageous mutual relationship exists between a student's academic reading skills and academic success, as presented by Hermida (Hermida 2009).

Once the benefits of reading primary literature are established, the question arises: How can this practice be implemented in undergraduate courses? Given that academic educators dedicate a great deal of time to reading primary literature, these skills can be taught and transferred. Fujimoto et al. explored optimal methods to support students in developing their literacy skills for reading academic articles within a particular discipline (Fujimoto et al. 2011). Similarly, Hoskins et al. focused on primary literature as a gateway to the scientific research process through the C.R.E.A.T.E. method (Consider, Read, Elucidate hypotheses, Analyse and interpret data, Think of the next Experiment), which they employed over a single semester in an undergraduate classroom (Hoskins et al. 2011). This method involved iterative classroom discussions, a process of discovery through a series of papers generated sequentially from one laboratory, and an email survey of their authors. Both studies reveal the twofold significance of helping students focus through discipline-specific reading and of fostering a sense of responsibility for their own learning.

Life science represents a crucial discipline devoted to cultivating scientific literacy in undergraduate education. Gormally et al. developed the Test of Scientific Literacy Skills (TOSLS), which assesses the competencies related to employing methods of inquiry leading to scientific knowledge, as well as the ability to organize, analyse, and interpret quantitative data and information. The TOSLS underwent testing and validation across three undergraduate institutions (Gormally et al. 2012). Van Lacum et al. presented a study focused on identifying rhetorical structures in research articles and formulating criteria for designing a teaching strategy aimed at enhancing undergraduate life science students' proficiency in reading primary literature (Van Lacum et al. 2012). Subsequently, they expanded the teaching strategy to include the heuristic Scientific Argumentation Model (SAM), comprising a set of seven key moves (motive, objective, main conclusion, implication, support, counterargument, and refutation) that play a critical role in the formation of an author's argument in research articles (Van Lacum et al. 2014). Through meticulous documentation and organization, these authors elucidated assignments, research designs based on pre-tests and post-tests, data analysis procedures, and the results of students' abilities to identify these moves. In these remarkable contributions to life science, their methodology positively empowers students by bolstering their confidence in analysing primary literature, deepening their insight into scientific processes, challenging their beliefs about learning, and bridging the gap between educators' intentions to teach scientific literacy skills and students' proficiency in these skills.

2.2 Strategies for reading primary literature

Researchers consult primary literature to find specific information they need for their own research. Due to the diverse disciplinary structures and audiences, research articles vary in both format and length across disciplines, as they are tailored to meet specific demands, contexts, mandates, and objectives (Fernandez

2020, and see Table 1). Furthermore, primary literature influences the social and cultural characteristics of academic fields through the production, relevance, and use of digital resources (Fry and Talja 2007). However, no standardised criterion exists for establishing the importance or relevance of a particular paper upon publication.

In light of these observations, the question arises: How should primary literature be approached? Instructors cannot presume mastery of academic reading skills, neither in primary literature nor in academic textbooks. Numerous books have been written aiming to introduce this discipline (Gillen 2007; Yudkin 2006; Yeong 2014).

Journal articles are written for a specific audience and adopt a highly condensed style under the assumption that the subject matter is already well-known. Moreover, finding the desired content can be challenging (Yudkin 2006). In the past, research papers adhered to page limitations due to hard-print distribution; however, this constraint no longer applies. Consequently, a surplus of text abounds while the researcher's time grows ever more constrained (Yeong 2014).

Indeed, efficiently navigating primary literature poses a challenge, but mastering these skills will empower students, leading to an enhanced self-reporting of their understanding and improved learning outcomes.

3

Science, engineering, research, and academia

3.1. An overview of science, engineering, and research literature

This chapter summarizes different types of scientific documents that a researcher will commonly read, while simultaneously addressing the challenges posed by a scientific parlance distinct from everyday language. We distinguish between scientific and non-scientific discourse, discuss how English serves as the lingua franca of scientific communication, elucidate narrative structures, explore concepts of correlation versus causation, and outline the application of the scientific method in interpreting results.

3.1.1. Scientific and technical documents

Research papers present original findings, methodologies, and results to a professional scientific audience. They may further address emerging knowledge or controversies. Refereed journal articles represent the most esteemed and valuable contributions to the archival literature.

Conference papers, whether in formal paper or poster format, report on research developments not yet published as articles.

Secondary sources consist of magazine articles, trade magazines, newspaper articles, dictionaries, infomercials, and specific websites, among others. These sources synthesize, summarize, or evaluate the primary literature. Technical documentation such as standards and patents is listed in Table 1 but falls beyond the scope of further discussion in this book.

Reading serves as the gateway to the scientific and technical realm, offering an opportunity to apply knowledge gained from textbooks and lectures. Consider it another resource in your toolbox.

Science students progressing through their studies are expected to adopt a deep approach to learning, demonstrating advanced problem-solving skills that allow them to apply assimilated knowledge and understanding to new situations.

3.1.2. The language game

A great deal of misunderstanding arises from our inability to clearly convey our intended meaning. Humans often struggle to create vivid mental images in the minds of their listeners. Figure 1 illustrates how incorrect images are formed in the minds of those who listen. As the eminent philosopher Ludwig Wittgenstein stated: “Language is a public tool for understanding private life.”

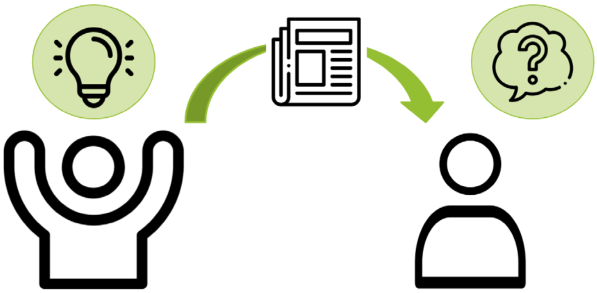


Figure 1. Misunderstanding and the language game

This issue poses a problem for scientific communication. Wittgenstein observed that scientific language does not precede our everyday conversations but instead emerges from ordinary language, not the other way around. It is therefore imperative not only to scrutinize scientific language but also to consider its roots in ordinary language. This realization gave rise to a new branch of philosophy: analytic philosophy, which aimed to establish a language free from ambiguities—an ideal language.

Philosophers like Rudolf Carnap engaged in the discipline of philosophy intending to eliminate ordinary language that, in their opinion, often invalidated philosophy. They contended that ordinary language could not be analysed using the scientific method due to its abundance of ambiguous expressions. Thus, they advocated for developing a precise, artificial, and ideal language comprising symbols devoid of contradictions. This group of philosophers, known as the “Vienna Circle”, formalised this approach into a doctrine known as “logical positivism”.

Logical positivism employed formal logical methods to construct an empiricist framework of knowledge, asserting that the truths of science are verifiable empirical claims. However, it is untenable to assert that empirical evidence alone constitutes scientific thought, as new discoveries may potentially challenge established "scientific facts", leading to paradigm shifts. This concept, introduced in the philosophy of science by the physicist and philosopher Thomas Kuhn, is exemplified in the paradigm shifts from Newtonian physics to Einstein's theory of relativity.

Daunting challenges are posed by the notion that only what is empirically verifiable is scientific, as possible exceptions always exist. In response to the perceived excesses of empirical verifiability, Karl Popper emphasized the role of falsifiability in the philosophy of science. Falsifiability refers to the possibility that any proposition, statement, theory, or hypothesis can be proven wrong. Popper argued that a scientific theory should be considered "provisionally true until disproved", asserting that the principle of falsification demarcates science from non-science.

Consider the following example: "Tomorrow it will rain or it will not rain." This sentence cannot be disproved, as one of two possibilities will inevitably occur. Consequently, it remains speculative and leads to a non-falsifiable theory. In contrast, the statement "Tomorrow it will rain" allows for a potential refutation: Tomorrow's weather will determine whether or not it is true. Whether it is a true or false statement is unknown but it is falsifiable. However, falsifiability also presents challenges, as this methodology forms a part of the analytic tradition.

3.1.3. English as the lingua franca of science and technology

The title of this sub-section conveys no new knowledge or surprises. English has attained widespread international status as a global lingua franca, as it is prominently employed in influential spheres such as media, economics, culture, medicine, intercultural and academic communication, and elsewhere.

Science, engineering, and research are no exceptions to this trend. Numerous studies and publications support this assertion, with approximately 95% of research papers being published in English. However, one might also question whether the problem lies in research being published in English or in the lack of publications in other languages. Reports on linguistic diversity in science indicate that more than eight out of every ten researchers opt to write in English, to the detriment of their mother tongues.

The aim of this book is not to analyse the linguistic diversity in primary literature but rather to underscore the importance of maintaining perspective and not disregarding the contents of a technical paper simply because it is not in English. For example, if one encounters a Japanese-language paper titled "Development of a High Power Micropump" while working on a micropump project, valuable information can still be gleaned (Harada et al. 1999). The abstract provides valuable information about the flow rate and working pressure (see Figure 2), and the figures provide highly detailed dimensions and specific tolerances of the micropump (see Figure 3). Additionally, contacting the authors for collaboration is always an option.

Development of High-Power Micropump

Takeshi HARADA†, Yasuhiko SASAKI†, and Akiomi KOUNO†

あらまし　本体直径7mmの高出力マイクロポンプを開発した．本ポンプの特長は，ネジシール・軸受一体構造のトロコイドギア回転駆動方式を採用したことにある．試作したマイクロトロコイドポンプは，発生油圧力1MPa以上，流量2.2～ 9.4ml/min以上と，機構体積当りの流量が大きい高出力特性を達成した．また，発生油圧力0.6MPa以上ではそのポンプ効率が理論値のほぼ1/2の10.7%で飽和した．この傾向については，ポンプ内部でのオイルの漏れ及び摺動部での機械的損失を考慮することにより説明できることがわかった．

キーワード　マイクロマシン，マイクロポンプ，トロコイドポンプ，ネジシール

Figure 2. Valuable information, flow rate, and working pressure in a non-English language abstract

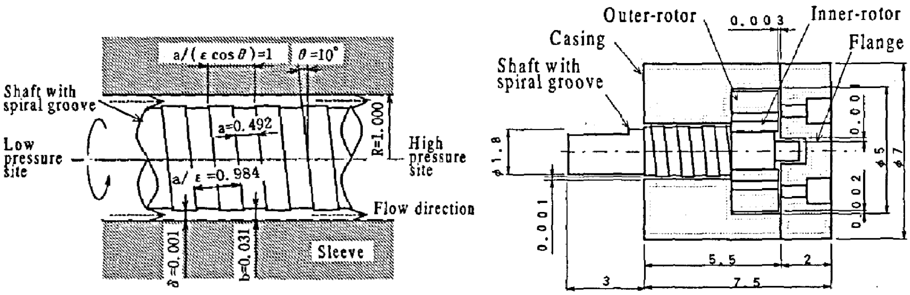


図2　ネジ型粘性シール基本構造　　図4　試作したマイクロトロコイドポンプの断面構造

Figure 3. Indispensable data, dimensions, and tolerances, in the figures of a non-English language paper

3.1.4. Telling the story

One obstacle to engineering students achieving success is the integration of mathematical concepts with fundamental engineering principles. Constructing a coherent narrative relies on linking previously memorized facts and learned methodology to the underlying laws and engineering mechanisms being applied to problem-solving scenarios.

Using research papers as a means to hone complex problem-solving skills entails merging a conceptual understanding of physics with mathematical symbology, and effectively applying this amalgamated knowledge productively and coherently. In essence, it requires a fully integrated understanding of engineering problems. However, because reading a research paper differs from reading a novel, making sense of it requires constructing a “new story” by adapting previously acquired knowledge, drawing on blended concepts, and applying fundamental engineering principles (Redish 2024).

In introductory engineering courses, students often manipulate equations in mathematics classes, working with abstract symbols devoid of any physical meaning. In advanced courses, instructors can blend conceptual physics knowledge with mathematical symbology using insights into how to approach engineering concepts. Reading research articles undoubtedly serves as a valuable tool in this process.

The mental structure, the network of connections, and ability to construct narratives, and the capacity to comprehend the concepts—these are all intrinsically linked, as summarized in Figure 4, which draws on the example of the discipline Fluid Mechanics. “Telling the story”, whether to oneself or others, involves progressing from lower-order to higher-order thinking skills, as delineated by Bloom’s taxonomy of verbs (Churches A. 2018).

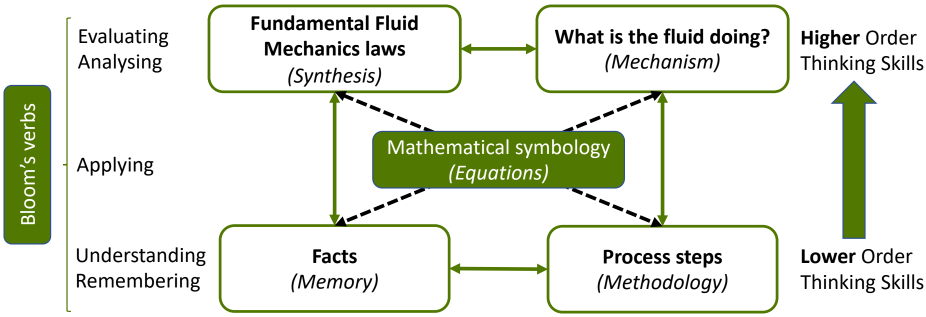


Figure 4. Building the conceptual network of fluid mechanics into a coherent knowledge base (adapted from Redish 2024)

3.1.5. Correlation vs. causation

Engineering involves conducting scientific analysis using measurable variables, with much research aimed at identifying the extent of relationships between variables. A change in the values of two variables is deemed related if the change in one is what produces the variation in the other.

In a statistical context, this relatedness is called **correlation** when it simply quantifies the magnitude and direction of the relationship between two or more variables as a numerical value—without necessarily implying that one causes the other. However, when a causal relationship exists between two occurrences, one is the result of the other, and this cause-and-effect form of relatedness is known as **causation**.

The occurrence of two events together (correlation) does not automatically establish one as the cause of the other (causation). This distinction is highlighted by Tyler Vigen in his exploration of spurious correlations, as depicted in Figure 5.

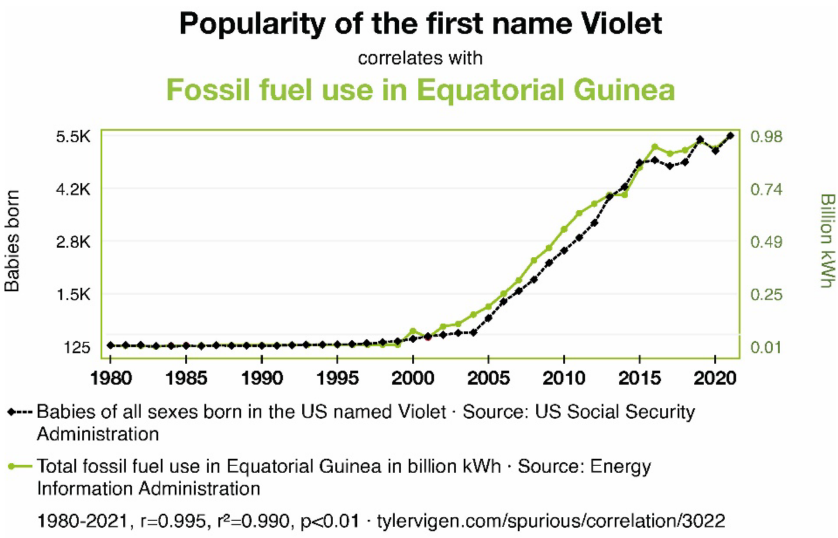


Figure 5. Correlation does not imply causation (from https://www.tylervigen.com/spurious-correlations, accessed on February 2024)

Further research is needed to investigate whether or not one action causes the other when a correlation is observed between two variables, as there may be a third variable that serves as the cause of both. For example, consider the humorous example of a morning headache (effect) being correlated with going to bed late and doing so with one's shoes on (cause). Although these two actions occur together (correlation), it does not imply that one causes the other (causation); clearly, there is a third variable at play. In this scenario, the distinction between the two types of relationships is evident and thus highlights the absence of cause and effect. In practical applications, however, establishing causation is often more challenging than determining correlation.

3.1.6. Positive, negative, significant, and null results

In scientific jargon, the term "positive" indicates that a result supports the tested hypothesis against an alternative or a "null" hypothesis of no effect. Conversely, the term "negative" refers to a result that fails to support the tested hypothesis. Rejection of the null hypothesis constitutes a positive result, as it strongly supports the alternative hypothesis. However, rejecting a true null hypothesis constitutes a false-positive error. The term "p-value" is used to assess the probability of a false-positive error. If p-values are reported, they directly indicate the likelihood of making a false-positive error:

– Very low p-values indicate that the null hypothesis can be rejected with high certainty.
– A high p-value means the observed result could easily arise by chance.
– As p-values decrease, the chance of making a false-positive error also decreases.

When using inferential statistics, the term "significant" means that the result is statistically significant based on the p-value. Findings are statistically significant when the p-value is less than a pre-established significance level. The commonly used pre-established significance value is 0.05, indicating that the null hypothesis will be rejected if there is less than a 5% chance of doing so mistakenly.

Negative results arise when the null hypothesis is not rejected. However, they can be challenging to publish, as research articles are less likely to be to be accepted and cited if they report negative results. This constitutes inappropriate practice, because all results are equally relevant to science, as long as they have been produced by sound logic and methods (Fanelli 2024).

Hence, terms such as ''positive'', ''significant'', ''negative", or ''null'' can increase researchers' bias due to the pressure to publish, as documented by Fanelli and other researchers in literature surveys and meta-analyses. Missing negative results are either completely hidden or, in some cases, turned into positive results through selective reporting of data and alternative examination, analyses, and reinterpretation.

As readers, we can also be influenced and adopt a biased disposition. When reading primary literature, focus on methods and results and try not to be influenced by the way the study is presented. The results presented in the document must be supported by evidence. Readers should be sceptical while also recognizing that research activity is challenging; studies are not expected to be flawless. Finally, accept uncertainty and do not anticipate finding absolute answers to every question.

3.2. Innovation: A word

Innovation can be defined as the process of creating, introducing, and applying new ideas, products, services, or methods. It involves implementing something new or significantly improved that adds value or solves problems in unique ways.

The surprising truth is that nobody really knows why or how innovation happens, let alone when and where it will happen next. Scholars "know remarkably little about the kind of institutions that foster and stimulate technological progress", says Mokyr in Ridley's book, *How Innovation Works: And Why It Flourishes in Freedom* (Ridley 2020). Innovators turn their own or others' inventions into useful innovations.

What is known is that innovation:

- Occurs when people are free to think, experiment, and speculate.
- Relies mostly on trial and error.
- Is heavily dependent on serendipity.

Serendipity refers to the phenomenon of finding interesting or valuable things by chance—that is, a valuable discovery made accidentally or casually. One of the most famous serendipitous events occurred when Alexander Fleming discovered penicillin in 1928, which led to major changes in medicine. Serendipity plays an important role in innovation; it implies finding one thing while looking for something else, but serendipity alone is not sufficient.

As an example, let us consider two paintings by the brilliant Dutch painter Piet Mondrian, depicted in Figure 6. On the left is "Composition No. I with Red and Blue", painted in 1931, which is part of the famous "Composition in Colours and Tableau" series by the artist. Inevitably, an unsophisticated viewer might think "I could do *that*", believing that the work is the result of luck, produced accidentally or casually while Mondrian was engaged in or seeking something else. However, as evidenced by the 1916 painting on the right in Figure 6, the notion of "I could do that" collapses for most individuals. In other words, with no foundation in painting, no experience, and without diligent work, serendipity is unlikely to manifest.

Figure 6. "Composition No. I with Red and Blue", 1931, by Piet Mondrian (left) and "Farm Near Duivendrecht", 1916, by Piet Mondrian (right)

Serendipity is one of many factors that may contribute to the advancement of science and have an impact on technology and technological development. However, hard work and basic knowledge are the key components of progress and these discoveries. As famously attributed to the former USA President, Thomas Jefferson, "I am a great believer in luck, and I find the harder I work, the more I have of it."

Another highly prominent concept worth mentioning here is Amara's Law, sometimes referred to as the "Amara hype cycle". Named after Roy Amara, it states "We tend to overestimate the effect of a technology in the short run and underestimate the effect in the long run" (Ridley 2020).

4
Anatomy of a research article

This section describes the main parts of a research article and the role played by each one. We will describe the fundamental sections of a research article and discuss the format, statistical analysis, appropriate validity checks of the results, and proper citation practices. Additionally, researchers must be familiar with their code of ethics and behave ethically (Thiel 2014). New knowledge is created only when it is made publicly available.

4.1 The structure of a research article

An initial overview of the structure of a research article can be observed in Figure 7.

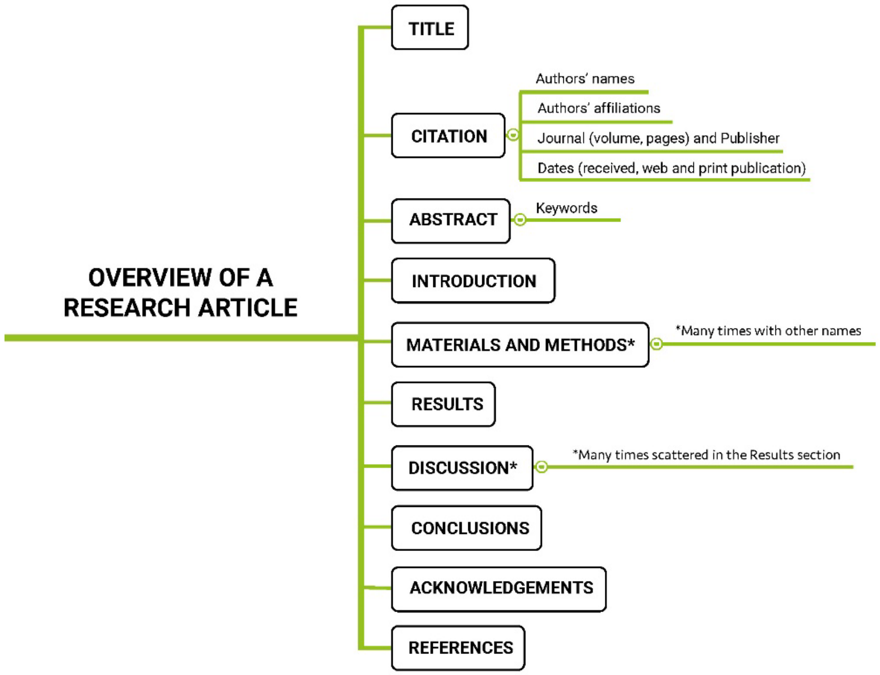


Figure 7. Schematic overview of a research article

Figure 8 offers a student-friendly learning tool to help remember and recognize the anatomy of a research paper. This word search is a didactic paper-and-pencil game that can be used as an in-class activity.

Reading Primary Literature word search **Date: ___/___/______**

A	C	K	N	O	W	L	E	D	G	E	M
X	Z	M	A	T	E	R	I	A	L	S	K
C	R	E	Q	C	Y	Q	T	I	B	N	I
S	A	T	W	A	T	A	G	K	V	O	N
N	Z	H	E	R	R	Z	B	O	R	I	T
O	F	O	R	T	E	W	R	O	E	S	R
I	S	D	T	S	W	S	F	L	F	U	O
S	Y	S	Y	B	Q	X	T	Z	E	L	D
S	C	I	T	A	T	I	O	N	R	C	U
U	U	R	A	R	T	P	U	Ñ	E	N	C
C	Y	X	C	V	N	Ñ	Y	L	N	O	T
S	T	L	U	S	E	R	U	L	C	C	I
I	O	V	B	I	Y	T	R	K	E	L	O
D	P	P	N	Q	W	E	E	T	S	P	N

Created by pjgm©2021

Find in this word search **11 words** related to the 'Anatomy' of a research paper. Words may be horizontal, vertical and diagonal (also backwards).

Figure 8. Reading primary literature word search

4.1.1 Article sections with no paywall charges

Articles published in open-access journals can be freely accessed and distributed without restrictions. They are free-of-charge and made fully available online without constraints, thereby ensuring that anyone can read them in full. If an article is not open-access, it is behind a paywall, meaning the site charges readers to access the contents.

Some sections are commonly made available without a paywall charge. These are the:

- Title
- Abstract
- Keywords
- Citations
- References (but not always, depending on the publisher)

4.1.2 Article sections with a paywall charge

For articles published under the traditional academic publishing model, paywalls limit access to the journal's content exclusively to subscribers or those who pay a fee.

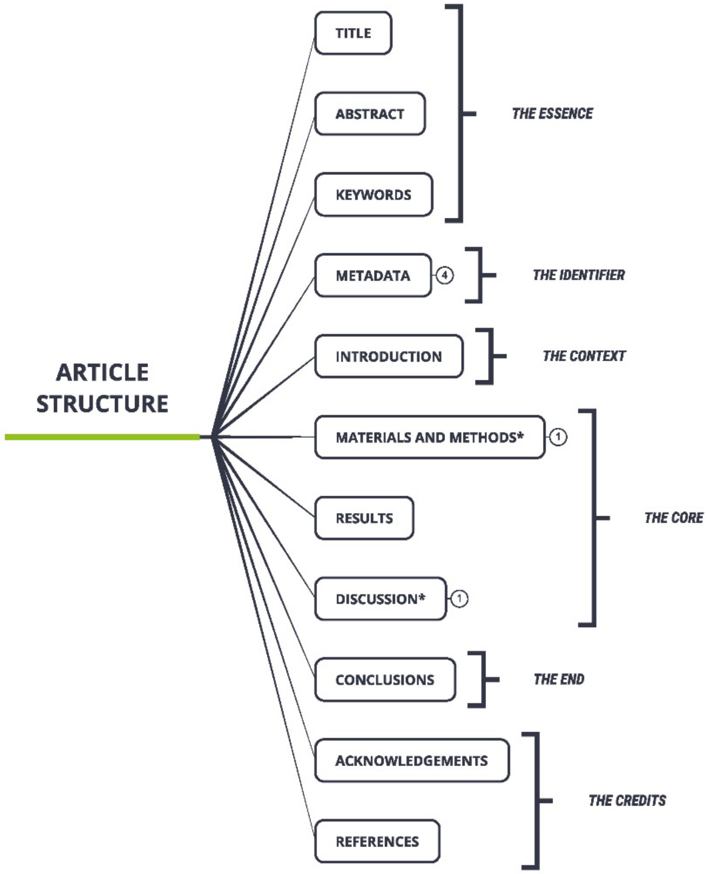


Figure 9. Article structure and sections: the essence, the identifier, the context, the core, the end and the credits

The sections that are most commonly subject to a paywall charge are the:

- Introduction
- Materials and Methods (often referred to by other names, especially in engineering)
- Results
- Discussion (sometimes integrated into the Results section)
- Conclusion
- Acknowledgments (often includes funding)
- References

As illustrated in Figure 9, the sections of the article with no paywall can be classified as the paper's essence and identifier, while those behind the paywall are the context, the core, the end, and the credits.

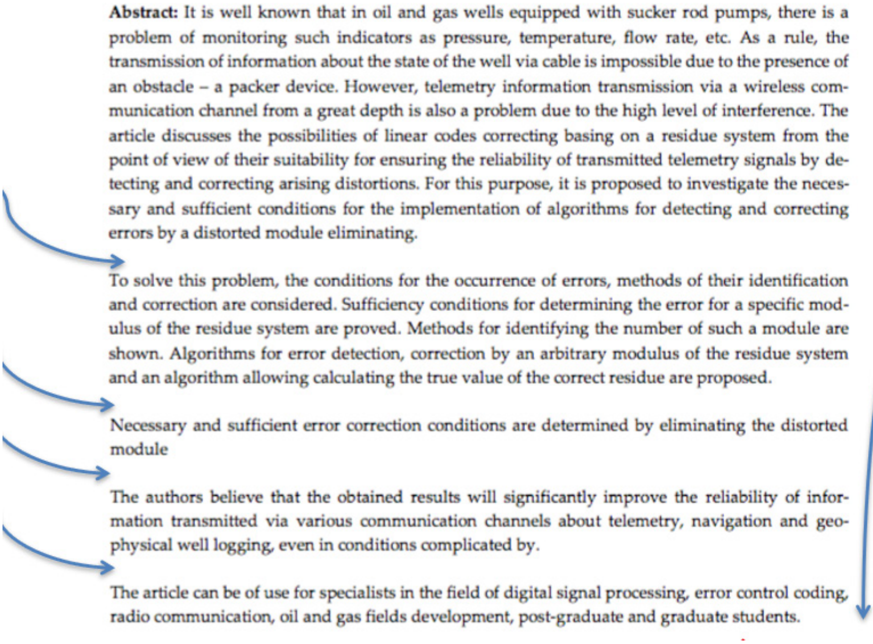
4.2 The Title, Abstract, and Keywords: The essence of the article

The Title and Abstract are, by far, the most important sections of a research paper. This is because the Title and Abstract are accessible to the World Wide Web without any paywall charge; in other words, to everyone.

The **Title**, if successfully crafted, should provide information that best summarizes the paper; researchers must attentively write a concise, attractive title that makes their potential audience think "I want to read this paper" (see Figure 10). Note the importance of the title and scrutinise it. The title should indirectly indicate the discipline of the engineering research.

Figure 10. Proportion of a reader's attention

Abstracts are concise summaries of research papers, typically limited to 250 words in a single paragraph. Thus, each word must be carefully chosen to convey the purpose of the study, the experimental approach, key results, and conclusions (for an example of an inappropriate abstract, see Figure 11). Avoid using acronyms, as not all readers, particularly novice readers, will be familiar with their usage.



Abstract: It is well known that in oil and gas wells equipped with sucker rod pumps, there is a problem of monitoring such indicators as pressure, temperature, flow rate, etc. As a rule, the transmission of information about the state of the well via cable is impossible due to the presence of an obstacle – a packer device. However, telemetry information transmission via a wireless communication channel from a great depth is also a problem due to the high level of interference. The article discusses the possibilities of linear codes correcting basing on a residue system from the point of view of their suitability for ensuring the reliability of transmitted telemetry signals by detecting and correcting arising distortions. For this purpose, it is proposed to investigate the necessary and sufficient conditions for the implementation of algorithms for detecting and correcting errors by a distorted module eliminating.

To solve this problem, the conditions for the occurrence of errors, methods of their identification and correction are considered. Sufficiency conditions for determining the error for a specific modulus of the residue system are proved. Methods for identifying the number of such a module are shown. Algorithms for error detection, correction by an arbitrary modulus of the residue system and an algorithm allowing calculating the true value of the correct residue are proposed.

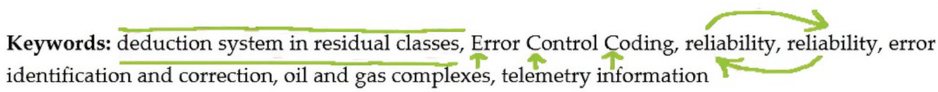
Necessary and sufficient error correction conditions are determined by eliminating the distorted module

The authors believe that the obtained results will significantly improve the reliability of information transmitted via various communication channels about telemetry, navigation and geophysical well logging, even in conditions complicated by.

The article can be of use for specialists in the field of digital signal processing, error control coding, radio communication, oil and gas fields development, post-graduate and graduate students.

Figure 11. An inappropriate abstract: more than a single paragraph and with too many words

Keywords are essential for capturing the essence of the paper, making it searchable and discoverable. Therefore, it is crucial to meticulously select and include relevant keywords to help others find your paper and to avoid mistakes like those presented in Figure 12.



Keywords: deduction system in residual classes, Error Control Coding, reliability, reliability, error identification and correction, oil and gas complexes, telemetry information

Figure 12. An inappropriate list of keywords: A preposition is not keyword; no groups of more than three words; no uppercase letters; do not repeat words.

4.3 Authors, Affiliations, and Publication Dates: The article's identification

The paper's identifier comprises information that other authors may use for citing the paper (metadata), typically located at the top of the first page between the title and the abstract. This information includes author names, institutional affiliations, journal and publisher names, volume, issue, page numbers, and publication date (see Figure 13).

Regarding the positioning of authors in the list, the following holistic rules apply:

- The **first author** is typically the researcher who contributed the most to the work.
- The **Principal Investigator** (PI) is often listed as the last author. Both first author and the principal investigator receive the primary credit for the study.
- The other authors, known as middle authors, are co-authors who collaborated to varying extents in the research and writing of the paper. They may have contributed in various ways, such as providing technical support, reviewing, editing, or otherwise.

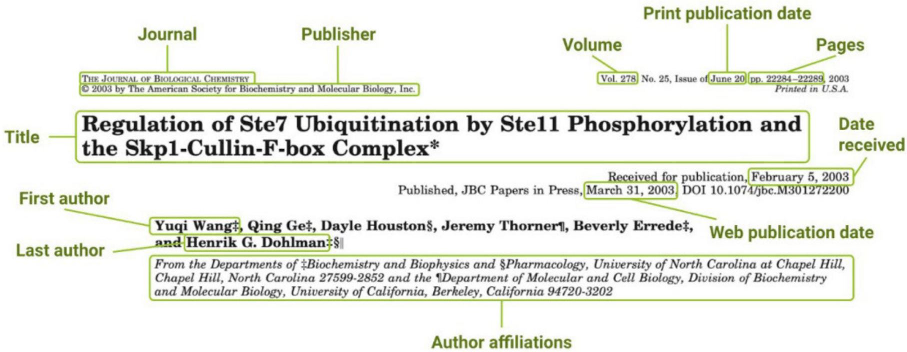


Figure 13. Schematic representation of the various components of the citation information (adapted from Guillen 2007)

> *Important*: The **author's affiliation is the institutional affiliation**, university, or research centre. No generic or personal email should be used.

Regarding the publication dates, submitted articles undergo initial consideration by an Editor, who will note the date it is received (as in Figure 13). The Editor assesses whether the manuscript falls within the scope of the journal. If deemed suitable, the Editor proceeds to send it out for peer review.

Two or more anonymous reviewers, who are the author's peers and have expertise in the study's topic will evaluate the work. These fellow research scientists will:

- Critically evaluate the manuscript and inform the Editor whether it is suitable for publication.
- Write a set of comments for the authors to revise and resubmit.

Ultimately, the final decision of the publication rests with the Editor, thereby determining the publication date, if accepted.

4.4 Introduction: The context of the article

The **introduction** section serves to provide background information and describe the study's purpose and research problems. It elucidates prior work and highlights areas of controversy. Choosing which questions to pursue is a crucial decision for researchers.

4.5 Materials and Methods, Results, and Discussion: The core of the paper

The **Materials and Methods** section describes how a study was performed. Researchers often conduct preliminary studies before undertaking the work reported in a paper.

The **Results** section is positioned centrally within the body of the paper, presenting the study's findings.

The **Discussion** section offers authors the opportunity to explain the significance of their findings, highlight key conclusions, and address potential criticism.

4.6 The Conclusions: The end

In the **Conclusions** section, the authors state the key findings of the study.

4.7 Acknowledgments and References: The credits

In the **Acknowledgments**, authors express gratitude to individuals or institutions that contributed to the work. It is important to check if the study was funded, as funded projects typically undergo rigorous peer review.

The **References** section includes only those articles cited in the text of the paper. By citing other studies, researchers acknowledge the work of others and position their own work within the broader scientific literature.

5
How to read a paper

Scientific writing is characterised by a highly specific vocabulary, concise and precise language, and often complex grammatical structures. Therefore, comprehending scientific studies can pose cognitive challenges, especially for readers unfamiliar with the field's terminology. The ability to critically and effectively read a paper is essential. Regular reading can aid in staying current with new research, fostering original ideas, and producing superior papers.

This section outlines an efficient method for reading a paper. Keshav (2007) proposed a **three-pass approach**, summarised as follows:

- **Gain a general understanding of the article:** Read the Title, Abstract, and Introduction → Read section and sub-section headings (ignoring other content) → Read the Conclusions → Scan references.
  - *Evaluation*: This pass should reveal the article's main highlights; if not, the article may not be worth reading.
- **Grasp the article's content (but not its details):** Examine illustrations, figures, and graphics → Focus on the quality and statistical significance of the results → Explore references for background information.
  - *Evaluation*: The level of detail in this pass should indicate if the article aligns with the desired research speciality.
- **Understand the article in depth:** Pay close attention to details → Adopt the same assumptions as the authors to recreate the work → Record ideas for future work.
  - *Evaluation*: This final pass offers a deep insight into the evidence, Discussion, and presentation techniques, and it typically requires about four to five hours for beginners.

5.1 Gain a general understanding of the article when unable to access all its contents.

When the contents are mostly behind a paywall, the Keshav three-pass approach is reduced to:

1. **Get a BASIC general idea about the article:** Read the Title and Abstract.

In other words, all you can read is the Title and Abstract.

5.1.1 Title

The title of the article must have impact, since it serves as the primary opportunity to capture the reader's attention. It is the essence of the research conducted and provides a preview of the article's contents. A good title critically provides a brief explanation of the article so readers can anticipate the contents before delving into specifics. It uses current terminology in the field and employs limited but substantial words (typically between ten and twenty words; fewer than five words is too brief).

One crucial practice is identifying the core essence of the article that aligns with the title. Unnecessary words like "study", "investigation", or "case" add little value and can be omitted, as they do not enhance understanding of the context.

5.1.2 Abstract

The Abstract serves as the initial immersion into the language of a scientific research paper. For instance, Figure 14 illustrates the importance of selected words in the Abstract of a paper titled "Influence of Having Breakfast on Cognitive Performance and Mood in 13- to 20-Year-Old High School Students: Results of a Crossover Trial" (Widenhorn-Müller et al. 2008). Initially, upon reading the Title, it can be inferred that having breakfast affects cognition, including memory, attention, and mood. Subsequently, upon reading the Abstract, the last sentence describing the Conclusions informs us that these effects indeed do exist, but notably, they are short-term, thus encapsulating the core findings.

The Abstract should succinctly articulate the research question and research hypothesis, which are also clearly stated in the Introduction section. These elements are the motivation behind the entire paper, forming points of departure for the subsequent sections: Methods, Results, and Discussion. The research question or hypothesis should address three key components:

a) What is known or believed about the research topic?

b) What is still unknown or problematic?

c) What is the investigative question or hypothesis?

ABSTRACT

OBJECTIVE. The goal was to determine whether breakfast had effects on the cognitive performance and mood of high school students.

METHODS. A crossover trial was performed in boarding schools, involving 104 students between 13 and 20 years of age. The participants were randomly assigned to 2 equal-size groups on the morning of the first testing day. One half of the total sample received a standardized breakfast, whereas the other half received no breakfast. Seven days later, the treatment order was reversed. Measurements of cognitive function included standardized tests of attention and concentration, as well as tests of verbal and spatial memory. In addition, mood was rated with a self-administered questionnaire covering the dimensions of positive and negative affect, information uptake, arousal, and alertness. Statistical analysis consisted of repeated-measures analysis of variance.

RESULTS. Breakfast had no effect on sustained attention among high school students. Visuospatial memory was improved in male students. Self-reported alertness improved significantly in the entire study population. Male students reported feeling more positive after consuming breakfast, compared with the fasting condition.

CONCLUSIONS. This crossover trial demonstrated positive short-term effects of breakfast on cognitive functioning and self-reported alertness in high school students. *Pediatrics* 2008;122:279–284

Figure 14. Paper titled "Influence of Having Breakfast on Cognitive Performance and Mood in 13- to 20-Year-Old High School Students: Results of a Crossover Trial". An example of selecting an important word in an Abstract (from Widenhorn-Müller et al. 2008)

5.2 Get a general idea of the article when full contents are available.

Referring back to the Keshav three-pass approach when you have full access to the article, recall that the first step is:

2. **Get a general idea about the article:** Read the Introduction → Read section and sub-section headings (ignoring other content) → Read the Conclusions → Scan references.

Next, you should read the Introduction and Conclusions, then scan the references.

5.2.1 Introduction

The Introduction establishes a compelling argument for the study's significance and relevance. Observation, explanation, and experimentation intertwine in a continuous cycle, as depicted in Figure 15. This section must effectively articulate the purpose of the research and set the narrative tone for the study.

A typical Introduction begins with an in-depth literature review or description of the state of the art. Skip it! Begin by finding the paragraph stating the study's

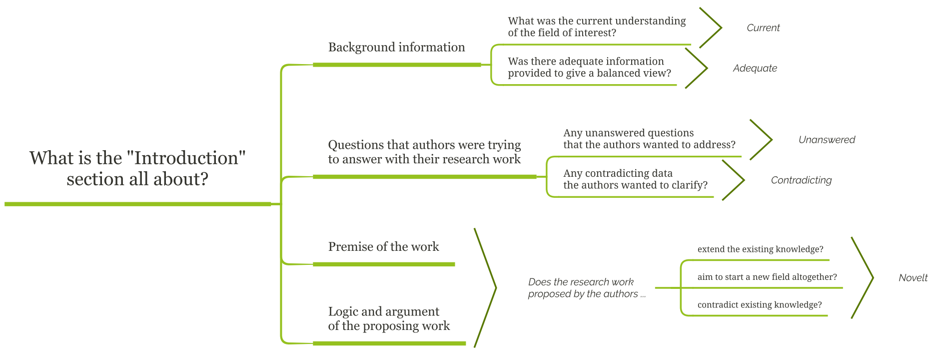


Figure 15. Comprehensive framework for the Introduction section's content

objectives and research questions, which can commonly be found at the end of this section (see Figure 16). This critical paragraph should describe unexpected results and a paradigm-shifting conclusion to all problem statements, research questions, research hypotheses, and objectives (see Figure 17). Figures 16 and 17 identify the four keystones of the paper: the problem statement, research question, research hypothesis, and study objective. These must be robust and, at this stage, authors should convincingly imply that the research question(s) will be answered following appropriate scientific rigour.

Guidelines:

- Read the Introduction section to identify the main research area.
- Ensure that you understand the most important terms used in the Introduction.
- Identify two or three key previous studies that are described in the Introduction
- Identify the primary objective of the paper
- Establish whether any controversies surround the research area.
- Determine the novel research question posed by the authors. Why is this question significant? How does it extend beyond prior work?
- Consider whether the paper aims to develop a new theory, refine an existing methodology, or introduce a novel approach. Understanding the paper's approach is crucial.
- Assess whether the paper aims to develop a new technique or technology.

Notes:

- Take time to learn the specialized vocabulary. Despite it being time-consuming, it is necessary.
- Secondary sources are useful for understanding scientific terminology.
- Hypotheses are often stated toward the end of the Introduction.

– Do not fret if you occasionally come across a paper that does not fit neatly into the framework discussed here.

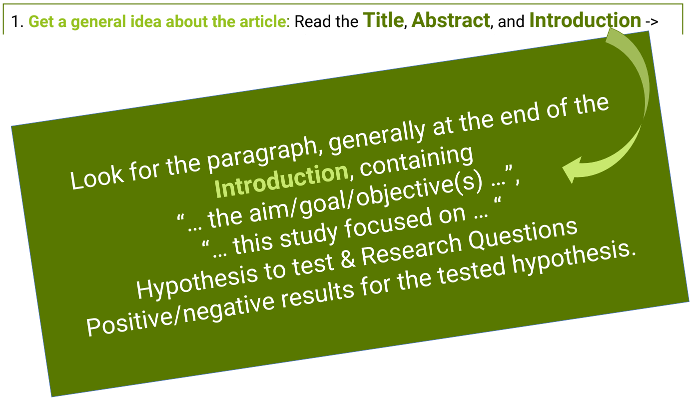


Figure 16. The last paragraph of the introduction

When you work on your **reading**, find these **four keystones** in the paper:

(i) **Problem statement**
- *What issues have they encountered and want to solve?*

(ii) **Research question**
- *What specific question does the study ask to solve the problem statement?*

(iii) **Research hypothesis**
- *The hypothesis responds to the research question with a predictive statement that aligns with the inquiry.*

(iv) **Objective**
- *The objective provides a roadmap for solving the problem, answering the question, and testing the hypothesis.*

Figure 17. The four keystones of the paper

5.2.2 Conclusion

The **Conclusion** section serves as the platform for the authors to explicitly articulate the key findings of the article. This section should seamlessly align with the purpose of the study and its objective. The authors face the challenge of substantiating their observations and conclusions based on their findings with a rigour akin to the legal notion of "beyond reasonable doubt".

Guide:

- Identify the significant findings within the article.
- Reflect on the main conclusions drawn by the authors.
- Assess whether the authors' conclusions align with their interpretation of the data.
- Evaluate whether the results address the questions or hypotheses posited by the authors.
- Determine if the conclusions cohere with the paper's objectives.

Notes:

- Deconstruct the conclusions into key ideas and findings.
- Briefly deliberate on whether your perspective aligns with the authors' conclusions based on your critical examination.
- Conclude with an overview of your overall assessment of the article.

The crux lies in formulating your own appraisal of the article and drawing your own conclusions.

5.2.3 Scan references

Relevant references emerge continually in newly published articles. Referencing serves as a means to acknowledge the authors from whom the researcher has drawn arguments, designs, and concepts. Moreover, they offer evidence that substantiates the assertions and propositions in the researcher's work. When it is unfeasible to peruse a multitude of articles, the reader can focus on the one extensively cited by other researchers. Undoubtedly, this one is the paramount paper to read.

✓ Identify the extensively cited article.

Evaluation: The highlights of the article should be revealed in the Keshav pass, "**Get a general idea about the article**". If not, the article may not be worth reading.

5.3 Grasping the article's content but not the details

If you can access all the article's contents, the second pass in Keshav's approach is:

- **Grasp the article's content (but not its details):** Examine illustrations, figures, and graphics → Focus on the quality and statistical significance of the results → Explore references for background information.

5.3.1 Look carefully at the illustrations, figures, and graphics

Research articles often present data visually through various graphical forms. Below are several examples of how to conduct a visual quality check, focusing on the overall quality and representativeness without delving into specific results.

- ✓ Scrutinize the illustrations, figures, and graphics for quality and representativeness.

Annotation and Dimension on Construction Drawings

Figure 18 shows a low-quality sketch that falls short of the standards for technical drawing due to deficiencies in annotation. Specifically, the linear dimensions feature minuscule arrows, the placement of length and diameter numbers are in the drawing's midsection, and the text size hinders readability.

- ✓ Assess the quality of construction drawings.

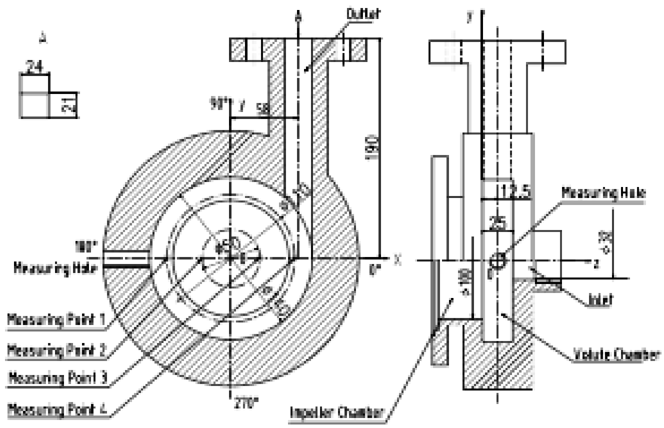


Figure 18. Example of annotation and dimensions: "Structure and distribution of hydraulic geometric sketch"

Graphical symbols for engineering diagrams and plans

International standards provide rules for designing graphical symbols to guide technicians and designers in adhering to best practices when creating drawings, diagrams, and plans for engineering applications and equipment. Figure 19 exemplifies the absence of standard graphical symbols in fluid mechanics, such as pumps, flow meters, and pipelines.

- ✓ Evaluate the quality of engineering diagrams and plans.

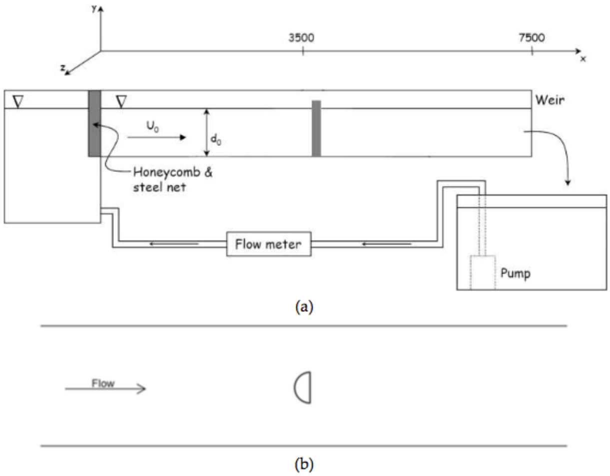


Figure 19. Example of graphical symbol in engineering diagrams: “Open channel (a) water flume and (b) flume plan view”

Images

When using CAD software, the default background may not always be the optimal choice and could potentially cause confusion, as depicted in Figure 20. This instance portrays trains appearing to circulate on grass rather than tracks. Furthermore, the locomotive shape of existing trains (on the left) and the nose of the S trains require improved accuracy.

✓ Look for the images and the quality of their presentation.

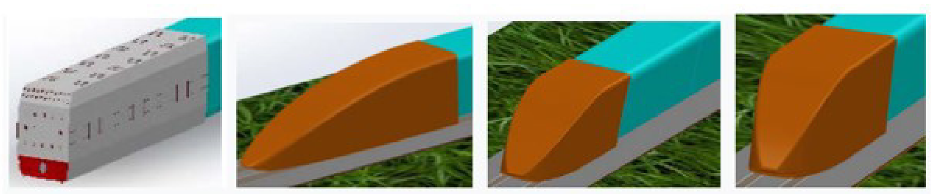


Figure 2. The locomotive shape of existing trains in [illegible] and nose S trains for $\gamma = 8$, 6, and 4, respectively.

Figure 20. Example of confusing images: “The locomotive shape of existing trains and nose S trains.”

Magnitudes and units

Technical documentation necessitates including units of measurement for the presented figures, with a preference for the International System of Units (SI), which is the modern form of the metric system and most widely used system of measurement in the world. Additionally, attention should be given to the readability of numerical characters. Figure 21 depicts the fluid dynamic results of static pressure, but critical elements are absent from the figure, such as pressure units in the legend, a legible scale, and length units for the axial cross-section location.

✓ Verify adherence to the International System of Units in all figures.

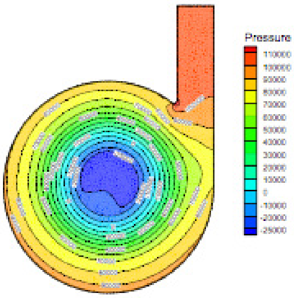


Figure 21. Example of missing units of measurement, a legible scale, and length units for the axial cross-section location in the figure: "Static pressure distribution on the axial cross section"

5.3.2 Scan graphical and tabular results

The Results are a core component of a study. Researchers gather data in various forms, including numerical outputs from instruments and visual information like photographs. Refer to Figure 22 to see the framework of the Results section.

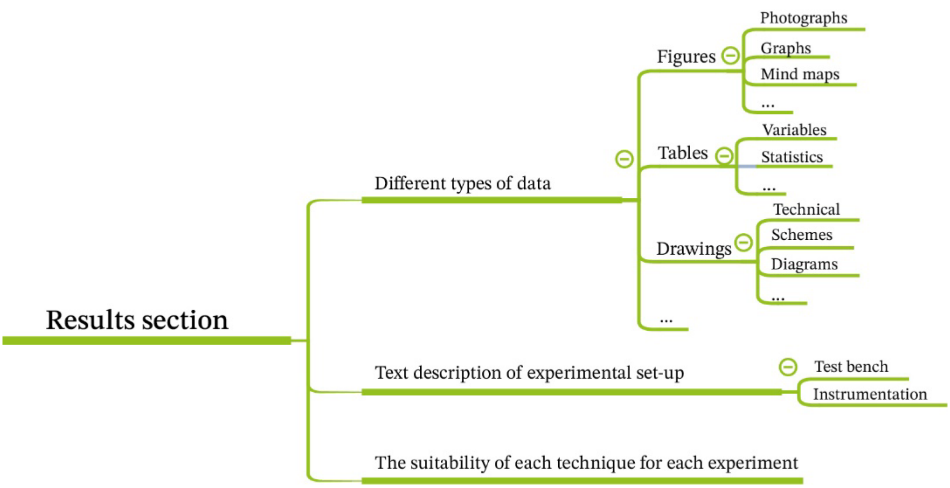


Figure 22. Results section framework

Research findings are derived from collected data presented in the article. Technical variability, or measurement error, occurs any time a measurement is made. The data acts as a lock, and the key that opens it is interpretation. In other words, facts support the findings. The data and interpretation open the door to implications that reveal the significance and relevance of the findings.

✓ Carefully examine the instrumentation and measurements.

5.3.3 Pay special attention to the quality of the result

Results should be coherent and consistent with the research question, but also clear, interpretable, and comprehensive. The graphical representation of an aerodynamics test in Figure 23 lacks clarity, as the test object is not clearly defined; it lacks interpretability due to the absence of a legend and magnitude indicators; and the legend fails to provide comprehensive information as to the type of aerodynamic performance (e.g., pressure, velocity, vorticity) depicted by the streamlines and isosurfaces.

✓ Assess the presentation quality of the research findings.

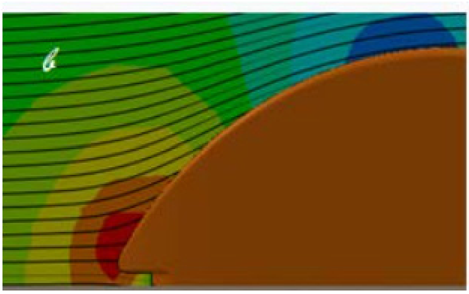


Figure 23. Example of low-quality results: "Aerodynamic performance"

The value of any research hinges on the presentation of the results, whose quality shapes their legitimacy and reliability. Legitimacy pertains to the precision of the measurements of the intended physical magnitudes (accuracy), reflecting the quality of the instrument measurement. Reliability encompasses the consistency of measurements, which is determined by the ability to continuously measure and transmit data (resolution), and the ability to duplicate a measurement (repeatability).

Figure 24 illustrates the concepts of accuracy, resolution, and repeatability. The precision of the calculated and measured velocity values is indicated up to the third decimal when using a differential U-tube manometer with an expected accuracy of one millimetre. This precision is inconsistent and compromises resolution and repeatability when employing a sphere probe. Additionally, the cross-section lacks units of measurement.

5. Experimental verification

Simulation

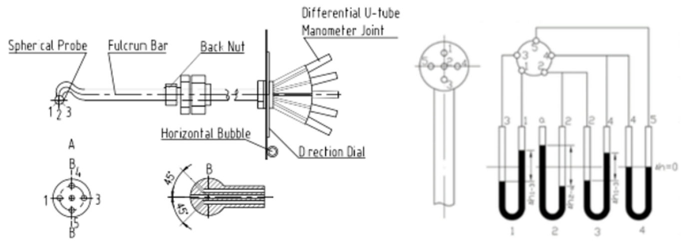


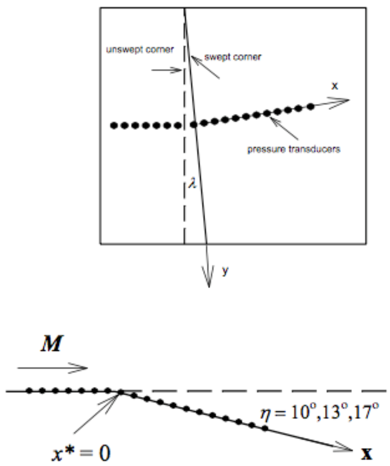
Fig 11 Probes measuring system

168 **Table 2.** calculated and measured value of flow field curves on the axial cross section Z=12.5

Calculated and measured position	Discharge q_v/m³·h⁻¹	Rotational speed n/r/min	Value type	Absolute velocity v/m·s⁻¹	Circumferential velocity v_u/m·s⁻¹	Radial velocity v_r/m·s⁻¹	Axial velocity v_z/m·s⁻¹	Static pressure p_s/pa
x= - 55mm Measuring point 1	9.31	2851	Calculated value	9.806	9.512	1.612	1.782	66126
			Measured value	9.312	9.002	1.237	0.657	59051

Figure 24. Example of experimental validation regarding accuracy and resolution of the instrument, measurement error: "Calculated and measured value of flow field curves on the axial cross section Z=12.5"

Figure 25 shows an example of an inadequate description of instrumentation placement, where essential details are lacking, such as distances and the positioning relative to the test object.



*solid circles: location of pressure transducers

Figure 25. Example of experimental instrumentation placement: "*solid circles: location of pressure transducers"

5.3.4 Pay special attention to the statistical significance of the results

As previously discussed, the value of any research is delimited by the validity and consistency of its design and findings. Managing variability constitutes a crucial aspect of the results, alongside statistical analysis.

✓ Assess the measurement quality and statistical analysis.

Dealing with variability

Variability is inherent in measurements of systems. Technical variability, otherwise known as measurement error, emerges whenever a measurement is taken.

Key instrument terminology:

- **Accuracy** represents a comprehensive assessment of performance that defines the quality of the instrument's measurement. Likely the most critical aspect of the results, it is typically expressed as a positive or negative percentage relative to either the reading, the calibrated span, or the full scale of the instrument.
- **Resolution** denotes the instrument's ability to continuously measure and transmit all process variables. It is defined as the smallest change in input detectable at the output.
- **Sensitivity** of a measurement system reflects the output change resulting from a slight alteration in input.
- **Repeatability** indicates the instrument's ability to precisely replicate a measurement under identical operating conditions.
- **Response Time** refers to the instrument's ability to respond to changes in process variables. The research outcomes may significantly rely on the sampling method employed.

Error and uncertainty

While accuracy in measurement denotes the degree of agreement between an experimentally determined value of a quantity and its true value, error represents the disparity between the experimentally determined value and the true value.

Since, in working conditions, the true values of measured quantities are rarely known in practical settings, error must be approximated. This estimation is termed uncertainty and should consider operational feasibility.

Uncertainty, error, and accuracy are closely intertwined. Accuracy improves as error approaches zero. Uncertainty is particularly relevant when addressing instrument and system errors. Absolute error quantifies the difference between the measured value and the true value.

Errors can be classified as:

– Precision error. This type of error is random and varies with each measurement, thus contributing to data scatter.

– Bias error. This type of error reflects the deviation between the average value of readings and the true value of the variable. For a single instrument measuring a variable, bias error manifests as a fixed value or constant error (e.g., scale resolution) and cannot be statistically determined.

In essence, there are two primary types of measurement error:

– Accidental error, such as misreading the pressure value on the dial scale of a manometer.

– Systematic error stemming from a bias in the measurement technique. For example, a miscalibrated scale consistently registers higher or lower pressure values. This is known as zero error.

Descriptive statistics

It is crucial to examine the descriptive statistics. Measures of **central tendency** describe the centre of the data set, and they showcase typical or representative values such as mean, median, and mode (see Figure 26):

– **Mean** represents the arithmetic average of the points in the data set.

– **Median** denotes the middle value when the points are arranged from highest to lowest.

– **Mode** signifies the most frequently occurring value in a data set.

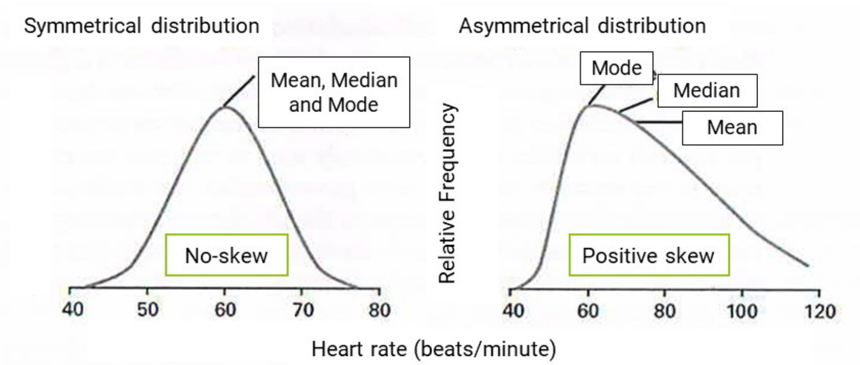


Figure 26. Example of central tendency measures

Measures of variability describe the **dispersion** within the data set, encompassing range, variance, and standard deviation. It is imperative that results not only present central tendency values but also dispersion.

– **Range** signifies the span between the minimum and maximum values.
– **Standard deviation (SD)** represents the adjusted average distance between individual data points and the mean. A large standard deviation indicates high variability.

For a normal distribution:

– About 68% of values are within one standard deviation of the mean (±1.SD)
– About 95% of values are within two standard deviations of the mean (±2.SD)

Values are often reported as **mean ± standard deviation.**

> ⚠ Consider the magnitude of variability in the context of the central tendency.

For instance, a standard deviation of one second may seem inconsequential when contrasting a mean difference of several hours, yet it becomes critical when evaluating a mean difference of a few seconds.

Inferential statistics

From a sample to a population

Inferential statistics facilitate generalisation from the sample (studied group) to the population (wider group). A crucial aspect of evaluating such results involves determining how accurately the sample represents the population. Uncertainty inherently exists in this process, resulting in statements of probabilities rather than certainties.

Statistical tests: Null and alternative hypothesis

– Only one hypothesis, either the null or alternative, is true.
– The alternative hypothesis requires robust evidence for acceptance.
– Support for the alternative hypothesis emerges only when the null hypothesis is rejected.

Example: Is there a human being hiding behind the curtain? (We suspect it might be a Martian! See Figure 27).

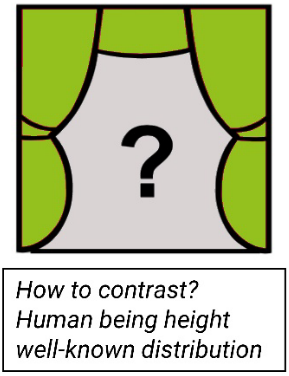


Figure 27. Is a human behind the curtain? Image associated with example

Let us formulate the **null hypothesis** (H0) against the **alternative hypothesis** (H1):

- **H0**: Yes, it is a human being {Which we assume to be true until proven otherwise. By default, we keep this one}.
- **H1**: No, it is not a human being {If there is sufficiently clear evidence, we will reject the null hypothesis and stay with the alternative.}

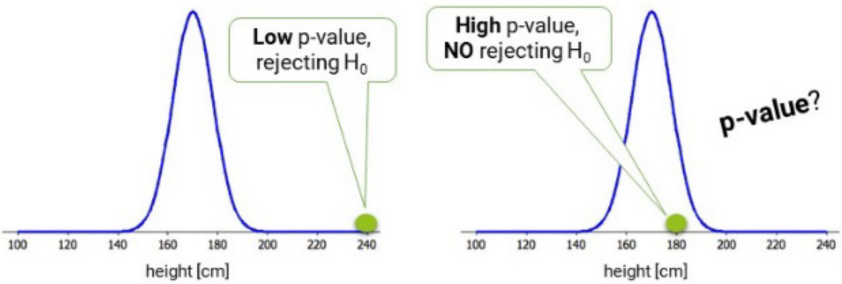


Figure 28. Graphic representation of two different hypothesis outcomes. The blue curve is the height test statistic of a human being: On the left, the null hypothesis is rejected; on the right, it is accepted.

Now, let us contrast hypotheses:

- Test statistic: This is a number derived from the available data, and its distribution is known when the null hypothesis H0 is true.
- Reference distribution: This is the distribution that the test statistic follows if the null hypothesis H0 is true.

Next, we compare the test statistic with its reference distribution. If the null hypothesis is true (indicating the creature is a human being), we know how the test statistic (height) is distributed (human heights follow a normal distribution with parameters N [170 cm; 8 cm], as depicted by the blue curve in Figure 28). Then:

- If the measurement of the height of the creature behind the curtain is 240 cm (the test statistic) and is contrasted with the reference distribution, is it reasonable to believe that such a value arises from the reference distribution? No, it is not, as illustrated on the left in Figure 28. Hence, H0 is likely not true, and we are inclined towards the alternative hypothesis H1.
- Conversely, if the measurement of the height of the creature behind the curtain is 180 cm (test statistic), then it is plausible that this value fits the reference distribution representing the distribution of heights of human beings, as shown on the right in Figure 28. When we lack sufficient evidence to reject H0, we maintain it. In this scenario, we cannot assert that the creature is not a human being.

How do we quantify our belief or disbelief regarding whether the test statistic arises from the reference distribution? This is assessed through the p-value.

Positive and negative results

Rejection of the null hypothesis is a positive result, indicating strong support for the alternative hypothesis. However, rejecting a true null hypothesis leads to a Type 1 error, commonly known as a false-positive error.

Assessing the probability of a false-positive error is done through the p-value.

Findings are deemed **statistically significant** when the **p-value is less** than a pre-established **significance level.**

When p-values are reported, they directly convey the likelihood of committing a false-positive error:

- Very low p-values indicate that the null hypothesis can be rejected with a high degree of certainty.
- A high p-value suggests the observed result could easily occur by chance.
- As p-values decrease, the likelihood of committing a false-positive error also decreases.

Statistically significant: $p < 0.05$

This means that the null hypothesis will be rejected if there is less than a 5% chance of doing so mistakenly.

Negative results occur when the null hypothesis is not rejected. However, as discussed in the previous chapter, they can be challenging to publish. This practice is inappropriate because terms like “positive”, “significant”, “negative”, or “null” are common scientific jargon, yet they can be misleading. In reality, all results are equally relevant to science as long as they are derived from sound logic and methods (Fanelli 2024).

Evaluation: In this pass called “**Grasp the article's content (but not its details)”,** the level of detail should indicate if the article aligns with the desired research speciality.

5.4 Understand the article in depth when you are sure it is the right article.

At this point in having access to all of the articles’ content, and having performed two of Keshav’s three-pass approach, we are left with only the third one:

3. **Understand the article in depth:** Pay close attention to details Adopt the same assumptions as the authors to recreate the work Record ideas for future work.

Therefore, carefully read the Materials and Methods, Results, and Discussion sections. These are the foundations upon which the entire article is built and flourishes.

5.4.1 Materials and Methods

The authors of a paper present their research design in terms of the planning and methodology used for conducting their study. Overall, the Materials and Methods section should use methodological detail to fully describe their research path:

- **Methodological detail** and technical terminology are often densely packed within this section (see Figure 29).
- **Reproducibility** is a hallmark of research progress. When authors thoroughly describe their methods, they enable their colleagues to easily build upon the work. This can save other researchers a great amount of effort, as successful approaches are often the result of time-consuming optimization.
- **Convincing** findings emerge when a study's design aligns well with its purpose. One of the main objectives of the Materials and Methods section is to evaluate the effectiveness of the experimental design.

The Materials and Methods section delineates how a study was conducted. Researchers frequently undertake preliminary studies before performing the work reported in a paper (see Figure 29).

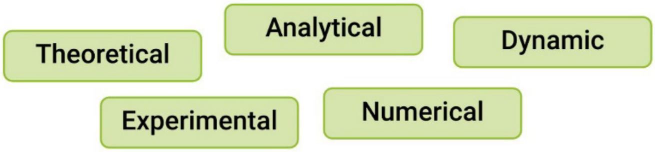


Figure 29. Types of study

Please bear in mind that this section is common in life sciences, but less so in engineering and technological papers, where it may not necessarily be called Materials and Methods.

Guide:

- Was preliminary work done before the reported methodological detail?
- Does this section provide enough detail for other investigators to repeat the work?
- Did the researchers fail to control any important variables?
- Does the design fit well with the study's main purpose?
- Is there a flowchart? A timeline?

Notes:

- To manage technical terminology, one strategy is to evaluate the variables that were assessed, measured, manipulated, or controlled, otherwise known as dependent, independent, and controlled variables.
- List the variables studied.
- Draw a flowchart.
- Draw a timeline depicting the experimental design.

5.4.2 Results

Results can be presented in various formats such as pictures, graphs, tables, figures, or statements within the text. When evaluating the results, it is essential to consider how they have been presented and answer the question: Are the findings aligned with the aim of the paper?

Guide:

- As you evaluate the results, consider how they have been presented.
- Evaluate the results independently of their presentation.
- Identify the main trends in the data.
- Assess how variability is depicted.
- Determine the relevance of the findings.

Notes:

- Carefully read the figure legend to identify the independent and dependent variables.
- Examine the units, axis scale, and labels of the graph.
- Examine the measures of variability, often given as error bars.
- Use standard errors or other statistical measures to support your analysis.

Results should incorporate statistical treatment and information to enhance their value and reliability (see example in Figure 30).

A graph can **accentuate** or **obscure** different aspects of the data.

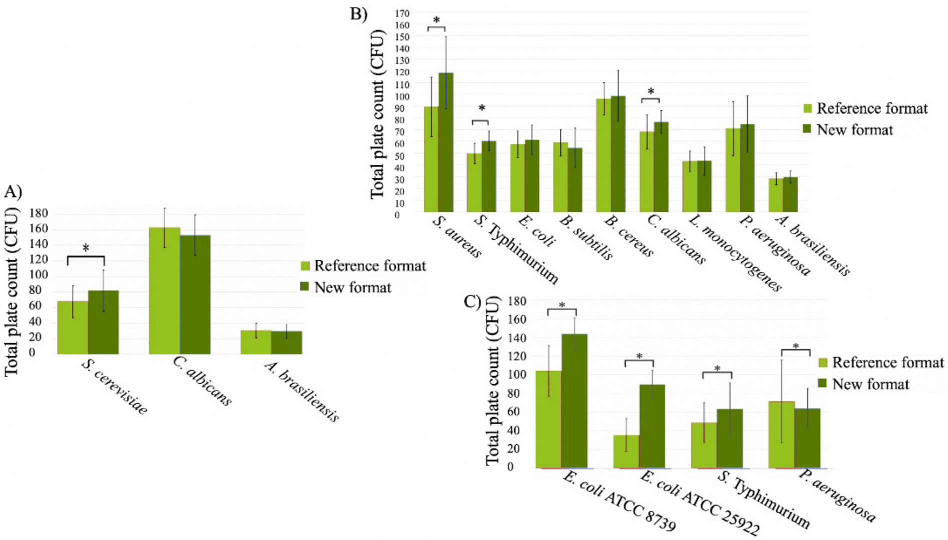


Figure 30. The importance of the statistical treatment and information: bar graph showing mean CFU obtained in different culture media, conventional and modified, seeded by the pour plate method, with statistical analysis, error, and significance level (from Terrones-Fernandez et al. 2023)

5.4.3 Discussion

The Discussion provides authors an opportunity to elucidate the significance of their findings, highlight key conclusions, and address potential criticism. Moreover, authors should demonstrate how their work contributes to advancing knowledge within the field.

Guide:

- Seek an in-depth interpretation of the results by the author.
- Assess the consistency of findings, identify any contradictions among the results, and evaluate the reliability of the conclusions drawn from the experiments.
- Examine how previous work supports the authors' conclusions.
- Identify the strengths and weaknesses of the study.

Notes:

- Interpretation differs from simple reporting of experimental results because it involves describing the meaning of the data.
- Evaluate the interpretations of the data critically.
- Exercise caution when considering criticisms of previous work.
- Explore cause-and-effect relationships and seek explanations of the mechanisms connecting cause and effect.

Evaluation: This final pass in Keshav's approach, "**Understand the article in depth",** offers profound insight into the evidence, discussion, and presentation techniques, and it may require about four or five hours for beginners.

5.5 Conducting a literature review

The three-step approach outlined above is an efficient methodology for conducting a literature review, particularly when faced with a large number of documents or delving into an unfamiliar field. The steps to follow are:

1. **Initial search and preliminary reading:**

   - Begin your research by using an academic search engine.
   - Select keywords that are both relevant and specific to your research topic.
   - Choose three to five recent articles that appear to be relevant.
   - Recency is crucial to ensure that you are looking at the most current research.

- Conduct a preliminary reading of each paper to gain a general understanding of the work, without concentrating on all the details.
- Focus on the Abstract, Introduction, and Conclusions.
- Pay attention to the graphs and tables.

2. Identifying common citations and authors.

- Examine bibliographies to identify citations repeated across different papers.
- These papers are likely foundational to the field.
- Take note of authors who frequently appear, as they may be significant personalities in the field.

3. Explore relevant conference proceedings:

- Identify major conferences based on the articles you have read and key citations.
- Visit the websites of these conferences and review their recent proceedings.
- Conference proceedings often contain the most innovative and recent work.
- Review these papers to gather current information and identify trends in the field.

This three-step approach offers efficiency by enabling the systemic filtering of extensive literature, thus allowing readers to concentrate on the most pertinent information.

6

Am I grasping the paper?

It is essential to comprehend the content of the paper. Achieving this necessitates persistent engagement in self-questioning. Thus, the next step is to delve deeply into the article itself, albeit non-sequentially but selectively; in other words, read nonlinearly and search for the research argumentation while focusing also on the Contents and Results sections.

6.1 Research argumentation

The reader may pose the following questions to identify the research argumentation. They have been adapted from Figure 50 in the Appendix.

The key questions for establishing research argumentation are:

a) What were the researchers' **motives** for conducting this research?

- Why the research was done.

b) What was the **objective**?

- What the authors pursue.

c) What is the **main conclusion** drawn by the researchers from the results?

- The main **outcome** of the research.

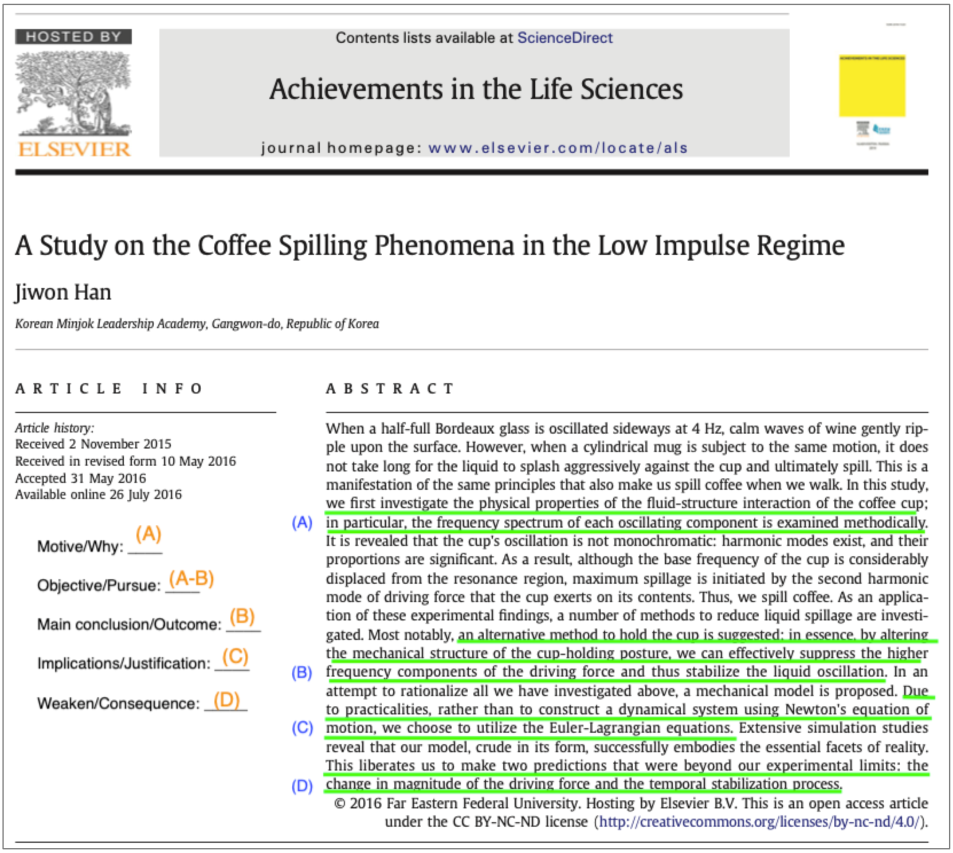
d) What are, according to the researchers, the **implications** of the research?

- The **justification** and consequences of the research.

e) Which factors do the authors mention that **weaken** the results or conclusion?

- What weakens the results of the main conclusion and its **consequences**.

For an example of the research argumentation explicitly provided in the Abstract, refer to Figure 31.



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A Study on the Coffee Spilling Phenomena in the Low Impulse Regime

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Motive/Why: (A)

Objective/Pursue: (A-B)

Main conclusion/Outcome: (B)

Implications/Justification: (C)

Weaken/Consequence: (D)

ABSTRACT

When a half-full Bordeaux glass is oscillated sideways at 4 Hz, calm waves of wine gently ripple upon the surface. However, when a cylindrical mug is subject to the same motion, it does not take long for the liquid to splash aggressively against the cup and ultimately spill. This is a manifestation of the same principles that also make us spill coffee when we walk. In this study, (A) we first investigate the physical properties of the fluid-structure interaction of the coffee cup; in particular, the frequency spectrum of each oscillating component is examined methodically. It is revealed that the cup's oscillation is not monochromatic: harmonic modes exist, and their proportions are significant. As a result, although the base frequency of the cup is considerably displaced from the resonance region, maximum spillage is initiated by the second harmonic mode of driving force that the cup exerts on its contents. Thus, we spill coffee. As an application of these experimental findings, a number of methods to reduce liquid spillage are investigated. Most notably, (B) an alternative method to hold the cup is suggested; in essence, by altering the mechanical structure of the cup-holding posture, we can effectively suppress the higher frequency components of the driving force and thus stabilize the liquid oscillation. In an attempt to rationalize all we have investigated above, a mechanical model is proposed. (C) Due to practicalities, rather than to construct a dynamical system using Newton's equation of motion, we choose to utilize the Euler-Lagrangian equations. Extensive simulation studies reveal that our model, crude in its form, successfully embodies the essential facets of reality. (D) This liberates us to make two predictions that were beyond our experimental limits: the change in magnitude of the driving force and the temporal stabilization process.

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Figure 31. Example of research argumentation provided in the Abstract (from Han 2016).

6.2 Contents and results

Additionally, understanding the research argumentation crucially depends on identifying the paper's criteria arguments and evaluating the results. Figure 51 in the Appendix provides a framework for proper analysis, which we have adapted here.

To achieve this, the key practices for reading the paper's contents and results are as follows:

a) Identify the **key features** of the presented work.

- The key features are: theoretical, analytical, numerical simulation, and experimental **studies**.

b) Identify the **tools** used by the authors in their work.

- Basic physical **laws** and state relations.

c) Identify and choose the key and most essential **table** and **figure**.

- The information and results are presented in table and figure **formats**.

d) Evaluate the **results**.

- **Numerical** results are to be calculated from the data in the paper.

e) Reliability of the data. Are the data **available**? Are the data **reproducible**?

- **Reproducibility** is a hallmark of the research progress.

6.3 Bear in mind

A comprehensive understanding of the research topic requires considering certain critical aspects. The essential questions to ask are as follows:

a) In the article's research field, what is the current state of knowledge?

- This information will be found in the article's **Introduction** section.

b) What idea is being tested in the article?

- This information will be found at the end of the article's **Introduction** section.

c) What are the key techniques used in the experiments described?

- This information will be found in the article's **Materials and Methods** section.

d) What were the data obtained in the study?

- This information will be found in the article's **Results** section.

e) What explanations explain the study's findings?

- This information will be found in the article's **Discussion** section.

f) What conclusions do the authors draw from their data and results?

- This information will be found in the article's **Conclusion** section.

7

Advice, and finding research articles

Advice to follow when reading research papers:

Focus on Methods and Results. Try not to be influenced by the way the study is presented.

Read nonlinearly. Exploit the format of the research article, skim it for overall comprehension.

Consider the big picture. Assess how it relates to previous research.

Take your time. Be patient and persistent; authors likely took years to publish their work.

Be a sceptic. Ensure the views are supported by the evidence.

Be fair. Research is difficult; don't expect studies to be perfect.

Accept uncertainty. Don't expect to find absolute answers to every question.

Expect to be challenged. If you are not an expert in an area, there might be aspects of a paper you cannot fully understand.

Useful questions to ask yourself when analysing and evaluating a research paper:

Author. Is there a single author or an organization? What are the author's affiliations and qualifications?

Scope. Who is the journal's intended audience? How does the scope relate to the author's expertise?

Timeliness. When was the paper published?

Presentation. What information is posted on the website? Are there broken links?

Review. Has the paper been peer reviewed? Was there a peer review process?

The following aspects can provide you with very useful information when reviewing a paper:

Journal rankings. The journals that are regularly cited are the most useful and prestigious.

Impact factor. This measures how many times other journals cite the journal's articles.

Open-access. Articles that provide open-access can be freely accessed and distributed.

Finally, if you have understood what the article says, you should be able to answer the following additional questions:

- What is the paper's takeaway message?
- What motivates this work in terms of both people problems and technical problems? How has this motivation been distilled into a research question? Why does the people problem not have a trivial solution? What are the previous solutions and why are they inadequate?
- What solution is proposed? What is the hypothesis, idea, or design? Why is it believed to be viable? How is the solution an improvement? How is it achieved?
- What is the author's evaluation of the solution? What logical arguments, evidence, artifacts (e.g., a proof-of-concept system), or experiments support the idea?
- What is your assessment of the identified problem, idea, and evaluation? Is this a good idea? What flaws do you perceive? What are the most interesting or controversial ideas? For work with practical implications, consider its feasibility, target audience, implementation requirements, and potential timelines.
- What are the paper's contributions (in both the author's and your opinion)? Think in terms of ideas, methods, software, experimental results, experimental techniques, or other.
- What are future research directions (as identified by both the author and you)? These may be driven by shortcomings or critiques.
- What questions remain unanswered? Based on the most intriguing and controversial points above, what queries would you raise in a discussion of the work? What aspects are challenging to grasp? List as many as you can.

Additionally, consider referencing the rubric for engineering research papers by Bill Griswold, which has been adapted and presented in Table 5 in the Appendix

8

Reading journal articles in an undergraduate Fluid Technology course: A practical case

Fluid Technology constitutes a core subject for an engineering degree. Despite its commonly large enrolment, it is extremely disliked due to its challenging material, particularly in fluid mechanics (Albers and Bottomley 2011; McClelland 2013; Gamez-Montero et al. 2015). An overarching challenge for educators lies in the fact that traditional lecture-based teaching methods in core engineering subjects tend to result in underperformance and overall poor student outcomes (Bullen and Russell 2007).

To date, fluid mechanics has not garnered sufficient interest from STEM educators (Science, Technology, Engineering, and Mathematics) compared to other scientific disciplines (Vaidya 2020), potentially leading to insufficient attention being paid to more advanced courses within the fluid mechanics curriculum. Consequently, there is growing interest in developing class-based experiences in core fluid mechanics subjects, including blended, hybrid, and flipped teaching models that integrate research-based approaches.

The case study presented in this section outlines a practical intervention focused on using primary literature to immerse students in the engineering research process, specifically within the curriculum syllabus of a one-semester Fluid Technology course for fourth-year undergraduates. This subject is more advanced than traditional Fluid Mechanics, and it is typically regarded as one of the most challenging courses for any engineering student due to the necessary interplay between understanding theoretical concepts and applying them to solve problems, which requires developing a diverse skill set.

This case study aimed to bridge the gap between the curriculum syllabus and research activities by engaging students in current research within the subject through reading scientific literature, including research conducted by their instructors. The approach involved aligning the curriculum course design with the selection of secondary reading sources and research papers, providing students with a methodology, guidelines, and best practices for analysing, evaluating, and critiquing them. Ultimately, the students engaged in self-directed learning through the transmission and assimilation of information, with selected readings explicitly linked to the subject syllabus and correlated with research in fluid mechanics. Additionally, out-of-class activities were graded within a framework of student-focused teaching, with an emphasis on conceptual change through active learning.

8.1 Intervention design

This intervention draws inspiration from previous studies on the research-based education by Healey and Jenkins (2009), self-assessment journal article reading and analysis skills by Hoskins et al. (2011), and the teaching strategy to improve primary literature reading abilities proposed by Van Lacum et al. (2014). Through a selection of in-class and out-of-class activities meticulously aligned with the curriculum syllabus and in order to promote the reading of research, students were encouraged to use higher-order cognitive skills to construct meaning (Hermida 2009). Additional benefits were gained through the process of students designing and executing exercises or experiments and taking responsibility for them, which in turn fosters intellectual maturation (Lopatto 2009). Instructor-implemented assessment tools indicate that students tend to adopt a deep approach to reading and learning, using the acquired skills effectively.

This practical intervention design is characterised by:

- Structured progression from secondary to primary literature, ensuring effectiveness.
- Provision of specific answers to well-designed questions.
- Active cultivation of students' discipline and professional literacy.
- Demonstration of feasibility, grading, and evidence through a series of guided processes and activities led by the instructor.
- Development of an effective reading style tailored to the target research area.
- A contribution to scholarly research that aims to effectively link reading primary literature to a curriculum syllabus in the field of fluid engineering, with an emphasis on research content as a source of information and discoveries.
- An emphasis on the curriculum syllabus and teaching students about the processes of knowledge construction in the subject, favouring active research-based learning over traditional lecturing.
- Construction of results based on data findings and a literature review.

For a more comprehensive explanation and context, refer to the article by Gamez-Montero and Rodero-de-Lamo (2023).

8.2 Course context

Fluid Technology is a mandatory course offered each semester and it consists of two six-week periods with a total of twelve sessions. The course is administered by the Department of Fluid Mechanics at the School of Industrial, Aerospace, and Audiovisual Engineering of Terrassa (ESEIAAT), a part of the Universitat Politècnica de Catalunya (UPC). Typically, the course enrols 60–70 students aged between 21 and 24, all of whom are required to take the subject.

Students are proficient in both official languages, Spanish and Catalan. Textbooks and slides are provided in Spanish, lectures are delivered in Catalan, and assignments are conducted in English. Course materials, activities, and assignments are accessible through the teaching support platform ATENEA (Moodle), hosted on UPC servers.

The course confers 4.5 ECTS, with 3 hours of teaching per week. The schedule is determined prior to each semester, disseminated to students one week in advance, and explained during the introductory lecture of the first week. The teaching intervention encompasses the following components:

- **Lectures and applications**. This component comprises 100 minutes (50 minutes + 50 minutes) of lectures per week, with class time dedicated to a variety of learning activities and problem-solving exercises. A special in-class activity consists of student-friendly learning tools aligned with the course syllabus. Specifically, seven in-house-designed paper and pencil didactic games are incorporated in Spanish. These are:
  - “Fluid properties crossword puzzle”, related to Fluid.
  - “The buoyance dilemma”, related to Pressure.
  - “Spotting the twelve differences between the two sets of conservation laws”, related to Mass, Linear and Angular Momentum, and Energy.
  - “Fluid mechanics: Eleven celebrities word search”, related to Dimensional analysis.
  - “Spotting the eleven differences in the Bernoulli equation”, related to Pump to System.
  - “Navier-Stokes’s terms matching game”, related to Newtonian viscous/inviscid flow.
  - “Power density mismatch”, related to all concepts.

- **Practice seminars**. This component involves 110 minutes of in-class activities every fifteen days, with a focus on learning computer activities such as computational fluid dynamics.
- **Self-study**. Student are expected to allocate 180 minutes of pre- and post-out-of-class activities per week. Considering the course's 4.5 ECTS, students should dedicate 4.5 hours per week to self-study. The total time scheduled for activities represents 66% of these hours. The activities assigned by the instructor are:
  - Pre- and out-of-class activities: 90 minutes per week.
    - Students must review slides of a pre-prepared presentation per lecture in advance, made accessible on the teaching support platform ATENEA (Moodle).
    - Short textbook-style readings, complementary to the instructor's slides, are provided in advance.
    - Course-related short online videos (maximum 5 minutes), selected by the instructor based on technical criteria, are assigned for viewing before class. These external videos, created using H5P open technology, are interactive and include embedded questions.
    - Problem statements, their resolution, examples, and technical case studies are presented clearly to promote self-knowledge. The instructor's scanned handwritten solutions are posted on the ATENEA platform as pre- or post-class problems.
  - Post-/out-of-class activities: 90 minutes per week.
    - A computer-based online multiple-choice individual quiz featuring numerical answers, is administered via the ATENEA platform. This quiz is available for five days (120 hours), opening on Thursday and closing the following Monday. During this period, students are given one 90-minute attempt to take the quiz.

Additionally, the course utilizes its own open-access book authored by Gamez-Montero and Codina (2018).

8.3 Teaching practice in reading primary literature

At the outset of the intervention, the instructor informs the students and outlines the course regarding all programmed pre-, post-, and in- and out-of-class activities.

I. Lectures on reading primary literature (RPL)
II. Reading assignments and post-/out-of-class activities
III. Warm-up readings
IV. Test readings and the pre- and post-test exams
V. Pre- and post-questionnaires and the SEEQ survey

(I) Lectures on reading primary literature (RPL)

The teaching practice is supplemented by lectures titled "Best Practices in Reading Primary Literature," abbreviated as RPL. These lectures aim to explain the process of identifying the "anatomy" of a paper, including research questions, hypotheses, research argumentation, contents, and results within research articles. The table of contents for these lectures includes:

1. Introduction: Guidance and notes on how to read, critique, and evaluate research articles.
2. Objective, motivation, and justification.
3. What are primary research articles
4. The importance of reading primary literature
5. The anatomy of a paper:
    a) Title, citation, publication dates, and Abstract: read nonlinearly.
    b) Take your time and focus on Methods and Results.
    c) Methodological details: reproducibility.
    d) Evaluating convincing findings: be fair and expect challenges.
    e) Dealing with variability and accepting uncertainty.
    f) Be sceptical about descriptive and inferential statistics.
    g) Visualizing results to grasp the big picture.
6. Understanding research argumentation and dissecting the Contents and Results sections.
7. Emphasizing best practices.
8. Exploring the concept of innovation.
9. Finding research articles: authors and journals.

(II) The reading assignments and post-/out-of-class activities

Figure 32 illustrates the intervention program, where two lectures, RPL (1/2) and RPL (2/2), are thoughtfully incorporated into the timeline alongside reading assignments designated as post-/out-of-class activities. This scheduling approach facilitates students' deeper understanding of the concepts introduced in the preceding lectures, thereby fostering a meaningful connection between acquired knowledge and the subsequent reading assignments.

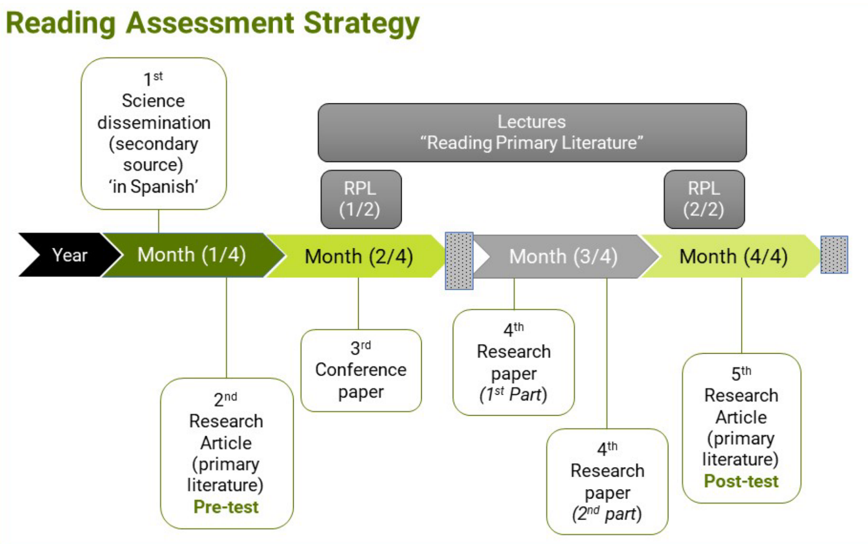

Figure 32. Lectures on reading primary literature and reading assignments as post-/out-class activities: warm-up readings (the 1st, the 3rd, and the 4th in two parts) and the test readings (the pre-test as the 2nd and the post-test as the 5th).

(III) The warm-up readings

The progressive approach designed for successful implementation of the intervention, based on warm-up readings, is depicted in Figure 32: the 1st and 3rd readings, as well as the 4th in two parts. These warm-up readings are strategically integrated to coincide with syllabus-related concepts, aiming to prevent student discouragement, particularly at the outset and prior to the RPL lectures. Additionally, the scheduling of warm-up readings is mindful to not overload them. Recognizing that students require structured guidance when learning reading strategies for RPL, the approach encourages them to engage more deeply with the material than simply reading a PDF.

(IV) The test readings and the pre- and post-test-exam

The primary aim of the intervention is to evaluate students' ability to read research articles and monitor their progression in this skill. To assess the effectiveness of the teaching practice, two test readings are scheduled: a pre-test reading (the 2nd) and the post-test reading (the 5th), as depicted in Figure 32. Careful consideration was given to selecting two articles with distinct contents and syllabus-related concepts for generating the pre- and post-test exams.

The pre- and post-test exams are designed as parallel tests, comprising eleven questions that assess article comprehension (pertaining to research argumentation, research contents, and the Results section, as well as the students' personal opinions about the contents. For further details, refer to Gamez-Montero and Rodero-de-Lamo (2023).

(V) The pre- and post-questionnaires and SEEQ survey

The second aim of the intervention is to measure student perceptions of their ability to read and critique primary literature before and after the teaching intervention. This is accomplished by means of the pre-questionnaire and post-questionnaire, as depicted in Figure 33.

Both questionnaires consist of the same 20 questions in Spanish, each with five possible answers and thus using a 5-point rating scale. The purpose is to assess students' self-awareness of conceptual cognition and its achievement over time. The questions are divided into the following four blocks related to reading: Capability, Ability, Skills, and Background.

- Capability: eight questions.
- Ability: seven questions.
- Skills: three questions.
- Background: two questions, one on experience and the other on the significance of reading research articles.

Given that the goal is to gauge self-awareness and perception, no grade or mark is assigned for completing the questionnaire. The total time allocated for the self-evaluation questionnaire in class is 20 minutes. For more detailed information regarding the questionnaire questions, refer to Gamez-Montero and Rodero-de-Lamo (2023).

Furthermore, as illustrated in Figure 33, the Student Evaluation of Educational Quality (SEEQ) survey is carried out to gather perceptions of not only the RPL intervention but also of the entire course.

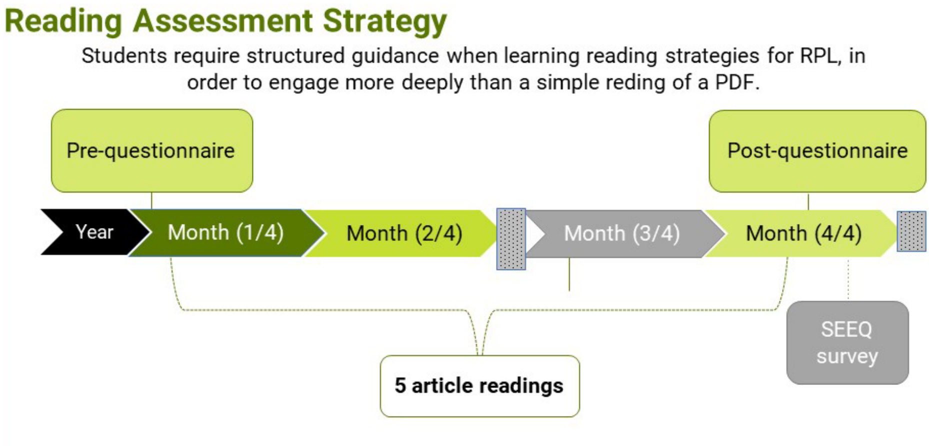

Figure 33. Schedule of the pre- and post-questionnaires, and the SEEQ survey.

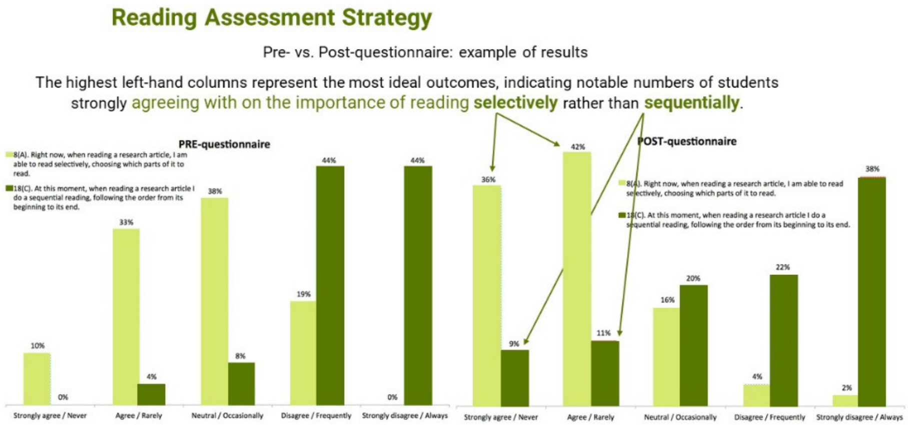

Figure 34. Student agreement on reading a paper selectively rather than sequentially. The questions are: “8(A). Right now, when reading a research article, I am able to read selectively, choosing which parts of it to read” and “18(C). At this moment, when reading a research article I do a sequential reading, following the order from beginning to end”.

Figure 34 illustrates an example of the results between the pre- and post-course questionnaires. A clear, notable, and positive evolution in reading performance is observed: Students agree with reading selectively rather than sequentially when approaching a paper. The percentage of students who "strongly agree" with this acquired capability has increased significantly, as indicated by a notable pre/post ratio, indicating students' heightened self-awareness of assimilating the competence of selectively reading research papers from pre- to post-test exam.

The slides used in the specific lectures on reading primary literature are included in the Appendix (Figures 45 to 56). The 12 slides are available, upon request to the corresponding author.

9
Writing scientific papers

Anyone aspiring to publish research papers must recognise the indispensability of reading a large volume of scientific literature in order to learn how to write. No alternative approach will suffice or even come close.

Scientific writing is characterised by highly specialised vocabulary, precise and succinct language use, and often intricate grammatical structures. Consequently, comprehending scientific studies can pose cognitive challenges, particularly for readers unaccustomed to the subject-specific jargon. The skill of effective and critical reading is thus paramount. Regular and frequent reading enables individuals to remain abreast of novel findings, generate innovative ideas, and improve their writing.

Moreover, engaging in research paper writing significantly improves one's reading skills. The process fosters developing the essential ability to acquire information and conduct critical analyses. Furthermore, reading materials for research purposes enhances one's capacity for reasoned inquiry.

9.1 Progression of a research project

Effective research alone does not guarantee publication in reputable academic journals. Equally crucial is the meticulous execution of each step in the process. This includes not only drafting the paper itself but also selecting the appropriate journal and addressing critiques from journal reviewers.

A scientific article serves as the documentation of an investigation that outlines a methodologically guided process of data collection or extraction. Thus, research must be properly planned and executed before a manuscript can be developed and produced.

The above discussion leads us to the initial step: creating documents that align with the conceptualisation or design of an investigation. These documents should include the investigation's purpose, objectives, preliminary descriptions of research questions, and hypotheses, as well as the methods and data employed.

A comprehensive review of existing literature informs the research plan, incorporating not only the team's innovative ideas and inventiveness, but also the body of previous studies in the same field. This familiarisation should be evident in the manuscript, either within the Introduction section or throughout dedicated sections. Figure 35 depicts the typical progression of a research project.

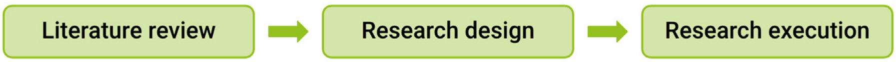

Figure 35. Typical progression of a research project

9.2 Structure of a paper

The most recommended structure for scientific articles is the widely adopted IMRaD format (Codina and Lopezosa 2023), which stands for Introduction, Methods, Results, and Discussion. Sometimes Methods also includes Materials and Methods. This format serves as the standard in academic communication, delineating the requisite structure and sections of scientific articles.

Utilising the IMRaD structure is pragmatic, as it aligns with the format requirements of most academic-scientific journals, thereby enhancing the likelihood of acceptance. Moreover, IMRaD's rigid structure ensures transparency, making it unsuitable for publications lacking legitimate research.

The **Introduction** section serves to describe the problem clearly and state the study's **contributions**, which will be demonstrated later in the paper. These contributions should be refutable.

For people entering the field of research, grasping the distinction between research and studying can be challenging. Although studying is a prerequisite for research, research is inherently defined by the processes of design, data extraction, systematisation, and elucidation of significance and implications.

9.3 Writing and publishing a paper

Preparing a paper for submission to a journal necessitates thorough documentation, in one or more documents, of the complete set of results obtained, alongside the research plan for traceability purposes. Only after this has been completed should the paper be submitted for consideration.

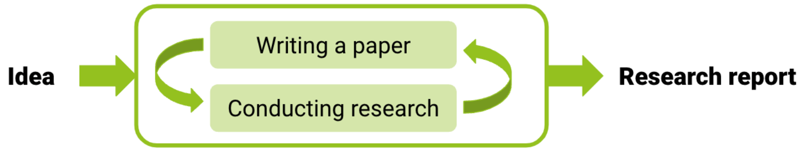

Figure 36. Relationship between writing and developing research

Typically, the process of drafting a paper commences once the research is complete. However, initiating the writing process as soon as an idea arises can nevertheless be beneficial to remaining focused on the research. This approach enables researchers to identify potential areas of misdirection and highlight some crucial areas requiring further attention. Early writing facilitates effective communication with peers.

Writing an article serves dual purposes: facilitating research and reporting findings (see Figure 36). The process of writing enhances clarity of thought more effectively than the act of thinking alone. Therefore, documenting every idea is valuable, even if they're not all great ideas.

Figure 37 illustrates the essential elements and process of submitting and publishing an academic article. Often, potential readers have access only to the article's title, Abstract, and keywords, not the full text. Hence, careful attention should be paid to these components, as they will determine the possibility of further reading and citations. Despite their importance, these three components are frequently overlooked, undermining the critical need to make well-informed decisions regarding them.

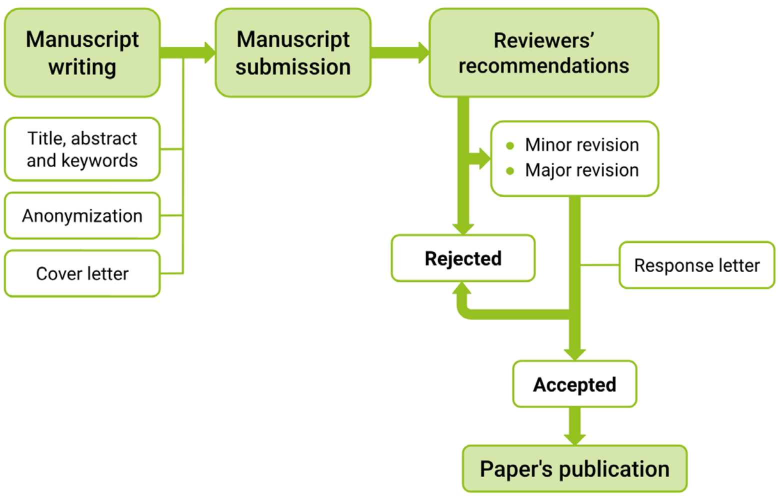

Figure 37. Process of submitting and publishing an academic publication

The **title** of a study should prominently feature its goal and subject, optionally incorporating information about the methodology. Concise and assertive titles are typically preferred. Furthermore, the emphasis placed on specific components of the topic or research determines any modifications necessary to align the title with the journal's scope and orientation, ensuring a suitable representation of its chosen themes.

Ensure that your **main idea** is clearly conveyed to the reader by explicitly identifying it and making it distinct and unambiguous.

The **Abstract** should function as a self-contained summary and adhere to the journal's content guidelines. Typically, it should not exceed 250 words unless otherwise specified. Crafting the Abstract requires careful attention to ensure that it encompasses key elements such as the article's main objective, methodology, relevant findings, and opportunities for further research.

Selecting **keywords** is equally crucial, as they determine the visibility of the work and serve as a good representation of both the article's content and rationale. Carefully considered keywords will attract readers to your article, but make sure they accurately represent the content.

Anonymisation involves submitting a version of the work with authorship concealed. This ensures transparency in the evaluation process, enabling unbiased assessments by reviewers unaware of the authors' identities.

The **cover letter** plays a crucial role in manuscript submission, serving as a formal introduction to the journal's editors. If it is a strongly written letter that effectively highlights the research undertaken and its significance, it could potentially help bypass any initial screening processes. While not always mandatory, a well-crafted cover letter is highly recommended.

9.4 How to reply to referees' comments

Here are some helpful tips for addressing the critiques of unfavourable reviews and crafting a response to them. The first step is to view the paper from the perspective of a referee.

When you write an article and choose to submit it to a journal, one of three scenarios typically arises following peer review: rejection, acceptance with minor revisions, or acceptance with major revisions.

9.4.1 Acceptance with minor revisions

If the manuscript is approved but requires minor adjustments, the reviewers concur that it is worthy of publication but suggest changes that will have no effect on the main findings of the study or the article itself.

In this fortunate scenario, one need only focus on the requested changes and promptly provide the edited manuscript to the editor.

9.4.2 Acceptance restricted to major revisions

If the submission is accepted with significant modifications, the reviewers acknowledge the potential value of the article but propose substantial adjustments. In this scenario, the article's ultimate acceptance is contingent upon the authors' ability to address these modifications and incorporate them into an updated version, which will undergo further evaluation.

A specific instance of major changes may involve a request for a complete rewrite of the manuscript. Only the authors can determine whether a total rewrite is worth the effort. To aid in the decision, authors can consider the nature of the referees' responses: detailed and constructive suggestions may warrant serious consideration of a complete rewrite, whereas vague or distant feedback may suggest a lack of sufficient interest in the work, making it advisable to submit it elsewhere.

In the event of a response requiring major changes, authors should anticipate several days of work to craft a proper response. While it may be tempting to consider sending the manuscript to another journal, it is always worthwhile to analyse and address the referee's comments. The time invested in this endeavour will also serve to improve your manuscript.

Authors must diligently engage with each referee's feedback, adhering to the prescribed layout and following **three golden rules** (refer to Table 2):

Rule 1. Answer completely
Rule 2. Answer politely
Rule 3. Answer with evidence

Table 2. Three golden rules for responding to referees' comments (adapted from Williams 2004)

The golden rules are also valuable in revising a paper to determine whether it's suitable to read. Observe if…

… the article is complete or lacking essential information.
… the information provided is clear.
… the article provides scientific evidence to support its claims.

Rule 1. Answer completely

It is imperative to fully address all referees' comments. This involves numbering each comment and repeating them in the response letter, ensuring each comment is attributed to its respective reviewer. This approach assists referees in their task and provides insight into the range of arguments raised by each referee.

Include all comments in your cover letter, regardless of whether they are compliments or critiques. Including a statement like "we thank the referee for these comments" also serves as a courteous acknowledgement of their input.

Rule 2. Answer politely

When responding to referees' comments, it is acceptable to express disagreement, provided it is done respectfully. Responses should adhere to a methodical and scientific approach. Before submitting the replies, it is advisable to have someone else review them.

Avoid opening remarks that dismiss or discredit the referee's input, such as "we totally disagree" or "the referee obviously does not know this field". Instead, focus on areas of agreement and use expressions such as the following:

- We agree with the referee that … , but …
- In accordance with the referees' suggestions, we have revised this sentence to …
- It is true that …, but …
- We recognize that our manuscript may have …, but …
- We also share the referee's concern regarding the low response rate. We concur that further research in this area is warranted.

Rule 3. Answer with evidence

If you disagree with the referee's remarks, provide logical explanations or, ideally, evidence in the form of data to support any disagreements. If the referee's remarks call for additional sentences or data, it is acceptable to incorporate them into the response.

However, if the referee's comments require more than one page of additional material, it would be prudent to advise the editor and seek guidance on whether these additions should be included.

The **response letter**, which accompanies the updated version of the manuscript, typically comprises the following elements:

- A brief expression of gratitude for the evaluators' efforts, particularly if their input was helpful.

- The updated version of the manuscript. Information regarding the revisions made to the article may be included if deemed appropriate. The most significant adjustments made can be summarised in this section of the letter.

9.4.3 Rejected

If the article is rejected, it will not be published because the reviewers concur that it is not yet ready for publication.

Facing the outright rejection of your work may be difficult, but even in this scenario, it is essential to objectively assess the referees' comments. Their input may offer valuable insights that could potentially improve your work. Moreover, it is important to keep in mind that the same reviewers may be involved in reviewing submissions to other journals and they might possibly encounter your manuscript again. If they find no changes were made, it could reflect negatively on your submission.

Understanding journal rejection notifications can be challenging. If unsure how to interpret implicit signals, seek guidance from a knowledgeable colleague or, ideally, someone with experience as a referee for that journal. If clarification is still needed, it is appropriate to write the editor again and request further explanation.

9.5 Article processing charge

Processing an article for scientific publication incurs expenses, which are often overlooked by individuals who question why publishers profit when authors provide their services for free.

- Under the traditional model, subscribers bear the cost. This model contradicts open science and is not without criticism.
- Alternatively, the cost is shouldered by authors through the open access model and article processing charges.
- These expenses may also be covered by scientific societies, universities, or similar patronage-based organisations.

10 Engineering education and educational practices

10.1 Engineering education and research

Engineering education has always been fundamental to serving society. In order to continue doing so, it must adapt to a wide range of divergent global factors, both present and future. However, doubts surround the question of whether the practice of engineering will be capable of keeping pace with the growing present-day demands of knowledge, skills, abilities, competencies, and attitudes (Lohmann 2008; Bubou et al. 2017). Adapting engineering pedagogy to higher education must occur rapidly and give students a solid and insightful foundation for approaching engineering endeavours judiciously, thus preparing them for the challenges ahead.

Research into engineering education has grown significantly, facilitated by departments focused on systematic research and outcomes assessment (Benson et al. 2010). In particular, discipline-based education research (DBER) has gained momentum since 2012, as evidenced by the work of Singer and Smith (Singer and Smith 2013). DBER represents state-of-the-art advances in understanding engineering and science student learning, as well as curriculum design and teaching methods.

To foster innovative progress in engineering student learning, an evolution in curriculum design and teaching methodologies is taking place. Consequently, engineering education must strengthen the connection between teaching and research in order to meet the challenges of the twenty-first century. Engineering educators are, and should be, integral to promoting active learning and developing this teaching-research nexus and research-based programs. Indeed, engineering educators can leverage current knowledge of neuroscience as a teaching methodology to enhance their lectures, thus aligning with the educational paradigm of neuroeducation (Sanchez-Carracedo et al. 2021).

For genuine promotion and implementation of active learning and to foster strong ties between teaching and research, it is imperative to consider how engineering educators conceptualise research and scholarship (Brew 2003). As Brew acknowledges, the reconceptualization of higher education, and consequently engineering education, must align with the evolving dynamics between instructors and students, as well as the transformation of the traditional reward system for academics.

10.2 Traditional lecturing, research, and educational technology

The traditional lecturing approach, which emphasizes information transmission from the syllabus to students/teachers, is less efficient and yields poorer learning outcomes compared to the active learning approach, which prioritises conceptual engagement and student involvement. This assertion cannot be attributed solely to an imperfect implementation of traditional methodologies by inexperienced lecturers, as demonstrated by Deslauriers et al. (2011). Their study compared the learning outcomes achieved on specific topics and objectives using two instructional approaches (traditional and active) under controlled conditions in two large groups (control and experimental sections) of an introductory undergraduate three-hour physics class. The lecture method was delivered by an experienced, highly-rated lecturer, while the active method was facilitated by a trained but inexperienced instructor. The disparities in midterm exam scores were significant, with more than two standard deviations of difference favouring the innovative methodology, which had been previously reported in the literature as effective. In other words, learning in the inexperienced instructor's class outpaced that of the experienced lecturer. Moreover, students reported higher engagement, and attendance rates increased.

In 2014, the performance of traditional lecturing versus active learning was once again examined in undergraduate Science, Technology, Engineering, and Mathematics (STEM) courses (Freeman et al. 2014). The study demonstrated that, in contrast to active learning, students in classes with traditional lecturing were 1.5 times more likely to fail.

On the other hand, the traditional research conception of research is rooted in the notion that research is conceived by bodies of knowledge and conducted by scientists within a research culture comprising other academics and scholars. Engineering research adheres to the scientific method, focusing primarily on the practical application of science in products, services, and infrastructure—real-world systems that benefit humanity (Thiel 2014). The knowledge generated through research is perceived as objective and performed by experts, necessitating a distinct teaching process for its transmission and engagement with students (Afdal and Spernes 2018). Consequently, the relationship between the traditional lecturing approach and traditional research conception is instructor-centred, with information being transmitted to student-receivers within a separate learning environment, thereby having little tangible connection with the research culture.

Conceptual shifts must also encompass the realm of educational technology, given the recent advent of digital technology. Lecturers and instructors must acquire a comprehensive understanding of the intricate relationships among content, pedagogy, and technology. A recommended approach is that of technological pedagogical content knowledge (TPCK), which is an evolving form of knowledge that transcends all three components (Mishra and Koehler 2006). The TPCK framework for learning technology by design serves as a valuable approach to teaching and also as an evaluation tool for assessing the development of instructor knowledge about educational technology. This new educational framework, based on cognitive capitalism, proposes a circular teaching method (see Figure 38).

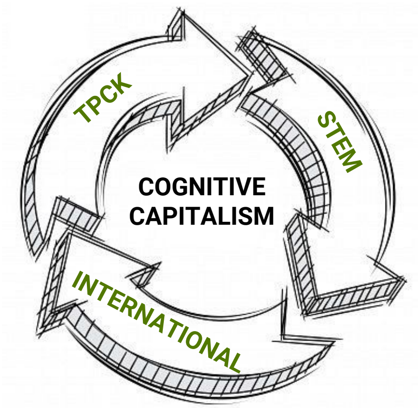

Figure 38. Educational framework for circular teaching

The past two decades have seen promising growth in research focused on connecting teaching and research in higher education, highlighting how students benefit from research experiences. Griffiths (2004) pioneered innovative approaches to integrating teaching and research in higher education, while Healey (2005) further developed a comprehensive framework based on the research-based approach.

Additionally, given the intertwined relationship between educational technology and traditional teaching and research, a novel demand has emerged, calling for a nexus that will enhance the quality, effectiveness, and depth of teaching, scholarship, and research (Musthafa and Sajila 2014). Therefore, the goal now is to improve the ways in which research and teaching mutually support one another under the global umbrella of research-based learning and the teaching-research nexus. Furthermore, it is crucial, as highlighted by Wallin et al. (2017), to investigate students' learning experiences and focus on motivational factors, challenges, learning outcomes, and how specific elements in the learning environment contribute to these aspects.

10.3 Research-based education

More and more, the current century has seen a transition from traditional lecturing to research-based education, particularly in the past decade. Numerous studies conducted across various institutions have concluded that students greatly value learning in a research-based environment (Jenkins 2004; Bubou et al. 2017).

The literature offers a variety of terms and expressions to describe the nexus between teaching and research, with a focus on teaching actions (Healey 2005). Healey observed that the nature of this nexus has evolved over time and varies across disciplinary boundaries. Table 3 summarises four primary methods of engaging undergraduates with research (Healey and Jenkins 2009).

Healey and Jenkins observed that traditional higher education curriculum design tends to prioritise activities where students are often passive participants, as indicated in rows (I) and (II) in Table 3, titled Research-led and Research-oriented. However, they also emphasized that these four approaches to engaging students with research are not mutually exclusive. To accommodate the diverse learning preferences of students within a subject, it is beneficial to utilize a wide range of learning methods.

Engaging nexus	Nature	Curriculum	Emphasis on	Student action
(I) Research-led	Learning about current research in the discipline	Dominated by staff research interests. Information transmission is the main teaching mode.	Research content	Passive (audience)
(II) Research-oriented	Developing research skills and techniques	Conducted by interlinking theoretical and practical knowledge of scientific learning acquisition.	Research processes and problems	Passive (audience)
(III) Research-tutored	Engaging in research discussions	Delivered by staff-led academic tutorials and seminars.	Research content	Active (participant)
(IV) Research-based	Undertaking research and inquiry	Mainly inquiry-based activities.	Research processes and problems	Active (participant)

Table 3. Research engagement approaches

The research-led approach outlined in row (I) centres on educators' research, highlighting the importance of research to student learning (Jenkins and Healey 2013). A further step-forward is the research-based approach in row (IV), which does not focus solely on teacher education or instructor-led pedagogic research. Instead, it emphasizes how undergraduate students can benefit from course-based research within specific subjects they are studying. Traditionally, undergraduate research has focused primarily on final-year dissertations and master's theses.

Undergraduate teaching-research practices undoubtedly offer an initial opportunity in higher education to involve instructors and students in scientific activities such as reading and evaluating articles, data analysis, assessment, model construction, critical observations, and research planning, as well as other activities. Emery et al. (2019) highlighted, among academics, a notable lack of attention to training in mentorship and collaborative work with undergraduate students. In particular, one major challenge in course design concerns balancing and integrating research-based and curriculum-oriented perspectives while ensuring that these readings are incorporated into the subject's curriculum syllabus and evaluated accordingly.

The nature of research experiences encompasses undergraduate research experiences (UREs) and course-based undergraduate research experiences (CUREs). UREs involve individual students working in faculty research laboratories, providing the opportunity for one-on-one mentoring. In contrast, CUREs are structured within a curriculum and are open to most students (Linn et al. 2015).

For more detailed and practical explanations on these topics, it is recommended to consult the comprehensive work of Laursen et al. (2010), which presents a rigorous study on the effects of working with undergraduates and confirms the overall value of the experience for both faculty and students. Additionally, valuable insights can be gained from Lopatto's (2009) exploration of what matters about the undergraduate research experience; studies focusing on how students benefit from participating in CUREs (Auchincloss et al. 2014); and summer undergraduate research and research internships (Hunter et al. 2006).

Once instructors have established a theoretical framework based on a selection from the extensive literature and they are committed to putting it into practice, the stark transition may seem overwhelming. Moreover, as observed by Linn et al. (2015), designing a course that links teaching with research cannot be based solely on the research experiences of undergraduate students. It is essential to present authentic depictions of scientific research and connect these experiences to students' own beliefs and expectations.

10.4 Active learning and STEM education

Active learning, in contrast to traditional teacher-centred lecturing, engages all students in the learning process, fostering an environment that encourages thinking beyond formal classroom settings and promotes self-confidence in knowledge acquisition. Inactivity and passivity are not viable alternatives.

The purpose of this book is not to investigate active learning per se, but rather to integrate research-based activities. In the context of revising active methodologies related to engineering subjects, three approaches—Peer Instruction, Team-Based Learning, and Just-in-Time Teaching—were examined, each centred on and devoted to the student. Alternatively, the Japanese Lesson Study approach focuses on and is devoted to instructor development. A disruptive alternative to the traditional lecturing method is inductive learning, which, while highly effective in developing critical reasoning and autonomous learning skills across disciplines, may struggle to cover a broad range of topics without hindering course progress. Hence, the preferred approach in engineering disciplines, particularly in the field of fluid mechanics, is evidence-based teaching, such as inverted teaching methods using blended, hybrid, and flipped models.

Blended learning, as a flexible approach to learning and teaching, integrates the best aspects of face-to-face and online course delivery modes to achieve desired learning objectives for students, as highlighted by Rhaman (2016). Since the adoption of this approach in fluid mechanics in 2013, this study has shown significant improvements in student learning outcomes, higher grade averages, and increased completion rates. Another intervention within a brain-based delivery framework called Knowledge and Curriculum Integration Ecosystem (KACIE) resulted in shifted grade patterns within the class, as students instructed with KACIE outperformed their peers in the control group, thus achieving higher grades (Solomon et al. 2018). Furthermore, in an active learning design, instructors should not assume that learners will engage with core content outside of class (Harrison et al. 2017). Moreover, the overall effectiveness of active learning may vary, depending on the student population, namely individual aspects such as academic preparation, scientific reasoning ability, and self-directed learning skills (Rhaman 2016).

STEM education (Science, Technology, Engineering and Mathematics) provides an ideal environment for developing new teaching-research synergies and experiences, as it allows examining the advantages and disadvantages of promoting research-based education and reinforcing active learning (see Figure 38). The work of Rodenbusch et al. (2016) demonstrates that not only do undergraduate students benefit from early engagement in STEM research experiences on their courses, but so do the institutions. This is true irrespective of the student's background, culture, gender, or school status. A recent study by Huet (2018) emphasizes the importance of holistic training for STEM professionals, encompassing both technical and non-technical knowledge and skills. In a student-centred environment, learning occurs through research, inquiry, and discovery (Huet 2018).

Additionally, given the underrepresentation of females in STEM fields, concerted efforts must be made within academic settings and programs. The sustainability of our higher education institutions and societies hinges on the academic success of both male and female students under conditions that ensure equitable educational opportunities, practices, and content (Pilotti 2021).

The flipped classroom, also known as the inverted classroom, is increasingly gaining traction in STEM courses (Barba and Le Doux 2016), with evident pedagogical impacts on students' perceptions of flexibility, guidance, engagement, and feedback (Sullivan et al. 2018). A recent study by Gamez-Montero (2020) conducted a post hoc analysis of a student-centred approach based on a flipped classroom intervention linked to threshold concepts in the turbomachinery section of a Fluid Engineering course, and these authors found an excellent ratio of benefit to cost. The overall class performance in the final examination improved notably, with activities showing a significant correlation with the final score, and students expressing satisfaction with the new implementation's level of suitability and degree of compliance.

A review of the literature and the promising progress it demonstrates in education convincingly shows that it is definitely worthwhile to adopt active learning with a research-based approach integrated into both in-class and out-of-class activities. Upon weighing its pros and cons, active learning emerges as an advancement and enhancement of teaching. As students actively obtain information for themselves, the transmission and assimilation of information take place individually, thereby eliminating delays in the progression of study programs and curricula.

10.5 Course design using primary literature as an academic tool

Primary literature, also referred to as research papers or journal articles, serves as the official documentation through which scientists communicate their research findings to their peers. Academics routinely rely on primary literature to enrich their professional knowledge, and numerous studies have highlighted its benefits as a learning resource for students.

Despite its importance, the skill of reading research articles is often overlooked in university curricula. In practice, most researchers and research professionals acquire this skill through self-teaching (Greenhalgh 2014). Nevertheless, it is a valuable skill with broad applications, both personally and professionally, extending beyond the realm of research. Proficiency in reading academic publications enhances analytical abilities, which are a desirable trait in a myriad of industries.

While the benefits of reading primary literature are evident and align well with engineering education, the skill of proficiently reading an article is seldom taught, even though engineering educators know all too well that they dedicate a great deal of their own time to reading research literature. Yet, incomprehensibly, so much knowledge and effort go to waste when undergraduate students are denied being taught this skill (Finelli and Froyd 2019). Occasionally, this skill is taught to graduate students, since efficiently reading a research article is a fundamental practice. Our proposal here is that instructors introduce the reading methodology and practical outlines for evaluating journal articles into the core of engineering subjects under the guidance and supervision of instructors.

Another collateral benefit of proficiently reading primary literature is the challenging aspects related to learning how to think and understand like an engineer, such as understanding the roles of engineers and the value of learning. As students develop this skill, they begin to take responsibility for their own learning, becoming self-directed learners. This transformation involves aligning their strengths and recognizing the importance of learning for their future endeavours. Success is not merely coincidental; it requires vision, planning, and commitment. Even serendipity, which plays a role in discovery, needs constant engagement and involvement.

Consequently, students do not merely gain increased exposure to scientific literature from well-designed, research-based subjects; rather, they experience a unique and hard-to-replicate encounter, which requires them to take responsibility for their own learning. As a collateral benefit, this approach helps prevent students from commonly experiencing frustration in this process, thereby saving much effort and avoiding the waste of educators' knowledge, preventing demotivation.

Demotivation refers to the absence of motivation, which serves as the driving force behind taking action and pursuing goals. Educators often focus on intrinsic motivation, wherein students aim to learn for the sake of learning itself, rather than for external rewards. Encouraging this type of learning involves prioritizing conceptual understanding over rote memorisation in the assessment system. Two effective means to achieve this are problem-solving and case studies, where knowledge is applied rather than simply absorbed. Through these approaches, student demotivation remains low while they gain more profound understanding of the concepts.

The next section is devoted to motivation.

11
Motivation

Let us begin with a reminder of how motivation is defined and why it is so vital. Motivation is a driving force that propels individuals toward accomplishing their objectives. It is especially critical for students, as it not only enhances their academic performance but also increases their chances of becoming successful professionals in the future. Motivation among students can stem from their competence, relatedness, and autonomy, as depicted in Figure 39.

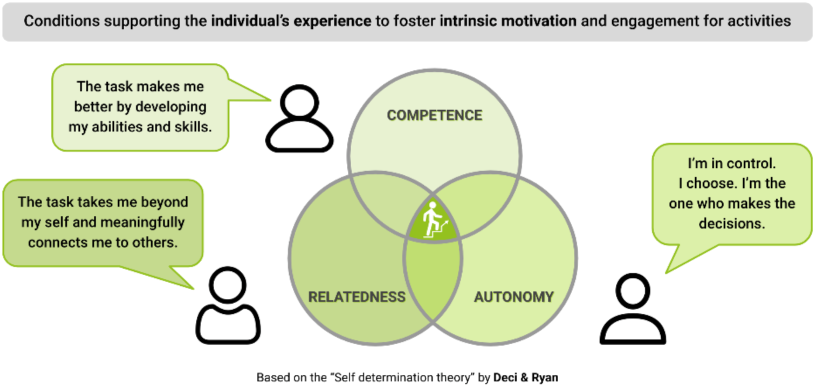

Figure 39. Favourable conditions for fostering intrinsic motivation in the individual

Due the importance of motivation, a plethora of articles delve into the topic, exploring diverse perspectives and applications in numerous fields. However, measuring student motivation poses a complex challenge, leading to the exploration of various methodologies and tools. In the following passage, we present a study conducted by Hoskins and Newstead (2009) aimed at measuring student motivation.

Several years ago, a research team hypothesised a correlation between student cheating incidents and their motivation to attend university. Therefore, this study sought to measure student motivation objectively. To test their hypothesis, the research team encountered the challenge of accurately measuring student motivation. They conducted surveys among university students to ascertain their primary reason for studying. The respondents' responses were categorised into three distinct categories (as illustrated in Table 4):

- "Means to an end", representing extrinsic motivation.
- "Personal development", representing intrinsic motivation.
- "Stopgap".

"Stopgap" refers to a temporary and improvised solution intended to address an urgent need until a more permanent and stable solution can be implemented. Stopgap measures are often quick and non-ideal, but necessary to prevent or stop a problem in the short term.

Percentage of students	
Means to an end (66%)	Improving standard of living. Improving chance for getting a job. Developing career. Getting a good qualification. Getting a worthwhile job.
Personal development (24%)	Improving life skills. Reaching personal potential. Gaining knowledge for its own sake. Furthering academic interest. Gaining control of own life. Being classified in this way.
Stopgap (10%)	Avoiding work. Laziness. Allowing time out to decide on career. Social life. Fun and enjoyment.

Table 4. Reasons for studying (adapted from Hoskins and Newstead 2009)

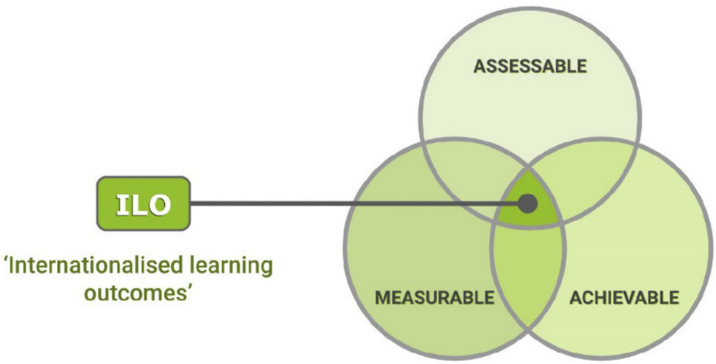

Figure 40. What is the student expected to achieve? The three -bles

A student-centred approach entails an active and intellectually engaged individual (student) in a classroom (environment) that emphasizes the learning process and outcomes, which comprise what can be considered "the three -bles'" (see Figure 40): Assessable, Measurable, Achievable. Here, we are interested only in Assessable. It is imperative to bear in mind that not all assessment methods are equally suitable for every student. Hence, students should always be provided with opportunities to familiarise themselves with the various assessment formats required throughout the academic year.

11.1 A motivation and achievement motivation

Ryan and Deci (2000) characterise amotivated students as those who lack a clear understanding of their purpose for attending university, perceive themselves as incompetent, and feel a lack of control over their circumstances. The concept of achievement motivation serves as a measure of the strength of a student's motivation. A student with high achievement motivation stands at the opposite end of the spectrum from an amotivated student.

11.2 Motives and behaviour

The primary focus of the research conducted by Hoskins and Newstead (2009) revolves around distinguishing between deep and surface approaches to studying. A deep approach involves comprehending the material conceptually and integrating it into one's existing knowledge. Conversely, a surface approach is characterised by rote learning, with the intention of reproducing the material in a different context.

Additionally, in analysing responses to the approaches to studying inventory, a device used to identify students approach to study (Entwistle 1998), another consistent pattern arises: the strategic approach, which is closely associated with achievement motivation. Strategic students adapt to the circumstances, with their primary objective being to attain high marks.

11.3 The development of motivation

Three fundamental dimensions influence motivation: lack of direction, academic self-confidence, and meta-cognitive awareness of studying.

A notable adaptation of the original approaches to studying inventory can be found in the Approaches to Study Skills Inventory for Students (ASSIST) tool developed by Entwistle (1998). These results align with findings obtained using a different method by Newstead et al. (1996). The main reasons reported for entering higher education were:

- To obtain a good job and develop useful skills.
- For personal development.
- The least frequently cited reason, stopgap.

The Magee study (Magee et al. 1998) finds that students highly rank an active social and sporting life, which the authors describe as presenting a slight discrepancy, likely because it is seldom the single most important reason given.

A three-year longitudinal study of 200 undergraduates found that students' approach to achieving academic success gradually declines during the first year of their degree, while surface and deep approaches fluctuate (Zeegers 2001). After an initial decline in deep approach, a return to the original level is observed. By the third year, it decreases to values slightly below the original ones. These changes were independent of the students' age or sex.

The study emphasizes that learning is fundamentally content-driven and therefore varies according to the discipline in which it is developed. Engineering students tend to adopt deep-memorizing strategies as their approach to learning, similarly to preparing for final exams.

Furthermore, the study highlights students’ age and their post-secondary education experience as two important factors impacting their learning approach, regardless of their age or previous learning experiences. Older students are more capable of investing effort in new learning strategies, as evidenced by their readiness to read primary literature.

The development of student motivation over the course of their degree is complex and not always predictable. Improved understanding of how students approach their learning process could enhance the learning experience.

11.4 Encouraging student motivation

During the study, two issues emerged:

- How can we prevent students from becoming amotivated? One way to mitigate student amotivation is by providing comprehensive and appropriate feedback.
- How can we encourage intrinsic rather than extrinsic motivation? The assessment system should emphasize conceptual understanding over rote learning. This may involve increased utilisation of problem solving, case

studies, and similar methods requiring applied knowledge rather than mere memorization.

Fundamentally, student motivation can be classified into two primary types: motivated and amotivated. This classification reflects the extent of a student's drive to achieve success. Additionally, the motivated type can be further divided into intrinsic and extrinsic categories. Intrinsically motivated students engage in learning primarily for the inherent enjoyment and satisfaction derived from the learning process itself. In contrast, extrinsically motivated students are driven by external factors, such as rewards or recognition.

11.4.1 Neuroeducation and motivation

In recent years, an increasing number of education researchers have directed their focus towards understanding how the brain operates during the learning process, particularly through the lens of neuroeducation. This specialised discipline combines research in neuroscience, teaching, and psychology.

According to Baumeister et al. (2003), the brain functions more effectively when motivated, a phenomenon rooted in physiology. Pleasure accompanies inspiration, enhancing our enjoyment of activities. A close relationship exists between motivation and attentiveness, making it easier for students to maintain focus when motivated. Furthermore, the emotions associated with learning influence memorization.

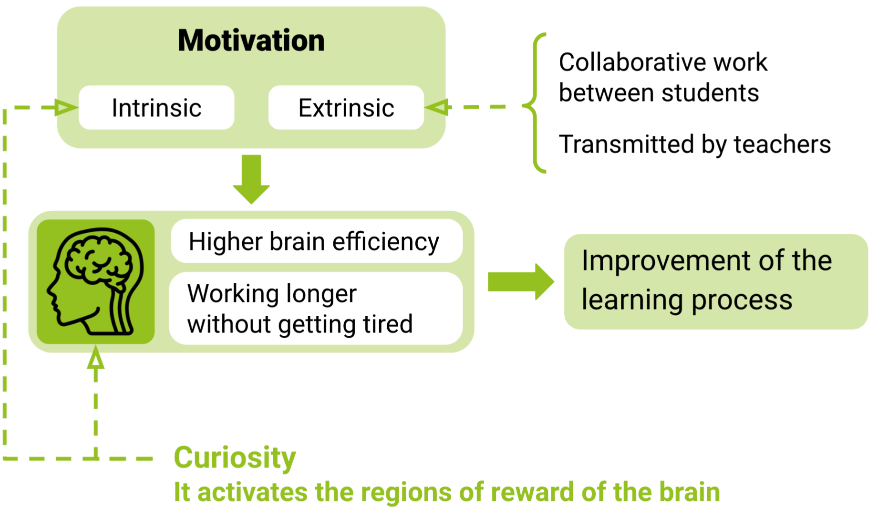

Figure 41. Stimulation of intrinsic and extrinsic motivation.

Baumeister et al. (2003) interpret that success in modern society relies on life-long learning and improvement across academic, social, cultural, and occupational domains. Consequently, they advocate for linking self-esteem to learning and improvement.

To enhance motivation, a distinction must be made between intrinsic and extrinsic motivation. Stimulating curiosity can bolster intrinsic motivation. Mirror neurons, as discussed by Rizzolatti et al. (1996), facilitate the transmission of extrinsic motivation from teacher to student or among students, such as through collaborative efforts. Figure 41 illustrates these mechanisms for stimulating motivation.

Sánchez-Carracedo et al. (2021) analysed learning from the perspective of motivation, attention, and memorization, and proposed strategies for addressing these three factors in lectures. They presented twelve recommendations on how to integrate these insights from neuroscience into the teaching-learning process in engineering education. These recommendations, rooted in neuroscience, are considered pertinent in lecture settings and are aligned with the seven principles for good practice in undergraduate education, as defined by Chickering and Gamson (1987):

1. Foster contact between teachers and students.
2. Promote cooperation among students.
3. Stimulate active learning.
4. Provide feedback on time.
5. Allocate time effectively to essential tasks.
6. Communicate high expectations to students.
7. Respect diverse talents and learning styles.

11.4.2 Sense of belonging and motivation

In addition to considerations regarding neuroscience and teaching practices aimed at promoting student motivation, research indicates that a sense of belonging and engagement positively influences the learning process (Pittman and Richmond 2007). Thus, understanding students' sense of belonging within educational institutions appears crucial for enhancing performance in the learning process.

Pittman and Richmond (2007) explored the associations between a sense of school belonging and psychological adjustment. They collected data from 266 late adolescents (aged 18–19 years), with a gender-balanced sample, using multiple questionnaires. The findings suggested that a sense of school belonging could serve as a vital component in fostering a positive experience for late adolescents in college. This underscores the potential for improving the sense of belonging and engagement within a university department through active mentoring and promoting involvement in extracurricular activities on campus.

Given the limited number of studies measuring sense of belonging, it is imperative to interpret the findings cautiously. Furthermore, since the sense of belonging varies depending on the environment (e.g., campus, department, classroom), the tools used to measure it must be adjusted and assessed for the specific context under question.

Knekta et al. (2020) developed and evaluated a questionnaire aiming to measure undergraduate students' sense of belonging and involvement within a university department. They adapted the Psychological Sense of School Membership scale (Goodenow 1993) to fit a departmental context and supplemented it with newly designed involvement items. These additional items included participation in undergraduate research, close interaction with faculty or staff outside of the class, joining a student group at the university, and reading research papers from a faculty member.

Results from the aforementioned study indicate that although sense of belonging and involvement are strongly linked, they represent distinct concepts. Regarding the involvement items, they were perceived as a suitable amalgamation of activities discussed by students during cognitive interviews and activities that most departments would recommend for student participation. However, it remains uncertain whether any significant aspects of student involvement in other departments were overlooked, as the questionnaire evaluation was limited to one department at one university.

11.5 Motivation and research-based education

The benefits of research-based learning are manifold, particularly in the teaching of engineering degrees. Engaging with scientific primary literature enables students to improve their skills in designing and analysing experiments, as well as their understanding of research methodologies, the current scope of technology, and various other aspects. Several of these are outlined in Figure 42.

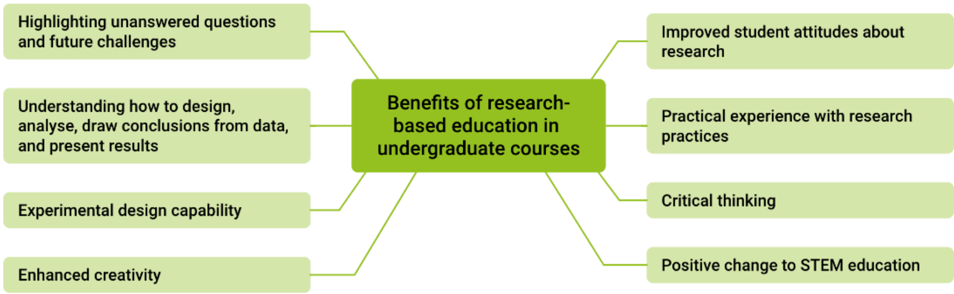

Figure 42. Benefits of research-based education in undergraduate courses

Motivation plays an even more relevant role in research-based learning in engineering courses. The complexity of mathematical and statistical knowledge, the specialized vocabulary, and the technical difficulty of reading research articles can be major obstacles to achieving student motivation.

Learning through the reading of primary scientific literature is a practice rarely undertaken by students in high school science classrooms. Consequently, undergraduate courses serve as the initial exposure for students to primary literature. The methodology employed and the manner in which research-based learning is introduced are crucial factors closely related to student motivation.

Chatzikyriakidou and McCartey (2022) developed and evaluated a four-factor questionnaire designed to measure undergraduate students' motivation for reading primary scientific literature. The results identified 19 items that effectively gauge student motivation across four subscales: expectancy values, self-efficacy, performance/competence, and interest. The factors influencing motivation, as considered in the questionnaire's design, are presented in Figure 43.

The questionnaire serves as a valuable tool for both researchers and instructors, enabling the evaluation of primary scientific literature-based interventions in undergraduate courses, which are content-independent.

The study's findings indicate that assigning introductory students primary scientific literature to read independently decreases their motivation. Therefore, efforts dedicated to implementing protocols for introducing students to research-based learning can significantly impact motivation levels. Conversely, positively changing student motivation regarding primary scientific literature is notably complex and likely influenced by various factors. As such, it is advisable to focus on identifying what does not work rather than solely emphasizing successful approaches.

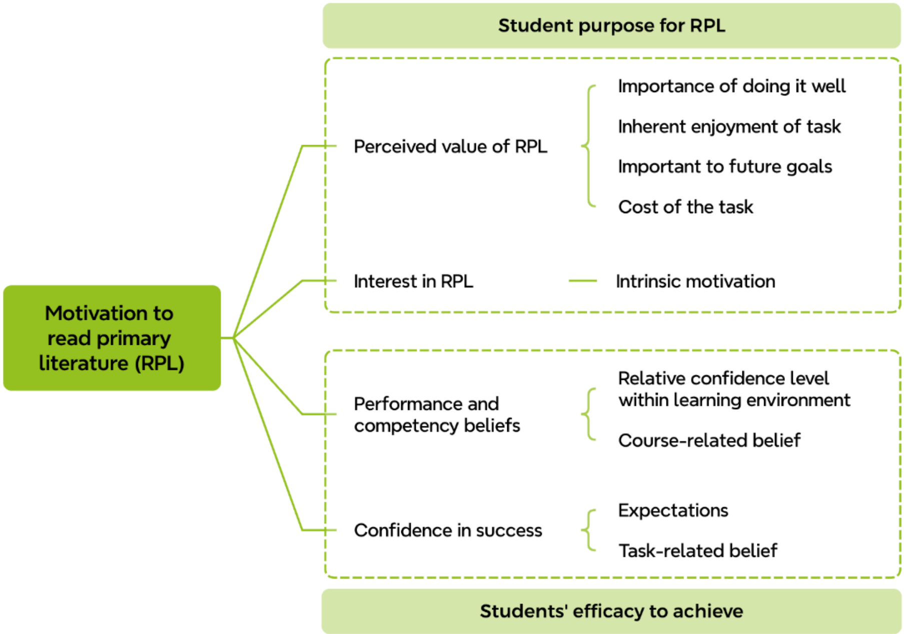

Figure 43. Motivation in Reading primary literature (adapted from Chatzikyriakidou and McCartey 2022)

Other considerations of the study include the need to account for cultural implications and the challenges associated with reading primary scientific literature in a second language when adapting the questionnaire.

11.5.1 Annotated primary scientific literature

Self-Healing Robot Muscles

EDITOR'S INTRODUCTION

Hydraulically amplified self-healing electrostatic actuators with muscle-like performance

annotated by Emily Frederick, Craig Benzinger, Alexis Stahl, Ian Palonis

A new class of soft, electrically activated devices, termed hydraulically amplified self-healing electrostatic (HASEL) actuators, can mimic natural muscle expansion and contraction. These devices are able to

TOPICS

Technology and engineeri

Glossary

A device which generates movement from electrical energy. The device consists of liquid segments which helps amplifying force generation and heals itself in case of an electrical breakdown.

ABSTRACT

Existing soft actuators … n the potential of soft robotics, highlighting a … erful, high-speed, efficient, and robust. We describe a class of soft actuators, termed hydraulically amplified self-healing electrostatic (HASEL) actuators, which harness a mechanism that couples electrostatic and hydraulic forces to achieve a variety of actuation modes. We introduce prototypical designs of HASEL actuators and demonstrate their robust, muscle-like performance as well as their ability to repeatedly self-heal after dielectric breakdown—all

REPORT

Human-made machines rely on rigid components and excel at repetitive tasks in a structured environment, whereas nature predominantly uses soft materials for creating versatile systems that conform to their environment. This discrepancy in mechanics has inspired the field of soft ro… orm the way we interact with machines and to enal… evices, industrial automation, and other app… proliferate, there is a need for an artificial muscle tec… performance, and reliability of biological mus…

Previous work

Fluid actuators, which converts fluid pressure into movement, were previously used in soft robots. This would make actuators bulky, slow and less efficient because of tanks and channel systems needed to generate the pressure.

Currently, soft robots pred… , which can be designed to suit a variety of applications (*8–10*). However, fluidic actuators require a supply of pressurized gas or liquid, and fluid transport must occur through systems of channels and tubes, limiting speed and efficiency. Thermally activated artificial muscle actuators made from inexpensive polymer fibers can provide large actuation forces and work density, but

Figure 44. Example of annotated paper provided by the SitC tool.

Annotated primary scientific literature serves as a valuable teaching and learning tool that offers undergraduate students a framework for becoming accustomed to the real-life scientific method of gathering and analysing data via primary scientific literature (Kararo and McCartney 2019). It supplements research articles with additional information to aid readers in comprehending complex scientific concepts.

Annotated primary scientific research literature differs from other genres that modify or rephrase the original text, as it maintains both the content and context of the original material. The primary distinction between adapted primary literature and annotated primary scientific literature is that the former alters segments of primary scientific literature to create pedagogical tools while the latter preserves the original content.

One notable example of well-developed and sophisticated annotated primary scientific literature can be found in the collection of freely available annotated papers know as Science in the Classroom (SitC; www.scienceintheclassroom.org). Its objective is to enhance students and teachers access to original scientific research literature. Figure 44 shows an example of annotated paper provided by the SitC tool.

11.5.2 Suggestions to increase motivation in research-based education

Since motivation influences students' choices regarding various activities, and it is desirable for them to appreciate primary literature and continue this practice beyond classes, efforts must be dedicated to developing this learning mode. Some practices to encourage motivation are outlined below:

- Design and implement simple initial activities with a high probability of success.
- Gradually introduce complex activities over time.
- Provide feedback that acknowledges dedication, not just the final outcome.
- Involve students in decision-making about the content they will work on.
- Encourage cooperative work.
- Offer adaptations to activities if necessary, such as incorporating annotated primary literature.

As a final thought, we would like to highlight the importance of not confining research-based learning to only one subject but to instead integrate it gradually and comprehensively throughout the entire degree program.

11.6 Overview

Fundamentally, student motivation can be categorised into two distinct types: motivated and amotivated. This classification reflects the degree of a student's desire to achieve success. Moreover, motivation can be further divided into intrinsic and extrinsic types. Intrinsically motivated students engage in learning primarily for the joy and satisfaction derived from the learning process itself, while extrinsically motivated students are driven by external factors, such as rewards or recognition. Motivation plays an even more relevant role in research-based learning in engineering courses, as learning by means of reading primary scientific literature is uncommon among high school students. This chapter has provided a brief insight into some of the research findings regarding student motivation, although the results are inconclusive.

To promote student motivation, it is crucial to consider the perspective on the learning process that neuroscience provides. Furthermore, efforts should be made to reinforce students' sense of belonging, as research has demonstrated a direct relationship between sense of belonging and motivation.

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Appendix

Slides for teaching how to engage the primary literature

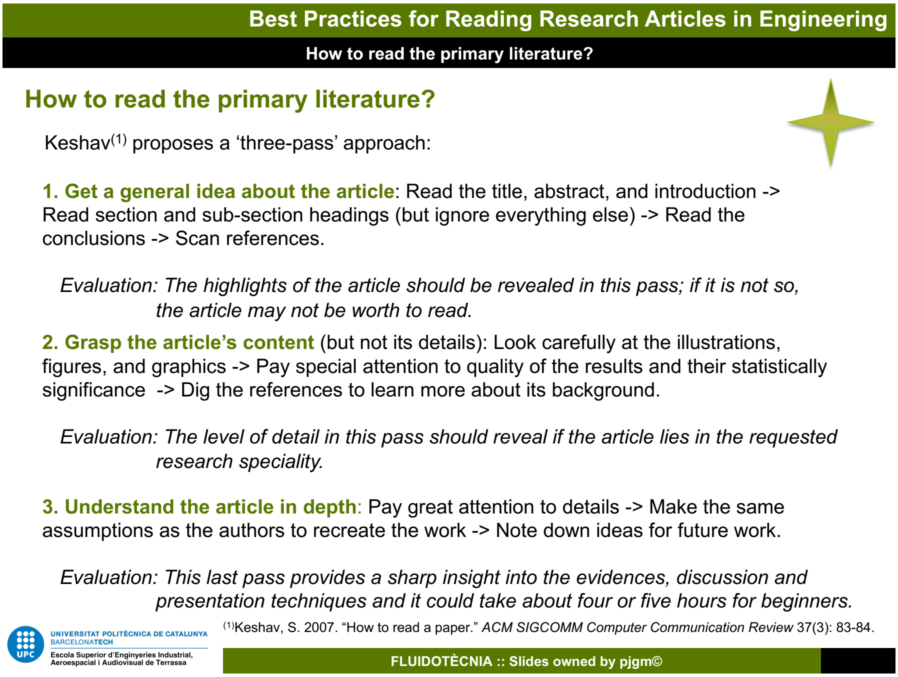

Figure 45. How to read primary literature

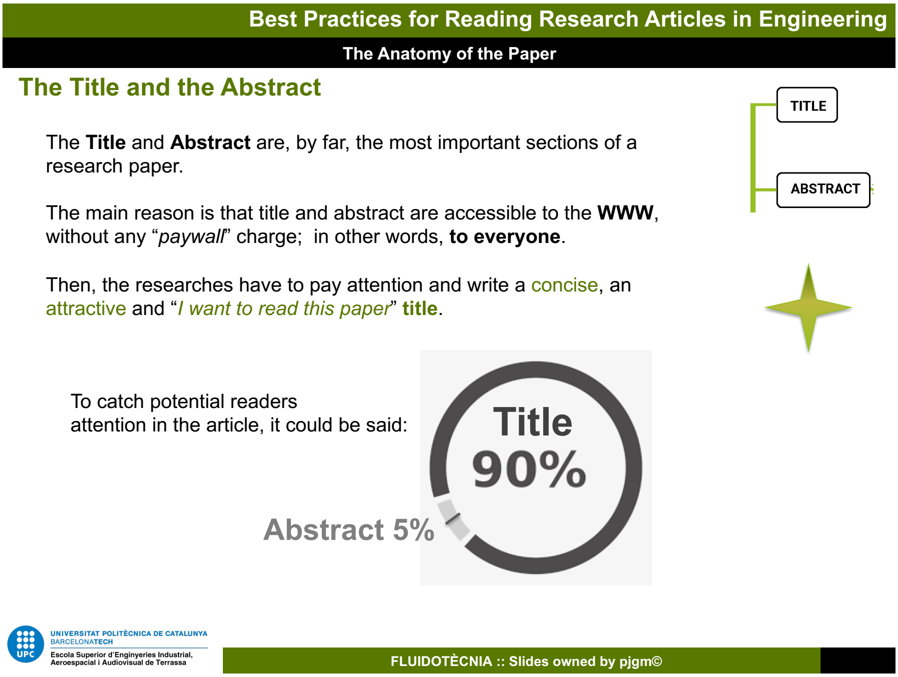

Figure 46. The importance of the Title and Abstract

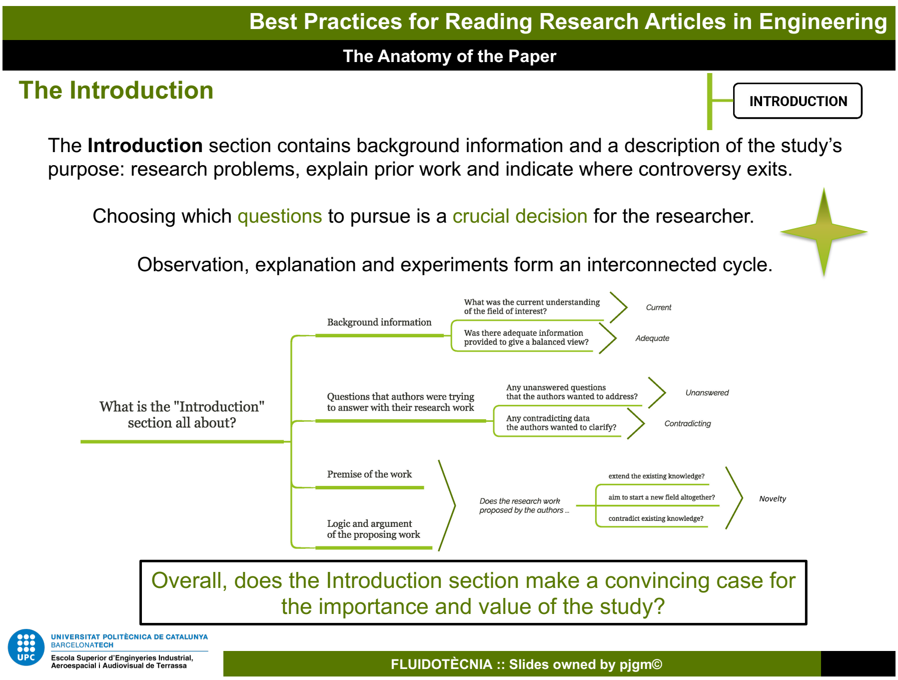

Figure 47. The Introduction, questions to pursue, and background information

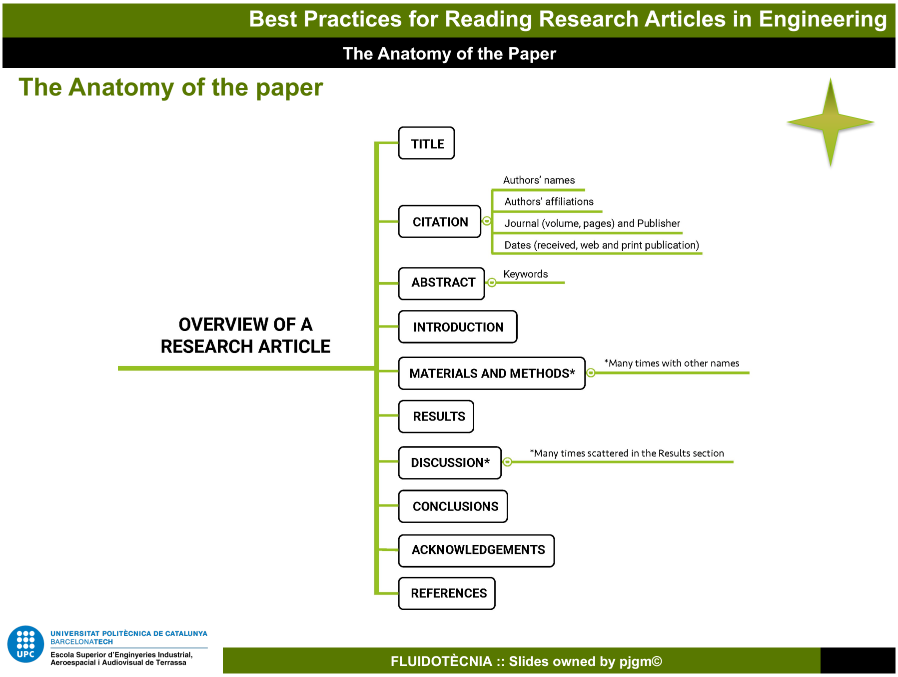

Figure 48. The anatomy of a research article

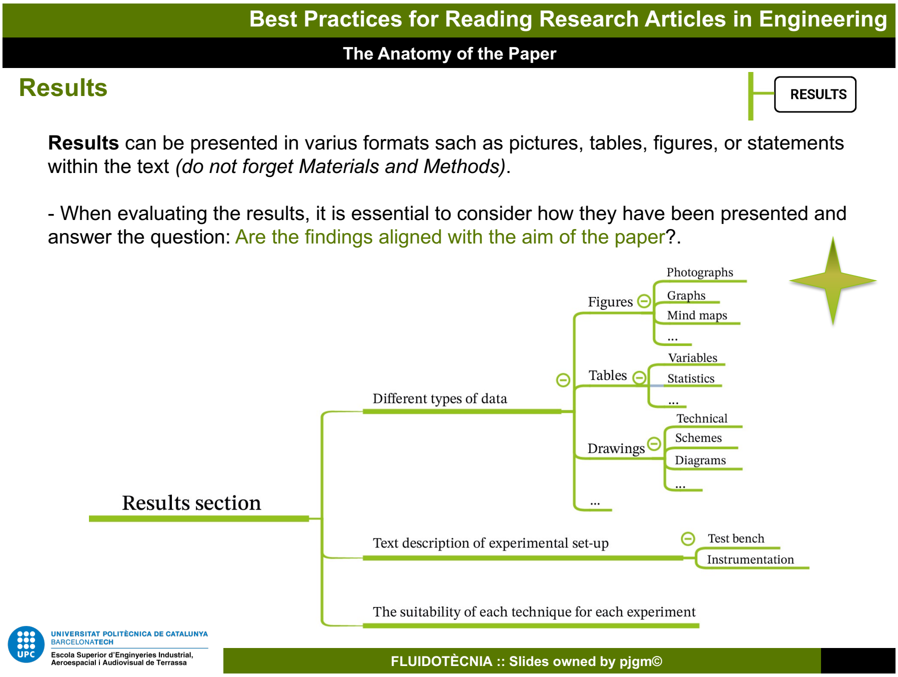

Figure 49. The results compile various forms of data

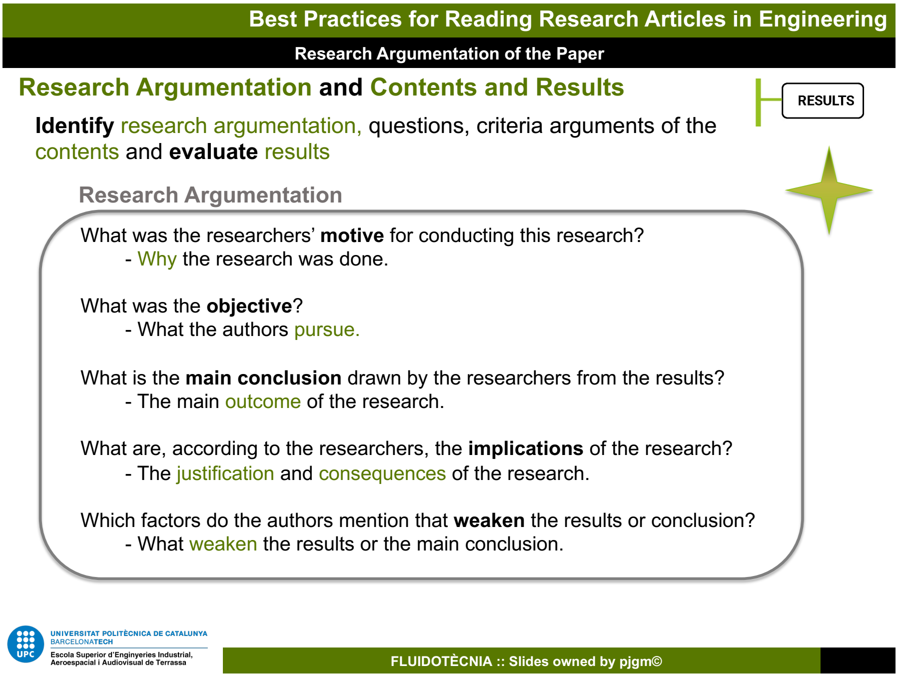

Figure 50. Question framework for understanding the research argumentation

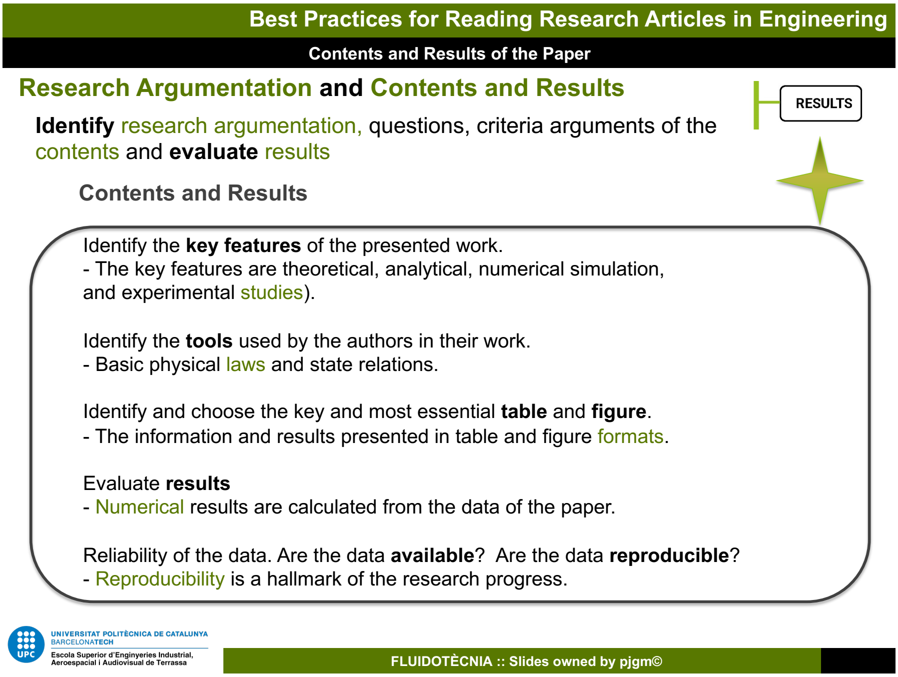

Figure 51. Framework for analysing an article's contents and results

Best Practices for Reading Research Articles in Engineering

Bear in Mind

Bear in Mind

I. In article's research field, what is the current state of knowledge?
- This information will be found in the article's **Introduction** section.

II. What idea is being tested in the article?
- This information will be found at the end of the article's **Introduction** section.

III. What are the key techniques used in the experiments described?
- This information will be found in the article's **Materials and Methods** section.

IV. What were the data obtained in the study?
- This information will be found in the article's **Results** section.

V. What explanations explain the study's findings?
- This information will be found in the article's **Discussion** section.

VI. What conclusions do the authors draw from their data and results?
- This information will be found in the article's **Conclusion** section.

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Figure 52. Concepts to bear in mind

Best Practices for Reading Research Articles in Engineering

General Advice

Advice to follow when reading research papers:

1. Focus on methods and results. *Try not to be influenced by the way the study is presented.*
2. Read nonlinearly. *Exploit the format of research article, skim it to understand overall comprehension.*
3. Consider the big picture. *Asses how it relates to previous research.*
4. Take your time. *Be patient and persistent, authors likely took years to publish their work*
5. Be a sceptic. *Ensure the views are supported by the evidence.*
6. Be fair. *Research is difficult: don't expect studies to be perfect.*
7. Accept uncertainty. *Don't expect to find absolute answers to every question.*
8. Expect to be challenged. *If you are not an expert in an area, there might be aspects of a paper you cannot fully understand.*

That's OK!

You can still learn form those parts of a paper that you can comprehend

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Figure 53. Overall tips

Best Practices for Reading Research Articles in Engineering

Finding Research Articles

Finding Research Articles

Useful questions for approaching a paper with specific objectives.

Author. Is there a single author or an organization? What are the author's affiliation and qualifications?

Scope. Who is the journal's intended audience? How does the scope relate to the author's expertise?

Timeliness. When was the paper published?

Presentation. What information is posted in the website? Are there broken links?

Review. Has the paper been peer reviewed? Was there a peer review process?

Journal rankings. The journals that are regularly cited are the most useful and prestigious.

Impact factor. This measures how many times other journals cite the journal's articles.

Open-access. Articles that provide open-access can be freely accessed and distributed.

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Figure 54. What to look for when seeking research articles

Best Practices for Reading Research Articles in Engineering

Finding Research Articles

Finding Research Articles: Authors

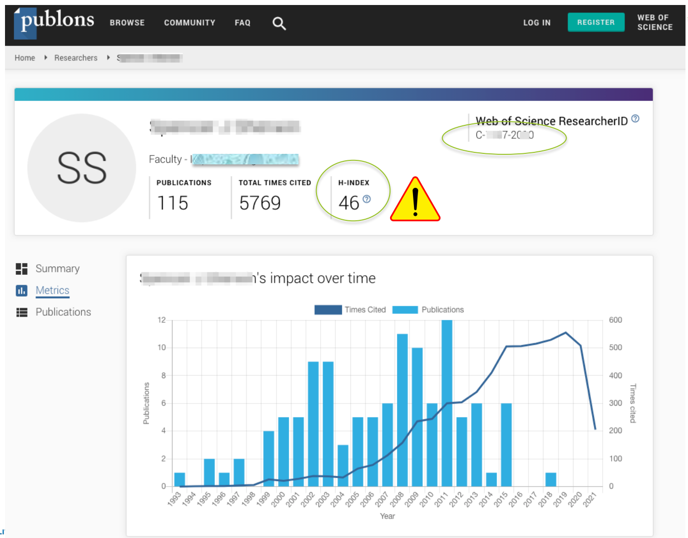

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Figure 55. The meaning of the h-index for authors

Figure 56. The meaning of journal impact factor and quartile

Table: Note-Taking Rubric for Engineering Research Papers

	Masterful	Value (1-10)	Competent	Value (1-10)	Developing	Value (1-10)
Style [10%]	clear highlighting or bracketing throughout paper		messy, hard-to see, or incomplete highlighting, underlining in tight text		obscuring or no highlighting, highlighting with lots of problems	
	tidy penmanship		messy penmanship		unreadable penmanship	
	commentary throughout paper		commentary ends mid-paper		no commentary	
	explicitly labels problem, solution, etc. in text		indirect or inconsistent labelling of problem, solution, etc.		no labelling of problem, solution, etc.	
	key questions and take-aways at front or end of paper		buried questions and take-aways		one cannot discern key questions or take-aways	
Reading [50%]	identifies distinct people and technical problems		identifies part of problem		did not identify problem	
	identifies distinct claim and solution		identifies claim/solution		does not identify solution	
	identifies evaluation		partially identified evaluation		does not identify evaluation	
	highlights salient text		much/little highlighting		random or no highlighting	
Inductive [20%]	asks pointed questions		asks questions		asks insincere/no questions	
	introduces creative or provocative ideas		introduces ideas		does not introduce ideas	
	makes salient observations		makes observations		no observations	
Deductive [20%]	draws own conclusions by applying rationale supported by evidence or logical inference		draws conclusions supported by overly vague rationale		offers opinions or accepts conclusions of paper as facts	
	draws on content in other papers, personal experience, or current events		makes overly vague reference to other papers, personal experiences, or current events		does not draw on outside sources, engages the paper only on its own terms	
	insightful take-aways, in own words, incorporating key idea		has take-aways, in own words		regurgitated/no take-aways	
Σ	Total:		Total:		Total:	
Other aspects to engage: future directions, conclusion and meta topics such as authors' background, writing, historical context, etc.						
From "Note-Taking Rubric for Engineering Research Papers (v1.2)" by Bill Griswold						

Table 5. Note-Taking Rubric for Engineering Research Papers (Bill Griswold)