edited by
Christian Tarchi

Critical Reading of Digital Texts: The EMILE Project

Empowering Schools in Self-Regulation of Media and Information Literacy Processes

Foreword by Giuliana Pinto

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Contents

Foreword

It is a pleasure for me to write the preface to the volume *Critical reading of digital text. The EMILE project*, for two main reasons: because the topic addressed is at once extremely up-to-date while also a "classic" of epistemological research. Indeed, the 21st century imposes a redefinition of literacy skills, owing to the multiplicity of the documents available, the speed of their fruition and production, and the diversification and increasing virtuality of the reading and writing environments to which people have access. And all of this makes it essential to investigate the mind's ability to understand and critically process the information coming from these texts.

But the principle of authority based on the "ipse dixit" (he said it himself) concept, which considers the word of a religious or cultural authority indubitable, was already questioned by Galileo Galilei, who pointed to the risks of the uncritical and mystifying use of text:

> Nor therefore do I say that one should not listen to Aristotle [...] I only blame the giving oneself over to him in such a way that blindly one subscribes to his every saying and, without looking for any other reason, one should have it as an inviolable decree; which is an abuse that pulls behind it another extreme disorder, and that is that others no longer apply themselves to trying to understand the force of his demonstrations. And what thing is more disgraceful than to hear in public disputes, while dealing with demonstrable conclusions, to come out a sideways with a text, and well often written in every other respect, and with it to close the mouth of the opponent? (*Dialogue Over the Two Chief World Systems*, 1632)

Readers today have access to documents that present conflicting perspectives on almost any subject, often based on false information, a phenomenon that is not new but is growing in magnitude, thanks in part to social media platforms that allow everyone to post their opinion easily and almost without filters. And so today, in their learning, students are engaged in complex reasoning tasks, increasingly based on consulting, comparing-contrasting, and integrating information derived from different sources, on their intratextual and intertextual integration, and on the creation of new structures of thought. In order to construct relevant and well-founded knowledge, it is essential to be able to critically find one's way among information, as well as keep judgment suspended for a long time, tolerate multiple outcomes, and evaluate comparatively: one must, in other words, think and understand critically. Thus, it is necessary to improve the critical forms of thinking and understanding text, through appropriate interventions.

The book is built around this awareness: indeed, looking at the subtitle, *Empowering schools in self-regulation of media and information literacy processes*, we see that the authors have taken up the challenge of making a "relevant" science, capable of transposing theory into intervention and producing empirically validated tools that are useful for informing good practices in education and instruction.

Studies on the impact exerted by smartphones and the Internet point out that when these tools are entrusted to students without any educational mediation, it often results in their passive use, hindering sociality understood as relationships and potentially leading to a kind of "digital autism." Therefore, it is of particular interest for schools to promote innovative and mature paths of "literacy" which tackle the new forms and languages of communication, and give pupils space to think, debate publicly, express their own reasons or motivations, listen to and possibly criticize the views and opinions of others in a way that is respectful but also free from conditioning.

An additional reason for this volume's interest is the fact that the interventions presented in it address adolescence. This period sees the stabilization of many functions related to neurobiological development and is a critical phase for the consolidation of cognitive skills such as working memory and executive functions, whose importance in the construction of instrumental learning such as reading and writing has been highlighted by psychological research. Weaknesses in the efficiency of these functions have been found not only in children with intellectual disabilities and developmental disorders, but also in children with typical development. And so it becomes desirable to pay attention to strengthening executive functions and provide the necessary tools for professionals engaged both in fostering typical development and intervening in neurodevelopmental disorders.

Finally, I appreciate that a game was chosen as a tool for improving students' critical skills, overcoming the (as dated and harmful as ever) dichotomy between cognition and emotion. Indeed, research on text comprehension increasingly documents how emotional engagement in reading and the activation of related brain areas correlates with increased activation of language areas, aids word and sentence memory, captures and holds attention longer, and is associated with faster and deeper processing of text. In particular when reading multiple documents, students' combined affective and cognitive engagement influences two dimensions of comprehension: motivation to complete the task and value assigned to it, and level of proficiency in the necessary skills. At the origin of any transformative action of one's self, whether it is academic learning or professional cognitive restructuring, there is heuristic motivation and pleasure, the desire to learn, and the pleasure of doing it. This state of mind supports agentivity, the active and propulsive, self-confident behavior that is the fuel of all growth, change, and discovery. Let them play, I say!

The volume also has major implications for the role of educational processes: it is not difficult to see how schools, assigned with the task to develop cognitive, socio-emotional, critical, and participatory skills suitable for a world of information characterized by technology and multimedia, are simultaneously called upon to train active citizenship.

Indeed, good citizens are those who know how to take part in public discourse, take responsibility for their positions and argumentations, explore possible alternatives, choose on the basis of well-founded conclusions, and make fact-based decisions on issues of importance to personal and community life.

The book is structured in such a way as to provide to readers with those same "guarantees" that the authors indicate as inevitable for a text to stand up to critical scrutiny. The presentation of the main theoretical nodes of critical text comprehension is timely and up-to-date; the objectives and working hypotheses are in lively dialogue with the ongoing debate on the topic in the international scientific community; the results are evidence-based, as it is their discussion. This outcome is achieved thanks to the rich interdisciplinary collaboration among psychologists, educational scientists, computer scientists, and literature scholars behind the EMILE project. The confluence in the project of researchers from various geographical backgrounds adds flavor to the project. Not only that: behind the pages, one can glimpse the valuable threads connecting the project to different cultural realities, enabling the different linguistic and educational experiences to dialogue with each other.

I hope you read this volume as I did. With interest: the topic, a crossroads of many intrapsychic and interpersonal dimensions, is one that cannot be ignored. With curiosity, "with your antennae up": to test whether, and how much, you are a critical reader yourself. With playfulness: have fun and become a more critical reader not just with "Ello" but with your own brain too....

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Introduction

Christian Tarchi

In the present-day media-saturated world, there is an abundance of easily accessible information sources about almost every topic. The digital revolution has made knowledge more accessible in several different ways: i) With any digital device and an Internet connection you can access the largest library that ever existed; ii) Almost anyone can author texts and share them with others, increasing the diversity of accessible voices and perspectives; iii) Text formats can be easily manipulated, to adapt them to the specific needs of any individual reader. But the digital revolution has not come without drawbacks, the most important being that all this variety of contents, perspectives, and representations can overwhelm the reader. The problem is making sense of all this information, which includes accessing it, having a critical understanding of it, interacting with it, and fact-checking.

In this scenario, it becomes "critical" to focus on "critical" reading competence. Indeed, nowadays being able to comprehend a text is probably not enough. As readers may encounter different texts with varying perspectives and levels of reliability on complex socioscientific issues, they are required to master at least two fundamental critical skills: intertextual integration and sourcing. Readers are required to integrate information from different sources, often expressing different perspectives on the topic. These perspectives can be complementary or, conversely, contradictory. However, readers cannot always treat all sources equally and must engage in source evaluation, assessing the source's trustworthiness, competence, and benevolence as to the topic covered. Research suggests that readers, including adolescents and young adults (Kiili et al., 2022; Tarchi & Mason, 2020), lack sufficient skills to evaluate and process digital information, which may endanger their possibilities as citizens to form evidence-informed decisions on important issues in their lives.

In these circumstances, there are two important aspects that would better prepare adolescents to improve their cognitive capacities and allow them to access media information, have a critical understanding of it, and interact with it.

Firstly, to support students' survival in this situation of information overflow, adolescents' limited cognitive processing capacity should be supported and taken into account when designing educational interventions. Indeed, reading online about complex topics can be extremely taxing for readers' cognitive systems and students need to be taught how to regulate their flow of attention and information construction.

Cognitive load is a core concept when reading (and learning) online. It is based on the assumption that human beings have limited resources to process information. Thus, when presented with multiple and complex materials, people may experience a cognitive overload that impairs their comprehension and, in turn, their ability to think critically about the topic of inquiry. Cognitive load is particularly problematic in school-age students, as their cognitive abilities are still developing. When students are able to self-regulate their cognitive processes, it is possible for them to implement more sophisticated critical processes and engage in complex learning. This reflection calls into question the role played by executive functions, a family of top-down mental processes that are necessary when we are engaged in complex cognitive tasks. We can identify three main executive functions that are involved in most tasks: inhibition (controlling attention to override the impulse to analyze irrelevant stimuli and suppressing prepotent mental representations), working memory (keeping information in the mind long enough to elaborate it), and flexibility (shifting attention across several relevant sources of stimulation). Executive functions are resource-demanding and as such they cannot always be active but need to be regulated by the learner when the task characteristics require it: if we are reading an easy narrative book for pleasure, we are required to exert less control than when we are studying a textbook to prepare for an exam. But also: if we are experts in a domain or knowledgeable in a topic, we need to exert less control when reading than novice learners.

It is possible to train executive functions, but we need to follow a few principles (Diamond, 2013): i) repeated practice, like drills in sport practice, seems to be the path to take; ii) transfer across tasks is not necessarily automatic: learners need to practice executive functions as embedded in specific cognitive tasks; iii) executive functions are mostly engaged in demanding tasks, so we need to push learners beyond their limits; iv) learners should also increase their awareness about how their executive functions work, what their limits are, and when it is more convenient to activate them.

Secondly, teachers should be better supported to design effective, research-based media and information literacy practices. Several studies have shown that the greater teachers' self-efficacy, the more open they are to new ideas, the more willing they are to experiment with new methods, and the more engaged they are in professional learning activities (Runhaar et al., 2010). Schools are called to improve their students' media and information literacy by providing equal media education opportunities to all adolescents. This would, in turn, help to reduce socioeconomic disparities in critical aspects of reading, such as distinguishing facts from opinions (OECD, 2021). According to the PISA (Program for International Students' Assessment) "21st-Century Readers: Developing literacy skills in a digital world" report (OECD, 2021), the time teachers spend using digital devices in teaching and learning activities is often negatively associated with learning performance, such as reading: few have managed to integrate digital devices in teaching and learning activities effectively. For effective media and information literacy education, teachers need to be given the competencies to promote media literacy in students (OECD, 2021). Unfortunately, however, a recent report on teaching media literacy in Europe (McDougall et al., 2018) confirmed the fragmented state of media literacy education in schools across Europe. Professional development for pre-service and in-service teachers should address media literacy in general and critical reading competence more specifically, providing schools with evidence-based interventions, a higher perception of competence in teaching critical reading, and a greater knowledge of the processes involved.

The EMILE project

The EMILE project was designed to address these issues and i) empower adolescents' critical (digital) reading competence by supporting the underlying cognitive processes; ii) provide cross-disciplinary professional development to support teachers' competence in critical reading education. EMILE (Empowering Schools in Self-Regulation of Media and Information Literacy processes, https://www.emile.unifi.it/) is funded by the Calouste Gulbenkian Foundation, through the European Media and Information Fund (https://gulbenkian.pt/emifund/), and coordinated by the University of Florence with partners Anastasis, Tampere University, and the Romanian-American University.

The project is grounded on a robust and innovative pedagogical approach, scaling up previous experiences with a successful track record to ensure a high impact on the targeted groups. The project applies the following four methodologies.

EMILE is an evidence-based program. In the scientific literature, the term evidence-based program is used to refer to those programs that have undergone rigorous evaluation of their effectiveness. This approach to design and experimentation aims to assess interventions by defining the populations on which they can be applied and the conditions that make them effective. The goal of EMILE is to build an intervention to empower adolescents' information and media literacy, supporting the underlying cognitive processes on accredited pathways of proven effectiveness.

EMILE is game-based and gamified. In recent years, the use of game design elements in non-game contexts (i.e., gamification, Deterding et al., 2011) has received increased attention and interest in educational research and practice. A recent meta-analysis (Sailer & Homner, 2020) confirmed the claim that the gamification of learning works, as the authors found that gamification had significant, positive effects on cognitive, motivational, and behavioral learning outcomes. In this project, we design and validate "Elli's World" ("Elli" comes from "cervELLI" which means "brains" in Italian), a game-based training "journey" into the functioning of the brain, across cognitive processes. Indeed, empowering cognitive processes and understanding their role in learning and school behavior is a protective action for all children, with no distinction. The game is adapted so as to understand and train the cognitive functions that are needed in critical reading.

EMILE applies educational data mining (EDM). Data mining is the process of extracting hidden and useful information and patterns from large data sets. EDM is an interdisciplinary research area created for the application of data mining to the educational field. EDM uses different methods and techniques from machine learning, statistics, data mining, and data analysis to transform raw data collected during learning into useful and meaningful information which can be used to better understand students and their learning conditions, improve teaching support, and aid decision-making in educational systems. In this project, EDM is used to identify the main predictors for performance in Elli's World, grouping participants based on the structure and relationship between the measured variables.

EMILE implements a teacher professional development model (TPDM). The TPDM implements design principles to support teachers' self-efficacy in educating critical online readers. The model takes into account several aspects underlying successful professional development. First of all, the TPDM supports the teachers' agency. Toom et al. (2015) defined agentic teachers as teachers who perceive themselves as pedagogical experts with the capability to intentionally and responsibly manage new learning at both individual and community levels. For teachers to develop a sense of agency, they have to interact with others as a resource for learning (Toom et al., 2015). Second, the TPDM acknowledges that teachers' continuous professional development is a complex process, which requires the cognitive and emotional involvement of teachers both individually and collectively. It also requires the willingness to examine where each one stands in terms of convictions and beliefs and the enactment of appropriate alternatives for improvement or change (Avalos, 2011). Third, teacher self-efficacy, namely teachers' beliefs about their ability to influence student learning and achievement (Bandura, 1997) play a pivotal role in applying new teaching methods, in setting higher goals, and in the academic progress of their students (Runhaar et al., 2010).

This book

This book is a collective effort by all the members who participated in the EMILE project to provide educational practitioners with relevant knowledge about digital reading: what it is, what processes are involved, how it can be improved, and how teachers can be supported. The book is structured in five chapters with a conclusion.

In the first chapter, Christian Tarchi (coordinator of the EMILE project, University of Florence) discusses reading comprehension in light of its role within media and information literacy. Starting from a definition of reading comprehension, the author goes through the main processes that are involved in reading comprehension, presenting how reading comprehension has and is changing when embedded in digital spaces. Finally, the chapter introduces readers to interventions to promote critical reading comprehension in digital spaces. In the second chapter, Chiara Pecini (University of Florence) and Clara Bombonato (Anastasis) discuss the role played by executive functions in self-regulated reading. In the third chapter, Clara Bombonato (Anastasis), Andrea Frascari (Anastasis), Antea Scrocco (University of Florence), and Silvia Della Rocca (University of Florence) present the core action of the EMILE project: to develop and implement Elli's World, a game-based and gamified intervention promoting self-regulated reading of multiple digital texts. In the fourth chapter, Andrei Luchici and Alexandru Tabusca (Romanian-American University) discuss how educational data mining (EDM) can be implemented to explore ways to make an intervention adaptive to a profile of users. The authors introduce EDM and explain how it has revolutionized the educational landscape by enhancing teaching and learning experiences.

Moreover, they discuss the impact of EDM on media literacy education. In the fifth chapter, Carita Kiili and Pirjo Kulju (Tampere University) discuss design principles for teachers' professional development, targeting critical online reading. In the conclusion, Chiara Pecini and Christian Tarchi (University of Florence) present some final thoughts on the future directions of research on media and informational literacy.

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1

Digital and paper reading comprehension

Christian Tarchi

The purposes of this chapter are to

- ✓ provide a definition of reading comprehension;
- ✓ identify the main processes involved in reading comprehension;
- ✓ present how reading comprehension changes in digital spaces;
- ✓ introduce readers to interventions to promote reading comprehension.

1.1. Reading comprehension in secondary school

1.1.1. A definition of reading comprehension

Reading is an essential life skill, contributing to personal, social, and intellectual development. There are several reasons why we read: for leisure, to reduce stress, to promote well-being, to spark creativity, or to increase self-awareness. Reading can also be used to expand knowledge, improve critical thinking, enhance vocabulary, and, overall, promote lifelong learning. In this sense, reading-to-learn is a fundamental skill for the acquisition, sharing, and construction of knowledge (Tarchi, 2010).

The first goal of reading is to comprehend a text. Reading comprehension can be defined as a dynamic process in which coherent representations and inferences of different levels of the text are constructed (Graesser & Britton, 1996). In other words, readers need to interact with the text to understand its content and integrate it with their own long-term memory through internal connections and links with their prior knowledge. Reading comprehension is not an all-or-nothing process. Essentially, it is possible to create three main representations of a text (Kintsch, 1986):

- a surface model: readers access the meaning of each sentence and represent the text as a list of disconnected ideas;
- a textbase model: readers process the text as a network of concepts;
- and a situational model: readers integrate the text content with prior knowledge and represent the situation that the text wants to describe.

Let us take the following text as an example:

> When, in 1531, Conquistador Francisco Pizarro reaches the Pacific coast of the Inca Empire by ship, he finds a nation in the grip of civil war. He immediately thinks of taking advantage of this, offering his services to one of the two contenders in the struggle for power, but the fortunes of the conflict soon turn in favor of Atahualpa, lord of northern Quito, who has managed to defeat his brother Huascar, ruler of Cuzco, the ancient capital of the Empire. Atahualpa allows Pizarro's small troop, which has only one hundred and fifty men with it, to approach. The Inca emperor, with an army of no less than thirty thousand, makes an unforgivable mistake: underestimation.

A surface model allows readers to understand that Pizarro arrived in a foreign land by ship, in which there was a civil war. This information is given verbatim in the text. A textbase model requires readers to connect "this" in the phrase "taking advantage of this" to "civil war" and understand that Pizarro ("He") wanted to take advantage of the civil war ("this"). Understanding why Pizarro would risk his men fighting a civil war in which they are not involved requires the application of prior knowledge about the reasons why Pizarro and his troop arrived in the Inca Empire (to conquer it) and what is gained by offering services to one of the contenders (to reduce the number of enemies). If readers are able to elaborate the text in these directions, a situational model is constructed.

Several models have attempted to capture the array of processes that are involved in reading a text, one of the most prominent being the "simple view of reading" model (Hoover & Gough, 1990). According to this model, reading comprehension depends on a combination of decoding processes and language comprehension processes: Good readers need to be able to correctly recognize written words by decoding graphemes into phonemes, as well as being able to access the meaning conveyed by the network of words in a text. In language comprehension in particular, Oakhill et al. (2021) identified five main processes:

1. activating word meanings: deep knowledge of the main words in a text and ability to deduce meaning of unknown words from the text;
2. understanding sentences: understanding the syntactic structure so as to grasp how words are connected to each other and how sentences are logically connected to each other;
3. inference-making: linking pronouns to referents, linking information across the text, and connecting text content to prior knowledge;
4. monitoring: realizing when we are not comprehending a word, a sentence, or the meaning of a paragraph;
5. understanding text structure: understanding how sentences are connected to each other according to a cohesive structure.

Again in reference to the above text, readers need to:

- **[activating word meanings]** understand the word *conquistador* and its implications (the Spaniards are on the Pacific coast of the American continent to conquer and not to discover);
- **[understanding sentences]** understand, in the sentence "Atahualpa, lord of northern Quito, who has managed to defeat his brother Huascar," that

Atahualpa and Huascar are brothers and rule over different territories;
- **[inference-making]** infer from the word "underestimation" the fact that the Inca troops would eventually be defeated by the Spanish troops despite outnumbering them;
- **[monitoring]** realize that the sentence "but the fortunes of the conflict soon turn in favor of Atahualpa" suggests that Pizarro was wrong to offer his services to Huascar;
- **[understanding text structure]** represent the sentence "Atahualpa allows Pizarro's small troop … to approach. The Inca emperor … makes an unforgivable mistake: underestimation." as a cause-effect chain: underestimation (cause) → let Pizarro's troops approach (effect).

Of course, when reading a text, several other cognitive processes are involved, which the simple view of reading may induce us to neglect. Cartwright and Duke (2019) suggested a driving metaphor to explain how we read. When driving, drivers need to have an active role: Drivers choose to deploy the driving process, in a similar way to readers who choose to deploy the reading process, rather than passively decode the text. Just as drivers drive a car for a purpose, readers read a text for a purpose too. The purpose (how far we have to drive = how much we have to read) will influence the process. The processes are interrelated: drivers who know the route well will have an easier drive, in the same way as readers who are more knowledgeable about a topic will read a topic-specific text more easily. Driving depends on the context (road types or traffic patterns) as much as reading does (respectively, text types or textual structures). Road signs help drivers to know how to behave, just as textual organization signs (outlines, headings, …) help readers to navigate the text.

Particularly salient in this metaphor is the function of "control" over the cognitive processes involved in reading. On this theme, research has dedicated specific attention to the role played by "executive functions," an umbrella term that refers to a set of higher-order processes that allow an individual's mental processes and behaviors to be controlled and regulated. Executive functions will be thoroughly discussed in chapter 2 of this book. Past studies have confirmed that readers' ability to update information in their memories, pass over irrelevant information, and shift attention across different sources of information (three of the main executive functions) are strong predictors of reading comprehension (Cartwright et al., 2020). In Cartwright and Duke's DRIVE model (2019), executive functions in reading are similar to multitasking when driving: for instance, drivers flexibly shift their attention between the elements critical for effective driving just as readers shift attention between the different elements included in the text.

1.1.2. Text and readers

So far, we have described reading comprehension in terms of individual processes. However, reading comprehension is also the result of interaction between text and readers (Tarchi, 2010). Many students have problems, especially when they have to understand expository texts encountered in school books. This can happen for many reasons, including the texts' properties: less familiarity (readers receive little exposure to expository texts before upper elementary school), more difficult vocabulary, more complex syntactic structures, unfamiliar text structures, and less availability of relevant prior knowledge, to name but a few (Tarchi, 2012).

Readers should adapt their reading approach to the properties of the specific text that they are processing and as a function of the specific reading goal. We may read a text for enjoyment, curiosity, to prepare for an exam, or to write an essay. Depending on the reading goal, we may implement different reading strategies. The more aware readers are of the reasons why they are reading and the type of task they have to perform after reading, the better they will be able to self-regulate. We can define goal-oriented reading as those situations in which we read to achieve an overall goal (e.g., reading several texts to become experts on a topic). We can define task-oriented reading as those situations in which we read texts because we have to perform a task for which those texts are crucial (e.g., reading a textbook to prepare for an exam). Goals tend to be personal (although they derive from past experiences with reading), whereas tasks can be self-assigned or assigned by others (e.g., schoolteachers).

Goal-oriented and task-oriented reading brings up the issue of relevance. Relevance is the extent to which text content relates to a specific task (McCrudden & Schraw, 2007). When reading the task instructions, readers create a "task model," namely, a representation of what it takes to complete the task. Relevance instructions should provide readers with indications on the criteria to apply to determine the relevance of the text content. For instance, if the task asks students to "Identify the main differences in the flora and fauna between two countries," students will focus on those words cueing towards differences (*on the one hand, differently, more than, instead …*), elaborate the paragraphs illustrating differences more deeply, and try to link these differences to causes, either in the text or from their prior knowledge. "Relevance" and "importance" are not the same concept. Relevance refers to the extent to which specific text content is useful to complete a task or to progress to goal achievement, whereas importance refers to the extent to which specific text content is essential to understand the whole text (McCrudden et al., 2005).

Take the following excerpt as an example:

> Venice (population 270,000, area 414 km^2). Venice is a city in northern Italy, located in a lagoon in the Adriatic Sea. It is built on 118 small islands, and is famous for its many canals and lack of cars. It has many monuments and tourist attractions. Venice was once ruled by the Doge, and in the 13th century it was the most powerful city in Europe. The city is slowly sinking and suffers from frequent flooding.

In this passage, each sentence contains an "important" piece of information. Moreover, if our reading goal were "to learn more about Venice," each sentence would contain "relevant" information. On the other hand, if the task for which we are reading the passage was "How big is Venice?", only the first part of the passage ["Venice (population 270,000, area 414 km2)"] would actually be "relevant."

1.1.3. Reading on digital devices

Since the advent of the Internet, and with the popularity of digital devices, such as PCs, tablets, smartphones, e-book readers, and the like, reading has become more and more digitalized. In the last decades, several studies have analyzed the effects of this technological shift on the way we read. Results from comparative studies seem to suggest that readers achieve a deeper level of comprehension when reading on paper rather than when reading on screen (Singer & Alexander, 2017). Moreover, readers seem to express a preference for print when reading for academic purposes, at least at college level (Mizrachi et al., 2018).

Despite the primacy of paper-based reading over screen-based reading, we cannot neglect the present-day pervasiveness of digital reading, and so we need to understand if information-making processes undergo a transformation when shifting across mediums.

Digital reading is an umbrella term that takes in different situations. It may refer to reading a text (generally a book) on an e-book reader, a handheld device that simulates the effect of paper, or reading a text (books, but also documents or articles) on a tablet or PC, devices that also enable us to read multimedia texts (texts with images or texts with animations). Moreover, these digital devices may be connected to the Internet, which exposes readers to a vast amount of information.

Several cognitive processes seem to be involved in different ways when reading on digital devices (Wylie et al., 2018). For example, attention can be influenced by text formatting. Digital devices allow readers to customize texts, supposedly for better readability. However, not all digital devices have the appropriate affordances. Smartphones, for instance, demand higher levels of attention to achieve a deep reading comprehension. Digital environments are also challenging for executive control over cognitive processes. When reading online, readers have to construct their own navigational paths. In other words, they have to plan what to read, predict what they will find next, monitor their comprehension, and evaluate whether they are achieving their reading goal. This is similar to what happens when reading on paper. However, in the case of digital texts, readers are more likely to continuously find new texts to read (through web searches or hyperlinks) and have to go through the cycle of planning, predicting, monitoring, and evaluating over and over again.

I will address the following issues in the next paragraphs: is reading an e-book the same as reading on paper? Is reading on a tablet or PC similar to reading on paper? Does reading in digital spaces (i.e., on the Internet) prompt different critical reading processes?

E-book readers

E-book readers "compete" with paper mostly as regards reading books, rather than shorter texts. E-book readers use electronic ink and reflect or emit light around the edges, rather than emitting light directly into our eyes, like tablets do. As such, they are comparable with paper in terms of visual ergonomics and readability. However, there are a few other aspects that differ between e-books and paper books, which could influence reading performances, especially for longer texts (Mangen et al., 2019).

While e-books and paper books may be similar to the eye, they are very different in the hand. When reading on paper, readers have access to visual and kinesthetic feedback as they progress through the text (Mangen & Kuiken, 2014): they "feel" where they are in a text, which allows them to better self-regulate their reading processes. Overall, it seems that the physicality of printed texts, at least when reading narratives, helps to remember what we are reading better. This is true for both young children and young adults (Baron, 2021).

Tablets or computers

When reflecting on the use of tablets or PCs in learning contexts, educational practitioners often focus on the potential risk of distraction, as learners can easily access off-task activities (van Der Schuur et al., 2015). However, digital devices may be detrimental to learning/reading performance even if used for on-task purposes alone (Salmerón et al., 2021). Most of the studies investigating reading on digital devices are based on the shallowing hypothesis (Annisette & Lafreniere, 2017): When using digital devices, we are accustomed to quick interaction with immediate rewards, hence we are induced to superficially process information, even when using digital devices for more complex tasks such as reading.

A meta-analysis (Delgado et al., 2018) suggests that reading on tablets can influence comprehension negatively compared to reading on paper, but only in certain conditions. The detrimental effect appears when reading under time constraints, rather than when people can pace themselves, and when reading expository or mixed (expository-narrative) rather than narrative texts. These conditions seem to hold true regardless of educational levels. Interestingly, the screen inferiority effect seems to apply to reading on computers, rather than reading on tablets. A recent study (Salmerón et al., 2021) confirmed that reading on tablets (as opposed to reading in print) is detrimental for 10- to 13-year-old students with low reading comprehension skills when reading expository texts under time pressure.

1.1.3. Reading in digital spaces

The Internet offers readers access to an immense amount of knowledge. It is possible to get information on any topic. However, navigating, evaluating, and integrating information when reading on the web requires advanced digital reading skills. In this section I will review two critical aspects of reading in digital spaces, namely multiple representations and multiple texts.

Multiple representations

According to a recent theoretical framework that attempts to characterize the spectrum of the digital reading experience (Coiro, 2020), readers can engage with several types of text on the Internet, including: literary texts, informational texts, hybrid texts (a combination of literary and informational text structures), multimedia texts, multimodal texts, onscreen texts, hypertexts, hypermedia, Internet texts, and augmented texts. Literary, informational, and hybrid texts are text types that can be found on paper too. Multimedia and multimodal texts refer to texts with images (the former) and texts with animations or sound (the latter). Onscreen text refers to static text on digital devices that is comparable with the printed format. Hypertexts are designed to link thematically coherent texts to each other, with readers being able to construct their personal reading paths. Hypermedia refers to hypertexts which also include images or videos. Hypertexts and hypermedia are networked texts generally made available within a closed environment (such as a thematic website). Internet texts are a particular form of hypertext that are found on the open Internet, with more dynamic links and connections than in hypertexts or hypermedia. Augmented texts refer to texts that are embedded in readers' physical environments (Coiro, 2020).

Among these text types, multimedia texts and hypertexts are the most frequently read by students as well as being the most investigated by scholars. Multimedia texts call into question the issue of cognitive load (Sweller et al., 2011). Multimedia is often used to capture students' interest with captivating images or graphs that are often unrelated or unnecessary for conceptual comprehension. However, with these additions, the texts may cause an excessive cognitive load – defined as extraneous (Sweller et al., 2011) – on readers' working memories, which is useless for task completion. In other words, fancy images absorb readers' attention and drain their cognitive resources, which thenceforth may not suffice to elaborate the text content.

Hypertexts (almost any text available on the web nowadays) bring us to the issue of coherence. When reading on the web, readers can interact with the text in multiple ways: they can click on a linked word while reading; they can click on sources linked at the end (or side) of the text to inquire further into the issue; or they can create their own hyperlink by opening another tab on their browser to look for a word, or a concept. As hypertexts require non-linear reading, it is up to readers to create a navigational path building a coherent representation of the issue that they are inquiring about. The non-linear nature of hypertext is a cognitive load for readers' working memories. If the hypertext is clearly organized and the structure made explicit, the load on readers' working memories is reduced, but if the structure of the hypertext is implicit and/or complex, then it is more difficult for readers to comprehend the text content correctly and coherently.

Multiple texts

Often, readers access multiple texts when reading to search and acquire information on the Internet. This particular case of reading has been defined as multiple text comprehension (or multiple document comprehension) and has received considerable attention in the research.

Texts are embedded in sources, which characterize the text content in terms of reliability. Certain sources are more reliable than others. Readers should accurately evaluate the source's trustworthiness, competence, and benevolence. These sourcing skills all contribute to a coherent mental representation of the issue we are reading about. *Trustworthiness* evaluation refers to the ability to discriminate between more and less trustworthy sources (Bråten et al., 2009). When assessing trustworthiness, readers may use more or less sophisticated criteria, such as evaluating the reliability of an author based on their credentials (a good criterion) or evaluating a source as relevant because we agree with its content (a weak criterion). *Competence* (or expertise) evaluation is a more fine-tuned form of trustworthiness evaluation. An author may be generally trustworthy but particularly competent in a specific topic given their expertise. When comparing two equally as trustworthy sources, one may display more competence as to the topic we are reading about. *Benevolence* evaluation can be defined as a sort of conflict of interest. Certain sources/authors may be benevolent towards a specific issue. This does not make them unreliable, but they will probably be biased. A benevolent source can be understood as a source acting in the particular reader's interest (Thomm et al., 2015).

Multiple text comprehension involves the "building of a coherent mental representation of an issue from the contents of multiple documents that deal with the same issue from different perspectives" (Braten et al., 2013, pp. 322–23). Multiple text comprehension is grounded on single-text comprehension: readers need to elaborate textual content and build a coherent representation of each text. In addition to this, readers have to understand how texts are linked to each other: Do they present compatible information? Do they agree with each other? Do they present discrepancies? Do they complement each other? In other words, readers have to create an intertextually integrated representation of the issue that they are investigating as presented by the texts that they are reading, including agreements and discrepancies in the different accounts (i.e., situations model or integrated mental model; Britt et al., 1999; Perfetti et al., 1999). Multiple texts can be integrated if readers are able to draw intertextual inferences, that is, take parts of information presented in different texts and draw inferences connecting them (Incognito & Tarchi, 2023).

Intertextual integration/inferences are facilitated by *relevance* determinations. Before the reading task, readers should construct a task model, that is, a representation of the end goal of the reading activity and the set of actions needed to achieve it (Rouet et al., 2017). When navigating on the web, on the basis of the task model created, readers should only choose those texts that are relevant to the task. Moreover, when reading the texts, readers should focus on the information that is relevant to the task, as well as drawing only relevant intertextual inferences.

1.2. Educational approaches

In this section, I will discuss how we can better support reading comprehension. I will first discuss a few evidence-based approaches to reading comprehension in general and then focus more specifically on reading comprehension in digital spaces.

1.2.1. Promoting reading comprehension

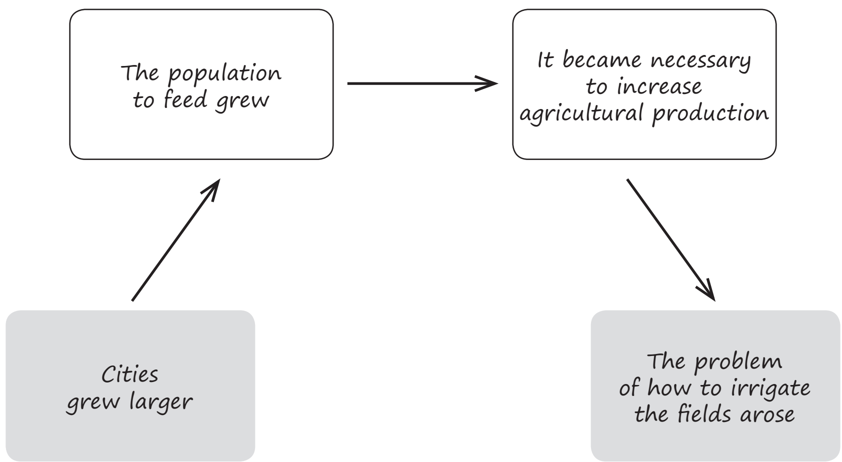
"How to improve reading comprehension" is one of the most studied topics in educational psychology research. All the same, given the complexity and ever-changing nature of reading comprehension, the perfect recipe to support struggling readers remains to be found. On the basis of the simple view of reading, two types of intervention can be identified: interventions targeting decoding skills and interventions targeting language comprehension processes. Here, I will focus on the latter.

A few years ago, Edmonds et al. (2009) reviewed intervention studies conducted between 1994 and 2004 on struggling secondary school readers. The main outcome of this contribution was that struggling readers can improve their reading comprehension when taught targeted practices. In most interventions, students are taught a combination of reading comprehension skills (e.g., inference-making) and strategies (e.g., note-taking). Whichever text comprehension strategy is taught (scrolling through the text to get an idea, monitoring comprehension, identifying main ideas), there are three actions to be taken:

1. Direct instruction: The teacher explicitly shows how an expert would apply the target strategy.
2. Practice: Students are given the opportunity to practice applying the strategy through specific exercises.
3. Feedback: Students are given timely and specific feedback on the degree of mastery of the target strategy.

For example, a teacher wants to teach students to use graphic organizers to make links in the text:

1. [**Direct Instruction**] Present a text ("Cities grew larger. The problem of how to irrigate the fields arose") on the multimedia board and present expert use of graphic organizer to achieve a coherent representation of the sentence:
2. [**Practice**] Similar sentences are given to students with empty graphics organizer templates to fill in.
3. [**Feedback**] Students are put into pairs so that they can compare the exercises they have done and correct each other.



A well-known example is the cooperative learning technique called "Reciprocal Teaching" (Palincsar et al., 1987). Students are divided into small groups (4–5 students each). It is important that the students in each group have a range of approaches to reading (e.g., readers with different reading skills, or readers with different interests, or readers with more reflective approaches alongside readers with a more superficial approach to reading). It is important that there is at least one expert reader in each group, that is, one who can correctly apply the main reading strategies. Once the groups have been made, each one is assigned a text to read. The text can be the same for each group, or different texts can be assigned to different groups, for example by adapting them to the characteristics of the group members. Once the teacher gives the go-ahead, students have to read the text in small groups and apply the preview, clarification, question generation, and summary reading strategies. The different members of the group go through the text in turns. The group member filling the role of "leader" reads a paragraph of the text and manages the group so that the four strategies are applied. When the turn is over, the baton is passed to another member of the group and so on until the whole text has been read. It may be appropriate for the teacher to first demonstrate how to apply these four strategies through direct instruction. Reciprocal instruction has been shown to be very effective in promoting reading comprehension in several studies (for a review, see Rosenshine & Meister, 1994).

1.2.2. Promoting reading comprehension in digital spaces

When reading in digital spaces, readers have to face three main challenges, besides the ones faced when reading on paper: a more complex reading environment; the need for source evaluation; the need to integrate information across sources.

Complex environments

As discussed in the "Multiple Representations" section, the complexity of digital spaces can overload readers' cognitive systems when reading. We can identify three sources of complexity: Intrinsic complexity, as readers tend to read about complex and multidisciplinary topics; germane complexity, as readers are required to implement several cognitive and motivational practices and strategies to self-regulate while reading; extraneous complexity, as readers may read texts within attention-demanding spaces.

Intrinsic complexity increases the intrinsic cognitive load (Sweller et al., 2011). The intrinsic complexity of a text depends on the level of interactivity between the elements making it up (words, images, graphs, …). The more the elements that are interconnected and the more interconnections there are between the elements, the higher the intrinsic cognitive load will be. For instance, if a graph needs to be integrated with the caption and the main text in order to be understood, the text will have a higher intrinsic complexity than if the graph were self-standing. Intrinsic cognitive load can be reduced by breaking down the text content, without fragmenting it too much, and by sequencing task instructions, so as not to overwhelm readers.

Germane complexity increases the germane cognitive load (Sweller et al., 2011). The germane complexity of a text depends on the individual mental resources required to elaborate the text. The more knowledge and expertise a text requires from readers in order to be understood, the higher the germane cognitive load will be. For instance, in order to be understood, expository texts generally require domain-specific prior knowledge, rather than common world knowledge. Hence, they have a higher germane cognitive load than narrative texts do. One way to reduce the germane cognitive load is to activate relevant prior knowledge before reading. This may expose readers to the vocabulary, pieces of knowledge, or structures required to create a situational representation of the text.

Extraneous complexity increases the extraneous cognitive load (Sweller et al., 2011). Here, the reading task becomes more complex because of unnecessary interference from non-relevant stimuli. This happens, for instance, when so-called "seductive details" are placed in the text, such as images that aim to capture readers' attention without being useful for text elaboration. The problem is that these elements not only capture readers' attention, but their cognitive resources too, which therefore cannot be dedicated to the actual reading comprehension task. One way to reduce extraneous cognitive load is to eliminate any source of interference and make the task instructions clearer, so that readers can self-regulate their attention better.

Source evaluation

When reading on the Internet, we cannot be wholly sure about the reliability of sources, so we need to engage in source evaluation. Such source evaluation skills can be assessed. For instance, Incognito and Tarchi (2023) validated an instrument to assess secondary school students' competence in identifying source information in a text, evaluate the author's competence in the topic, and judge the website's relevance.

There are several interventions available to improve students' sourcing skills (Brante & Strømsø, 2018). For secondary school students, providing specific guidelines on sourcing through worksheets, modelling expert sourcing, and discussing sourcing processes all seem effective methods to improve their source evaluation skills.

For example, to assess students' know-how on how to identify and reflect on an author's competence in relation to a specific topic we can ask them:

> *Author's Competence.* You will now read three short texts. After reading them, please answer the questions below by choosing one of the proposed answers:
>
> "The CultureNetwork platform has launched a competition to write a special article of the month focusing on new trends in the world of contemporary literature.
>
> In your opinion, which of the following authors/authors is the most competent to write the requested article?
>
> a. Biagio Anzi, librarian
> b. Anita Serpi, literary critic
> c. Francesca Fermi, pencil maker".

Alternatively, it is possible to assign a source-based writing task and check whether and how often students mention the source in the text and whether they reflect on the reliability and/or competence and/or benevolence of the source. However, it is necessary to include a clear reference in the assignment instructions to the fact that the students' use of sources in their essays will also be evaluated.

Intertextual integration

Another challenge students have to face when engaged in source-based writing tasks is retrieving information across multiple texts, and integrating content not only within texts but also across texts. Intertextual integration can be assessed through synthesis writing tasks or through a sentence verification task. If we ask students to write a synthesis essay, we can then code their productions in terms of depth of intertextual integration. Indeed students can: 1) simply consider the content of one text; 2) list the content of all texts; 3) integrate information by selecting information from one text only and explaining why the information from the other texts is neglected; 4) compare and contrast the texts and choose one as the main source of information for their essay; and 5) synthesize the content across texts through knowledge transforming processes. This list is progressive: Synthesis strategy (5) is more sophisticated than listing strategy (2).

Another way to assess intertextual integration is through a sentence verification task. After reading the texts, students are given a list of claims and have to choose whether they were discussed in the texts or not (see Incognito & Tarchi, 2023). The claims are: verbatim expressions from the texts, intratextual inferences, intertextual inferences, and distractors. Strong readers would correctly identify the first three categories as true and the items from the last category as false.

Barzilai et al. (2018) have reviewed studies testing the efficacy of interventions to promote intertextual integration. Knowledge about text structures, use of graphic organizers or outlines to plan the writing, and explicit teaching of integration strategies all seem to be effective interventions for secondary school students.

For example, we can show students two contrasting texts, and ask them to apply the three strategies described above to:

- Try to list the arguments of each text (*listing*);
- Try to figure out which argument from one text can refute which argument from the other text (*weighting*);
- Try to synthesize, that is, to find a third solution that can satisfy the two conflicting arguments (*synthesizing*).

1.3. Future directions

Research has made incredible progress in understanding how reading works and how it can be better supported. Several interventions are available for different populations of readers. Both professional development and resources are available to schoolteachers for the improvement of students' reading comprehension skills.

However, the digital revolution had an extensive, deep, and long-lasting influence on the way we read now, how learning to read takes place, and the type of texts we read. This revolution has unclear effects on our knowledge about reading, leaving open some issues with strong educational implications.

Issue #1: Is reading on digital devices the same thing as reading on paper?

There is mounting evidence that people learn more if they read on paper. So, we should push students to read on paper as much as possible. At the same time, we cannot forbid digital reading. On the contrary, we need to help students gain awareness of the differences between reading on paper versus reading on digital devices. However, we only have an emergent knowledge of what these differences are. Can reading strategies be transferred across mediums? Or should readers learn different ways of reading in order to adapt to the affordances of the specific medium?

Issue #2: Are new technologies pushing towards a more social view of reading?

When we read in digital spaces, we may be more exposed to other readers' reactions to the same text. For instance, when reading a newspaper article we can then read other readers' comments. Or when reading a text shared on social media, we have access to everyone else's reaction to it. Readers may interact in the text itself. When reading a book on an e-book reader we can see which part has been highlighted by other users and how many times. Some scholars are studying collaborative digital text annotations by having readers collaborate on the same platform to make goal-oriented annotations in a shared text. Overall, it looks like we are moving from an individual to a more social view of reading, according to which we can read and elaborate a text together with other people. Being an emerging area of research, it is unclear what the effects of collaborative annotations on reading performances are, and the conditions in which they are most effective.

Issue #3: What of type of prior knowledge really matters when we read?

One main principle in reading comprehension theories is the fundamental importance of prior knowledge. The more knowledgeable readers are, the easier reading the text will be. Expert readers are more strategic and achieve deeper levels of comprehension. While there is broad consensus on the relevance of prior knowledge, there is less clarity as to the contribution of prior knowledge components. Indeed, when reading a text we may have expertise about the domain to which the text belongs (e.g., history if reading a historical text), but we do not necessarily have specific knowledge about the topic discussed in the text. Knowing the meaning of the main words in a text also plays an important role. Not only do we need to know things, but prior knowledge should be coherently organized to facilitate reflective reading. And finally, prior knowledge should be correct and accurate, or we may approach a text feeling that we know more or less than we really do know. Future research should design ways to assess the multiple components of prior knowledge and verify which component matters most when reading.

Issue #4: What kind of environment better supports digital reading development?

"Home literacy environment" describes all the literacy-related interactions, resources, and attitudes that children experience at home. Before entering school, children have emergent literacy experiences (Pinto et al., 2017) such as reading with parents, pretending to write, acting being a postman, and so on and so forth, which are longitudinally associated with reading acquisition. In other words, the more of these experiences children have (i.e., the better their home literacy environment), the easier learning to read will be for them. While we have now achieved a good understanding of what characteristics a home literacy environment should have to support young readers, what a "home digital learning environment" should be like is less clear. What kind of experiences with digital devices can foster functional emergent "digital" literacy in children?

Summary

Reading comprehension is a complex skill that involves a variety of cognitive processes, including decoding, language comprehension, and strategic processing. There are a number of evidence-based approaches to promoting reading comprehension, including teaching reading strategies or using graphic organizers. New technologies have radically influenced reading comprehension. We are now elaborating different types of texts on different types of devices for different types of purposes. All these changes are affecting the way we read. There are a number of specific strategies that can be used to promote reading comprehension in digital spaces. These strategies include: managing the cognitive load, teaching source evaluation, and fostering intertextual integration. By implementing these evidence-based approaches, educators can help students to develop strong reading comprehension skills, in both traditional and digital environments.

Glossary

Executive functions. A set of higher-order processes that allow an individual's mental processes and behaviors to be controlled and regulated.

Inferences. Connections of information across the text and integrations of text content with prior knowledge.

Intertextual inferences. Connections of information across multiple texts.

Prior knowledge. Accurate and coherent domain and topic knowledge that is relevant to the text content.

Reading comprehension. A dynamic process constructing coherent representations and inferences of different levels of the text.

Shallowing hypothesis. A hypothesis suggesting that when interacting with digital devices we adopt a superficial manner of processing information.

Simple view of reading. A theoretical model describing reading as the interaction between decoding and language comprehension processes.

2

Executive functions toward self-regulated reading

Chiara Pecini and Clara Bombonato

The purposes of this chapter are to

- ✓ examine the role and development of executive functions by exploring their definition, importance, and how they progress over time, highlighting their impact on cognitive processes and learning abilities;
- ✓ understand executive functions in learning contexts through an analysis of their influence on learning, especially in reading comprehension, and examining how these cognitive processes affect educational outcomes;
- ✓ describe strategies to enhance executive functions through the analysis of educational interventions and strategies to improve these functions and support academic achievement and self-regulated learning.

2.1. Introduction

Many readers will have heard of executive functions (EFs). EFs are a construct, first appearing in the field of psychology in the 1980s, that encompasses a number of different mental operations enacted by the individual to consciously or unconsciously regulate other mental processes and personal behaviors, thoughts, and actions in order to achieve a deliberate goal. An example might be getting up one morning and having to do a medical examination that requires fasting and drinking plenty of water. In this case, our actions will be guided, unconsciously perhaps, by the control processes that help us to perform all those automatic morning-time actions, while avoiding the breakfast action and following the "drink a lot of water" rule, all of which until the medical examination, that is, until the goal has been achieved. Based on this example, we can reasonably assume that we perform EFs every day, clearly with variations in the type and degree of our engagement.

However, many educational and learning psychology professionals have questioned whether it is useful to place so much emphasis, as has been the case in recent decades, on this cognitive construct. Indeed, EFs risk overlapping with other processes that may be considered equally important for learning and adaptation.

The answer to this legitimate question can be found in the many changes that have occurred in both the environment and human beings' mental functioning, and their development from birth to adulthood, over the past twenty years. Indeed, in today's increasingly changing environment, it is hard to make predictions on the basis of prior and learned knowledge alone. What is more, prior and learned knowledge is poorly suited to automated behavior and routines, which pose individuals and society with continuous challenges. The same also goes for the "learning environment"; nowadays, effective learning requires different strategies to process and store information, drawn from various sources, at different times and in different ways. Hence, adjustments have to be made to learning behavior and the mental processes involved, including the emotions and motivations associated with the task.

Moving on to reflect on our brain, neuroimaging techniques that allow us to visualize its structure and activity have enabled us to understand its high degree of plasticity, namely, its ability to modify its structure and function in response to experiences and the surrounding environment. Thus, the decisive role of the environment in shaping the brain circuits essential for learning and adaptation becomes clear. These circuits have to become increasingly specialized (Karmiloff-Smith et al., 1994; Johnson, 2011) to enable the automatic use of numerous skills with minimal cognitive effort. Nevertheless, they need to maintain interconnections with each other and integrate with the neural control systems which define their rules and modes of activation according to specific contextual circumstances and personal goals (Jonson & de Haan, 2015). "Specialization" and "flexibility" are therefore the key words of a brain capable of learning and adapting to the times we live in. However, paradoxically, when the environment is overly changeable or overstimulating in the early developmental eras (e.g., due to diminishing temporal and spatial boundaries, or to information relevance and salience thresholds), brain circuits may struggle to specialize and be used flexibly at the same time. Consider, for example, the fact that nowadays, from early on, novice readers can "switch" between written texts of different lengths, types, and content (e.g., paper texts vs. digital "messaging"). The risk is that they may not devote sufficient time to automating the decoding process specific to spelling stimuli, something that years ago, when there was only one reading mode, children were more encouraged to do. In the absence of adequate specialization, control over different reading strategies or modes are also likely not to be practiced spontaneously, as the circuits to be regulated are either not yet well defined or do not send clear information to the areas of the brain that have to modulate them, limiting their flexibility.

In this scenario, therefore, mere exposure to the environment is no guarantee that the brain will develop in a manner suitable for the current learning tasks. Therefore, the need has emerged to understand the mental processes of regulation and control, with the ultimate aim of implementing innovative intervention strategies that will foster effective ways of learning and adapting in different contexts in all individuals, regardless of their personal characteristics and socioeducational contexts (Friedman & Miyake, 2017; Moffitt et al., 2011).

2.2. Executive functions

2.2.1. Defining executive functions

There is unanimity in calling EFs an umbrella term for a family of mental abilities that come into play when we need to exercise control over our thoughts and behaviors, especially when we are trying to overcome our habits, impulses, and desires (Diamond, 2013; Marzocchi & Mingozzi, 2022). However, different definitions of this construct can be found. For example, one of the leading EF scholars, Philip Zelazo of the University of Minnesota, describes EFs from a behavioral perspective, that is, based on what people do when they have to deliberately solve a problem, such as enacting solution strategies. Adele Diamond, of the University of British Columbia, describes the cognitive operations going to form EFs, such as the ability to focus on and inhibit distracting stimuli or to go beyond prior knowledge and skills so as to be creative and change points of view. Again, Michael Posner, of the University of Oregon, emphasizes the neurofunctional underpinnings of EFs, pointing out how the brain circuits that underlie them allow us to prioritize the many brain areas that are simultaneously spontaneously active in our brains. These seemingly different perspectives are complementary to each other, as they allow the complexity of EFs to be grasped from different behavioral, cognitive, and neurofunctional angles. Indeed, EFs are metaphorically defined as an "air control system" capable of managing incoming information in order to give a controlled, non-impulsive response: the absence of good executive functioning, therefore, generates an absence of control of different mental processes (Center on the Developing Child at Harvard University, 2011).

However, while it appears possible to say what EFs are, it is very complex to define what EFs are not. This information is nevertheless necessary to make the construct sufficiently specific. However, it is recognized that EFs are influenced by and can simultaneously influence other processes that are important to learning and adaptation. This is done through bidirectional and dynamic relationships, according to trajectories that evolve throughout childhood and the preschool period into adulthood.

Several scholars have questioned the extent to which EFs overlap with other skills, such as metacognition, as it is recognized that the regulation of mental processes can also make use of explicit knowledge and strategies of which an individual is therefore aware (Bryce et al., 2015; Wu et al., 2023). Still, we can question the extent to which inhibition of interfering stimuli, one of the three basic components of EFs, is distinct from or overlaps with controlled attention processes (e.g., Peters & Posner, 2012; Panesi & Morra, 2015). Furthermore, executive skills have been shown to influence the ability to anticipate and understand the actions and mental states of others, namely, the ability to adopt a different point of view, commonly known as theory of mind (Carlson et al., 2015). Finally, another construct often confused with EFs is that of self-regulation. Nonetheless, although some overlap can be identified between the two constructs, again they are not synonyms. Although a clear definition is still lacking, self-regulation implies the dynamic and adaptive ability to autonomously modulate internal states and behaviors, of which processes such as EFs are part (Nigg, 2017).

Finally, it should be emphasized that any behavior involves the processing of incoming information and the execution of an outgoing response, which also makes executive behaviors dependent on the goodness of sensory processing (e.g., auditory, visual) and motor programming (Rivella et al., 2022). Not only that, they are also in continuous bidirectional interaction with language (Slot et al., 2018). For example, executive processes such as the ability to inhibit interfering stimuli and to update information in the memory are critical in interpreting complex sentences and integrating semantic-pragmatic and morphosyntactic aspects. At the same time, however, language can help regulate behavior by keeping rules and goals active in the memory.

In summary, whenever we think of observing, evaluating, or intervening on EFs, we must remember that other cognitive processes (of reasoning, theory of mind, emotional regulation, language, and so on) can make EF measures impure. EFs, therefore, have a complex definition, and despite a seemingly unanimous view, their dynamic interaction with other mental processes can provide valuable keys to understanding both typical psychological development and possible abnormalities or disorders (Zelazo, 2020).

2.2.2. Neurofunctional bases of EFs

In recent decades, sophisticated noninvasive techniques to analyze nervous system functioning have made it possible to visualize the neurobiological and neurofunctional changes taking place in early executive control skills. If we are to adopt the educational neuroscience perspective and investigate the trajectories and maturation characteristics of the circuits underlying EFs, we can understand how the environment can be modulated and adapted to facilitate the gradual development of these circuits in the individual. It is important to note, first, that the terms executive functions and "frontal" functions, namely functions carried out exclusively by the frontal lobes of the brain, are not interchangeable (Bettcher et al., 2016). In fact, despite having a major neural basis in the prefrontal area, EFs are performed by extended brain circuits (Vallesi & Brovedani, 2022). The prefrontal cortex is a richly connected region, having many fibers that allow communication between neurons, both internally and with other cortical, subcortical, and limbic areas involved in various cognitive, motor, and emotional processes (Catani & Thiebaut De Schotten, 2012). The prefrontal cortex is thus the region that has the largest number of connections with the rest of the brain, and although it is one of the last regions to mature both phylogenetically and ontogenetically (Teffer & Semendeferi, 2012), several studies have shown that it is functionally active as early as the first few months of life, playing a key role in driving connectivity with other areas of the brain (Hodel, 2018) and in regulating behavioral responses (Grossmann, 2013). In fact, many changes are observed in the structure and function of frontal and prefrontal circuits in the first year of life, such as an increase in the number of neurons, connections between them (e.g., synapse and dendrite formation, myelination of fibers), and brain metabolism, promoting connectivity between the prefrontal cortex and other brain areas.

The maturation of frontal lobe connectivity accompanies EF progress for about 20 years, from early childhood to young adulthood (van den Bos et al., 2015; Fiske and

Holmboe, 2019), with activation becoming progressively more localized for specific operations or executive components (Durston et al., 2006). In fact, the neurofunctional circuits of EFs change from early adulthood to adulthood itself (e.g., in terms of less specialization, greater recruitment of specific areas, or less wide-ranging functional connectivity). In addition to age, they also vary according to task-specific demands and interindividual differences in executive abilities (Vallesi & Brovedani, 2022).

Given the protracted maturation of the neural circuits underlying EFs, the both proximal (e.g., parenting) and distal (e.g., educational style, sociohistorical period) environment assumes a key role in shaping EFs, with a direct effect on the circuits themselves. In fact, one can recognize both a high degree of malleability in the prefrontal circuits, which leaves ample possibilities for intervention (Chorna et al., 2020; Salmi et al., 2018), and a parallel vulnerability of the same, which frequently alters EFs in many conditions of atypical development or special educational needs (Pecini & Casalini, 2022).

2.2.3. Cognitive models of EFs

For the purpose of this volume, in this section we focus on the EF models most widely used in developmental and educational psychology.

The fractional model, proposed by Miyake in 2000, is considered among the most cited in the scientific literature and has helped provide a detailed and articulated view of basic EFs. Miyake and colleagues divided EFs into three independent, albeit interrelated, basic components: inhibition, working memory updating, and cognitive flexibility. Briefly, inhibition allows the control of automatic or instinctive responses and the suppression of interfering information. Updating working memory allows the active manipulation and reprocessing of information held temporarily in the memory. Cognitive flexibility, which Mijake identifies more specifically with the operation of "shifting," refers to the ability to change response type, rule, or mental representation. All these processes are necessary to enact complex behaviors that require, for example, planning and problem-solving and are indispensable for learning and adaptation. This model has been confirmed by later studies (Friedman & Miyake, 2017) and is similar in part to that of Adele Diamond (2013) who specified additional differences within each basic component. However, the three basic components of fractional models are rarely observable independently of each other, and a limitation lies in the difficulty of identifying a single executive process responsible for task success or failure, especially in real-world contexts of daily life.

Another widely used developmental model, considered more "ecological" than fractional models, is the sequential model proposed by Zelazo et al. in 2003. According to this model, every behavior, from the simplest to the most complex, may require executive control. Executive control is defined as problem-solving requiring four main stages that are organized hierarchically and distinct in time and function. The first stage involves mentally representing the problem and the goal that has to be achieved, the second involves planning the actions and strategies to be implemented, the third executing the strategies, and the last evaluating the results achieved.

While seemingly different, fractional and sequential models are not in opposition, since the basic EF components required in each stage of problem-solving may vary to different degrees. For example, representation requires the flexible evaluation of the different perspectives of a problem; planning requires the organization of objectives, alternative solutions, and resource management in the working memory; execution requires storage of the planned solution in the memory and following the rules to translate the plan into action, without yielding to interfering impulses or stimuli; and finally, the last stage, evaluation, requires cognitive flexibility in order to update the plan according to the correspondence between objectives and results, the correction of any errors, and revision of previous stages of the problem.

It has also been recognized that both the EF components of fractional models and the problem -solving steps of sequential models may vary in the degree of emotional connotation required, especially when dealing with daily challenges. With this in mind, Zelazo and Müller (2002) emphasized the need to take it into account that EFs should not be imagined solely as neutral cognitive processes (i.e., "cold" EFs), since in emotionally engaging contexts EFs also involve the capacity for emotional self-regulation ("hot" EFs). The same task may require both cold and warm EFs simultaneously, and integration between them is crucial for effective adaptation to the real-life environment, especially for effective social functioning. Furthermore, a more recent reformulation of EF models (the IR model, Cunningham & Zelazo 2007) emphasizes the interaction between EFs and reflexive processes activated by uncertainty or conflict. According to this model, basic EFs (inhibitory control, updating working memory, cognitive flexibility) are top-down processes of emotional or cognitive self-regulation that modulate attention and control behavior by interacting with reflexive processes activated by information that signals a problem and thus requires deliberate processing.

Finally, it is worth noting that, whichever model is considered, EFs also reflect knowledge, beliefs, and values, which are influenced by the sociocultural context. This must be taken into account in both assessment and intervention (Doebel, 2020).

2.2.4. Developmental trajectories of EFs

Previously, a few decades ago, EFs were only thought to emerge at the end of the slow maturation of the prefrontal circuits, and thus were not present at an early age. Subsequently, developmentally appropriate assessment tools and models have traced the emergence of EFs from very early ages (Aylward et al., 2022) and studied their complex interactions with the environment. While it is now well established that preschool and school ages are critical periods for the development of executive processes (Garon et al., 2008), their functional organization in the developmental age remains a debated issue (Scionti & Marzocchi, 2021).

For fractional models, executive processes are organized hierarchically, leading to a progressive differentiation of the basic components, similar to what is described in adulthood, with complex EFs appearing at later ages (Huizinga et al., 2011). Although until the age of three it is difficult to distinguish the different emergent components, inhibition is deemed the first executive component to develop, seeing a rapid growth between the ages of two and six (e.g., Wiebe et al., 2011). From the age of four, two separate executive dimensions can be identified: inhibitory processes and working memory processes, while cognitive flexibility develops later, as it is strongly correlated with the other two executive components. Therefore, based on this developmental trajectory, early alterations in inhibition and working memory may have important consequences on the later development of more complex EFs. It becomes of utmost importance to define the developmental trajectories of EF components especially when outlining interventions aimed at enhancing these processes: hence, it is important to start by enhancing the basic EFs that emerge first, and then to intervene on the more complex components in later stages of the intervention.

Unlike the fractional model, the sequential models proposed by Zelazo describe the development of EFs through the increase in complexity of the rules used to solve a problem and the ability to reflect and elaborate hypotheses through internal language. They emphasize the progressive increase in reflective processes in children's development, with children learning to stop, reflect, and identify conflict situations by deliberately activating their EFs. Zelazo also points out that while the development of cool EFs tends to follow a curve in line with advancing age, improving until adolescence, EFs in emotionally salient contexts show two phases of fragility, followed by qualitative jumps around the age of three to four and adolescence.

Finally, Dobel (2020) recently pointed out that the development of EFs should not be considered in isolation as it is strongly conditioned by children's assimilation of specific mental contents dependent on the family and sociocultural context. In short, although there are differences in patterns of EF development, derived from the breadth of age groups considered and the difficulty in choosing appropriate tasks for assessment (Wiebe et al., 2011), EF development has multifaceted dynamic features that should be taken into account when implementing educational tasks and EF interventions.

2.3. Executive functions and reading

2.3.1. EFs as tools for learning

There is extensive literature on the relationship between EFs and various types of learning such as oral language acquisition or specific skills, for example, in sports or the arts. For the purpose of this volume, we will focus on the relationship between EFs and school learning and, in particular, written text comprehension.

The strand of research investigating the links between EFs and school learning is extremely extensive and includes the study of skills for learning, the foundations of which are fostered as early as kindergarten, and instrumental skills (i.e., reading, writing, computation), which are acquired during school age and can be improved throughout life. A large body of literature suggests that EFs support school readiness and contribute to academic success, both directly, by affecting specific skills, and indirectly, by making children more prepared for structured school life (see Cortés Pascaul et al., 2019 for a systematic review). When adequate inhibition and self-regulation skills, working memory, and cognitive flexibility mature during childhood, children begin elementary school with greater abilities to sit, plan, pay attention, remember instructions, and comply with the rules of structured learning typical of this phase of schooling (Shaul, 2014).

In addition, longitudinal studies identify preschool EFs as significant predictors of individual differences in prerequisites to learning (Ruffini et al., 2021) and students' academic performance in the areas of mathematics (Purpura et al., 2017; Viterbori et al., 2015), reading decoding (Blankenship et al., 2019), writing (Shaul & Schwartz, 2014), and written text comprehension (De Franchis et al., 2017; Gandolfi et al., 2021). Specifically, processes related to inhibition, working memory, and cognitive flexibility assessed in the last year of kindergarten, before formal education, were found to be predictive of individual variability in the acquisition of metaphonological skills, early decoding, writing, and retrieval of arithmetic facts at one-year intervals, but also of text comprehension and problem-solving skills at three-year intervals, highlighting the long-term effects of EFs in the school learning process. It should be noted that good EFs in preschool mitigate early school leaving and dropout risk factors, such as belonging to disadvantaged sociofamily backgrounds (Blair & Raver, 2016).

The role of different executive components in learning processes may change over time as EFs are progressively reorganized and school task demands are met. For example, at school age it has been observed that processes related to working memory, rather than inhibition whose role predominates in preschool, constitute an important source of variability for individual differences in reading decoding, written text comprehension, and mathematics (Gandolfi & Usai, 2022). In addition, stronger associations are expected in the early years of elementary school, when reading, writing, and computation skills are not yet automated, but also at later stages of development, such as during secondary school, when school demands become more complex.

The relationship between EFs and school learning is also evident in atypical development: indeed, research in this area shows a significant association between specific learning disorders and deficits in EFs (Capodieci et al., 2023). However, the focus on the role of EFs in school learning is not based on the idea that EFs are the only factor or that they play the most important role: in fact, we know that they are just one of the factors in interaction with many others (e.g., oral language skills, socioeconomic level, Taylor et al., 2023) and, precisely because of their transversality and malleability, they can be an "open window" for intervention and inclusion.

2.3.2. Which EFs in reading

By reading skills we mean both the acquisition and automation of decoding and less automated text comprehension skills. In the early stages of literacy, the acquisition of the rules of grapheme-to-phoneme conversion and retrieval of the verbal label of the written word may require various executive processes such as interference control (e.g., of letters adjacent to the word to be decoded), inhibition (e.g., of letters that are similar in sound or shape), working memory (e.g., in maintaining the sequence of letters that make up a word), and cognitive flexibility (e.g., in changing phonological decoding strategy according to consonant groups or phrasal context; van der Sluis et al., 2007; Johann et al., 2020). However, in the absence of specific learning difficulties, decoding processes are quickly automated by the third year of elementary school, after which, save specific features of the environment (e.g., low readability) or of the type of stimulus that is to be read (e.g., new words or an unfamiliar language), an experienced reader will read a text fluently without the special engagement of EFs.

The situation is different if we think of the text comprehension process, which cannot be automatic, as it requires construction of coherent mental representations by linking the specific information of the decoded text with prior knowledge, acquisition of new information from the text, and, in advanced stages, integration of different sources and texts.

Many studies (Follmer, 2018; Butterfuss & Kendeou, 2018; Cartwright & Duke, 2023) suggest that various EFs, such as working memory, cognitive flexibility, planning, monitoring, and sustained attention, are moderately associated with the ability to acquire information and infer content from a written text, with stronger associations in readers aged 6 to 17 than adult readers. Some authors (Cutting et al., 2015) suggest that EFs may be important for allocating resources to text-specific information, as well as successfully orchestrating the development and interaction of written text decoding processes with oral language comprehension processes.

Considering the basic components of EFs, working memory may explain a high proportion of individual differences in written text comprehension abilities (Swanson et al., 2009). In fact, to successfully construct a representation consistent with the meaning of a text, readers must: i) update information retained in the short-term memory, ii) retain relevant information, iii) connect it with information further on in the text, with the visuospatial memory also playing a role in helping integrate different viewpoints (Mammarella et al., 2015; Garcia et al., 2019). Response inhibition and interference control support comprehension by suppressing the activation or intrusion of irrelevant information in the text or the memory (Butterfuss & Kendeou, 2018) and by selecting one piece of information or interpretation rather than another (e.g., Borella & de Ribaupierre, 2014). Regarding cognitive flexibility, although evidence supporting a relationship with reading comprehension is limited, it is hypothesized that it supports comprehension by integrating semantic information with phonological information and flexibly distributing attention according to text features and reading task goals (Butterfuss & Kendeou, 2018; Johann et al., 2020). A recent meta-analysis exploring the relationship between EFs and academic achievement showed that the relationship between reading comprehension and working memory and flexibility tends to remain constant during elementary school, while the association with inhibitory control tends to decrease (Spiegel et al., 2021).

Although existing studies have mainly focused on the three basic components, it is useful to understand how higher-level EFs, such as planning and problem-solving, are also related to reading comprehension. For example, Conners (2009) argues that reading process monitoring, stopping the reading when a problem occurs, and adopting alternative processes when a process fails, is an operation that can be traced back to the different stages of problem-solving and is essential to reading comprehension.

The role of EFs in text comprehension skills is further supported by studies of children with low text comprehension levels. Carretti et al. (2005) found that children with low comprehension levels perform less well on a working memory update task and make more errors of intrusion of irrelevant information than children with better text comprehension skills. Similar findings are supported by more recent studies (e.g., Linares & Pelegrina, 2023; Ruffini et al., 2023), underpinning the hypothesis that reading comprehension difficulties are associated with low levels of working memory.

Despite this evidence and the need to clearly define the role of EFs in different text comprehension tasks (e.g., expository vs. argumentative, Eason et al., 2012), major models of text comprehension have not explicitly included EFs (Potocki et al. 2017). Considering the role of EFs in current models of reading comprehension, as Cartwright and Duke's DRIVE model recently pointed out (Cartwright & Duke, 2019), could help explain substantial interindividual variance in comprehension performance and would help address recent calls in the literature to focus on higher-level processes (Kendeou et al., 2013; McNamara et al., 2015) that support deeper understanding (Graesser, 2015).

Finally, it should be considered that in many school or academic tasks reading and comprehension skills need to be integrated with writing skills, for example, for the construction of an argumentative text from texts presenting different positions on a certain topic. The role of EFs is widely recognized in the acquisition of text-writing skills, so much so that EFs are included in cognitive models (e.g., Hooper et al., 2002). Executive functioning in writing takes place through the abilities to plan, organize, set goals, self-regulate, and self-control. Regarding the basic components of EFs, inhibition supports selection of the most appropriate words while ignoring irrelevant ones, and working memory supports the ability to update representations according to the vocabulary used (Drijbooms et al., 2017). In addition, writing acquisition requires inhibition and attentional control processes, for example, to select the correct orthographic representation by discriminating between homophonic (same sound) and non-homographic (different sign) words (Hooper et al., 2002; Peng et al., 2018). Finally, some EFs, such as planning, also control the execution of the graphomotor components of writing, supporting the scheduling and speed of movements such that they influence text length, fluency in handwriting, and even the content and syntactic complexity of written texts (Hebert et al., 2018). These findings are supported by a recent systematic review that confirms the involvement of all basic EFs, with working memory playing a greater role, in text writing, with varying relationships depending on the writing process under consideration (Ruffini et al., 2023).

2.3.3. Different EFs across different reading tasks and modes

The need to consider the role of EFs in text comprehension becomes even more compelling when it is necessary to select texts from reliable sources and then to integrate information from multiple texts which have different structural features or modes of performance (e.g., digital vs. paper). As reiterated throughout the book, understanding multiple texts involves the selection, processing, and critical evaluation of texts, processes in which we expect EFs to play an important role. However, as pointed out by a recent systematic review of the literature (Tarchi et al., 2021), the few studies carried out have predominantly investigated the relationship between multiple text comprehension and verbal working memory capacity, while problem-solving skills, inhibition, and cognitive flexibility, other EFs considered crucial for single text comprehension, have rarely been explored. Moreover, even when considering the literature on the association between working memory and multiple text comprehension, the results are difficult to interpret, as they differ in constructs and measures used (e.g., essay writing vs. a sentence-checking task) and the study populations predominantly involve secondary school or college students, omitting developmental trajectories from early ages of schooling. Therefore, although a strong relationship between multiple text comprehension and EFs is hypothesized, at the current state of the art it is very complex to define which EF is involved in which stage of the multiple text comprehension process. For example, while evidence supports the involvement of working memory in intertext comprehension (Isberner et al., 2013; Braasch et al., 2014; Andresen et al., 2019), there is more disagreement as to the involvement of working memory in the provision of documents (Braasch et al., 2014; Mason et al., 2018) and the creation of an integrated model (Braasch et al., 2014; Beker et al., 2019; Florit et al., 2020). In elementary school children, it has been found that when creating an argumentative text, working memory supports the ability to integrate multiple texts after the main information has been identified (Florit et al., 2020).

Moreover, recent studies have suggested that readers' performances in multiple text comprehension tasks may change depending on whether the medium is digital or paper-based (Latini et al., 2019). Given the recent increase in digital texts, new studies have focused on investigating differences in performance between digital and paper texts, hypothesizing that digital media are more difficult to comprehend (Clinton, 2019; Delgado et al., 2018) and require more cognitive control than paper texts (Ackerman & Lauterman, 2012). A number of studies have investigated the comprehension of digital texts in relation to working memory, demonstrating the involvement of this component among adolescents and young adults, especially under very demanding conditions in terms of cognitive resources (Burin et al., 2021; Hahnel et al., 2017).

Studies conducted on elementary school children confirm the role of basic EFs in the comprehension of digital and paper texts (Ruffini et al., 2023; Florit et al., 2023). Florit's 2023 longitudinal study shows that the working memory and interference control ability of preschool-aged children can predict comprehension of informational or narrative texts in both digital and paper modes. Ruffini's study confirms the role of all basic EFs, but especially working memory, in comprehension of digital and paper texts among third and fourth graders. Similarly, Kanniainen et al. (2021) showed that in the first year of secondary school, students with low EFs have difficulty in online research and comprehension of digital texts.

2.4. Educational approaches

2.4.1. Protective and risk factors for executive function development

Given their great malleability and protracted development, EFs turn out to be highly dependent on the environment, defined according to a bio-psycho-social model (Engel, 1977) that includes individual (e.g., typical vs. atypical development), proximal (e.g., family and school), and sociocultural (e.g., geopolitical) characteristics.

Regarding individual characteristics, as we have mentioned throughout the chapter, various cognitive processes can be affected and in turn influence EF development. For example, a condition of prematurity may be associated with difficulties in stabilizing circadian rhythms and regulating responses to the environment (i.e., arousal), leading to a cascade effect on the development of emergent EFs in early life (Sandoval et al., 2022). Another example is children with mood disorders, in whom poor performance is documented in tests on working and long-term memory, attention, language, and executive functions (Schumacher et al., 2024). Again, children with a specific learning disorder (SLD), for whom weakness in EFs is frequently documented, may be less exposed to the typical challenges imposed by learning tasks and therefore have fewer opportunities to train them. However, the need to overcome the challenges imposed by specific difficulties may also lead these children to develop greater problem-solving skills or cognitive flexibility (e.g., flexibly using different compensatory tools depending on the type of learning task; e.g., Mishra et al., 2023). These examples, while not exhaustive, suggest that many risk and protective factors can affect the development of EFs already at the individual level, according to complex dynamics that are difficult to predict. However, this complexity should not prevent us from recognizing and then intervening on the various characteristics of individuals that might promote the development of EFs. This approach could also be useful in the context of neurodevelopmental disorders (Pecini & Casalini, 2022).

As anticipated, the context of EF development, in relation to both proximal and distal environmental factors, has been extensively explored in the literature. Parental relationships, studied through analysis of caregiving style and attachment, significantly influence the development of EFs (Hughes et al., 2009). In fact, parents who adopt encouraging, task-oriented behaviors and foster problem-solving skills support the development of executive skills in their children.

Socioeconomic status (SES) is also critical, influencing the quantity and quality of cognitive and affective stimulation and affecting neurofunctional maturation of the brain (Olson et al., 2021). SES is associated with disparities in EF development, with children from high-income families more likely to develop better EFs. Conversely, children from disadvantaged backgrounds may be at greater risk of stress, affecting parental care stability and educational styles, with negative impacts on EF development (Lawson et al., 2018).

With this in mind, it is also important to consider the role that schooling and the school environment play in promoting and supporting EF development. Indeed, entering school is an occasion full of new learning and social challenges: the complexity of this experience and the need to deal with new activities and situations is in itself an effective stimulus for the development of EFs throughout life (Meltzer, 2018). In this light, some studies demonstrate the effect of school educational methods on academic achievement and underlying cognitive processes, suggesting that the implementation of certain educational principles that promote autonomy and self-regulation (e.g., those based on the Montessori method) have a moderate effect in improving EFs, and in particular working memory (Randolph et al., 2023), as early as kindergarten (Guerrero et al., 2023). Recently much attention has been paid to malleable environmental factors such as the quality of relationships with the teacher and among peers in the classroom. Numerous observational studies have demonstrated a correlation between the quality of teacher-student relationships at the dyadic or classroom level and students' EF and self-regulation skills, particularly in those considered vulnerable or disadvantaged (Sankailate et al., 2021).

In short, the environment in which children or students live plays a crucial role in the development of EFs and, in the context of atypical development, the environment becomes a risk or protective factor for neurodevelopmental disorders associated with deficits in EFs. EF-targeted interventions can mitigate the long-term effects of environmental disparities, positively affecting learning, mental health, and school continuity. Indeed, the relationship between EFs, school learning difficulties, and dropping out of school suggests the need to implement EF-targeted interventions to support the learning processes of all students (Sherif et al., 2023).

2.4.2. Interventions to enhance EFs: benefits and methodological features

In order to support EFs and promote children's well-being and adaptation to the environment, it is possible to act at several levels (Traverso et al., 2022). It may be functional to act on the physical context (e.g., by eliminating sources of distraction present in the study context), or the social context (e.g., through peer group involvement), or the adults of reference (e.g., by proposing psychoeducational strategies or programs such as teacher and parent training). In addition to acting at these levels, it is possible to propose reinforcement or rehabilitation paths to the students through which to directly stimulate the different simple and complex components of EFs.

For any type of intervention, it is necessary to evaluate not only the feasibility and users' perceived enjoyment, but also its effectiveness in respecting the scientific methodology (e.g., random assignment of participants to the intervention group and to a control group, pre- and post-intervention measures with parallel tests, statistical evaluation of effectiveness, etc.). In addition, when considering boosting interventions on cross-cutting functions, such as EFs, it is necessary to verify which processes and behaviors associated with them benefit from the intervention, as effect transfer cannot be taken for granted (Melby-Lervåg & Hulme, 2013; for a meta-analysis of neurodevelopmental disorders, see Bombonato et al., 2023). In contrast, at preschool age, probably due to the lower functional specialization of the brain, there is a greater transfer of the benefits obtained after EF interventions to other cognitive processes (Scionti et al., 2020).

Specifically, Diamond and Ling (2016) identified the characteristics of EF enhancement interventions needed to maximize their benefits:

1. the interventions must be frequent and intensive;
2. the interventions must include activities of increasing complexity that engage the EFs in new and different ways;
3. the activities must be emotionally meaningful to the children;
4. there should be a mentor who believes in the effectiveness of the interventions and the children's ability to improve;
5. the interventions must allow the children to experience positive emotions and a sense of self-efficacy.

To these characteristics we can add the need to respect the developmental trajectories of EFs as predicted by specific models. For example, to demonstrate the developmental trajectories of EFs, with the transition from simpler to more complex components and progressive differentiation from a single inhibitory factor in infancy to three factors at the threshold of school age, exercises can be organized in a hierarchical manner so that they are always challenging yet accessible for the children (Thorell et al., 2009).

In addition, owing to the multicomponentiality of the EF construct, pre- and post-intervention assessment must include both direct measures of EF (e.g., with specific tests) and indirect measures of executive behavior (with questionnaires completed by parents and/or teachers) (Marzocchi et al., 2022).

Another important feature concerns intervention at an early age and type of activities proposed. Considering EFs as tools for learning, it is important that they are reinforced during periods of maximum brain plasticity, from infancy to young adulthood, and before or simultaneously with the emergence of a new competence, by lowering the intervention to the domain of emergent learning in a given developmental window (Gunzenhauser & Nückles, 2021).

With digitized activities, based on self-adaptive algorithms, it is also possible to operate in such a way for "error-free learning" to take place (Warmington et al., 2013). This characteristic can foster a sense of self-efficacy and stimulate useful self-knowledge for the identification of functional strategies.

Finally, for an EF intervention to be effective, it is necessary to keep a high level of motivation among the participants by providing for the children's active participation and interaction of the activities with the play and social context (Diamond & Ling, 2016). Indeed, it should be remembered how important it is to consider children in their entirety and how essential active participation and confidence in their capabilities are.

2.4.3. Empowering executive functions during learning and reading tasks

The studies in the literature testing interventions to promote school learning through EF enhancement have predominantly involved students with SLDs or poor performances in academic tasks. Within these populations, the focus on the role of EFs has been greatest for difficulties in graphic and spelling control, text comprehension, and arithmetic problem-solving, which, compared to reading fluency and numeracy difficulties, rely more on control rather than automation of processes.

In general, even for learning skills, it is not enough to enhance EFs outside the instrumental skills of interest, as this will not automatically translate into improved learning (Walda et al., 2014). For example, a meta-analysis of 87 publications on the effect of working memory training revealed immediate improvements in intermediate transfer measures, such as verbal and visuospatial working memory, but no effect on measures "far" from the trained skill, including reading comprehension (Melby-Lervåg et al., 2016; Roording-Ragetlie et al., 2016). Therefore, more recent studies have sought to integrate EF exercises with the domain of impaired learning (e.g., updating exercises, inhibition, and flexibility during numeracy and computation tasks, Sánchez-Perez et al., 2018; Ruffini et al., in press) or with the underlying cognitive processes (e.g., control of visual-verbal integration to improve spelling control, Capodieci et al., 2022)

Regarding text comprehension specifically, there have been several interventions focusing on the basic components of EFs (e.g., Dunning et al., 2013; Gray et al., 2012; Garcìa-Madruga et al., 2016). However, to date, few have incorporated EF activities into reading comprehension tasks in the school context (Carretti et al., 2017; Cirino et al., 2017; Garcìa-Madruga et al., 2013). Cirino (2017) tested a brief EF training exercise, supplemented with self-regulated learning strategy enhancement during reading comprehension tasks, on third-grade elementary students, obtaining improvements in reading comprehension on texts whose content had been covered in the training, but not on texts of different content. Garcìa-Madruga et al. (2013) conducted studies to incorporate EF training and metacognitive strategies into reading comprehension tasks on third graders within the school setting. For example, a selective attention training exercise asked students to identify inconsistencies in texts. The results showed an improvement in reading comprehension and nonverbal reasoning, and a greater improvement among the group with low reading comprehension levels than the group with high reading comprehension levels. Carretti et al. (2017) proposed a similar version with some revisions to the training of Garcìa-Madruga et al. (2013), testing it on third graders. The children participated in several reading activities that involved working memory along with four executive control tasks: focusing on relevant information, linking new information with long-term knowledge, updating working memory content, and checking irrelevant information. The training was effective in improving trained comprehension processes, updating working memory skills, and bettering performance in standardized comprehension tasks. However, these improvements were not maintained at the two-month follow-up. Note that the Carretti et al. training program was intensive (twice a week) and sufficiently long (ca two months on average).

The studies described above support the importance of combining EF exercises with activities related to the learning process to be promoted, namely comprehension of a written text.

The digitized or game-based implementation of this type of integrated training also appears promising. For many years now, technology has been introduced to the treatment pathways of children with learning disabilities as a tool to improve and rehabilitate not only school learning, but also the various cognitive processes underlying the same, including EFs. Multiple studies have pointed out that, when compared to traditional treatments, interventions with computerized activities lead to better benefits, both at preschool and school age, plausibly due to the use of multimodal stimuli, immediate feedback, and more attractive material (Torgesen et al., 2010). In addition, game-based or digitized interventions can, if appropriately organized and adopting best practices, also be implemented remotely or through tele-intervention, offering greater and more flexible opportunities to larger populations.

In a recent study, Ruffini and collaborators (under review) implemented computerized cognitive training to improve reading comprehension in elementary school children. This was done through EF activities embedded in text comprehension exercises, following a modified version of Carretti's 2017 intervention. The children were given several text comprehension exercises that required EF processes (e.g., identifying inconsistencies in the text, sorting events, etc.). The intervention proved feasible and effective for improving processes of reading comprehension, working memory, and nonverbal reasoning.

2.5. Future directions

New technologies can promote game-based interventions on EFs. The complexity, novelty, and diversity of the exercises can continuously be recalibrated, with a simultaneous increase in task difficulty at three levels: system processing capabilities (for example, by imposing time constraints or altering the amount of information to be retained in the memory), processing modalities (e.g., integrating text and images), and the number of EF components involved (e.g., from inhibition to planning and interaction between them).

At the same time, it is clear that interventions on EFs need to be integrated into students' everyday environments, and adapted to both school and home activities. Hence they should also promote a metacognitive approach to the various proposed activities, generalizing them so that they not only cover academic tasks but also daily life experiences and require the enactment of both behavioral and emotional self-regulatory processes.

Summary

In this chapter we addressed the topic of the regulation of mental processes with a focus on cognitive control during tasks of reading and comprehension of written texts. The construct of executive functions was introduced, briefly describing its definition, cognitive models, neurofunctional basis, and developmental trajectories. Next, the role of EFs in learning processes and, in particular, in the acquisition of reading-writing and text comprehension was analyzed. In this regard, we defined which EFs are particularly important for the self-regulation of reading processes according to task goals, context, mode, and type of texts. Finally, early educational interventions for fostering good executive control in students were described.

Glossary

Bio-Psycho-Social Model. A comprehensive approach to understanding human health and disease, considering biological, psychological, and social factors and their interactions.

Error-Free Learning. A teaching and rehabilitation strategy that minimizes the learner's chances of making mistakes, reinforcing the correct information or behavior for future recall or application.

Metacognition. The awareness and understanding of one's own thought processes, involving monitoring and regulating cognitive activities in learning and problem-solving.

Neural Plasticity. The brain's ability to change and adapt as a result of experience and learning.

Prefrontal Cortex. Region of the brain involved in complex behaviors such as abstract thinking, planning, emotion regulation, and decision-making, critical for executive functions.

School Readiness. A child's preparedness for the formal learning environment of school, encompassing skills such as basic knowledge, social skills, emotional self-regulation, and executive functions.

Socioeconomic Status (SES). A measure of an individual or family's social and economic position relative to others, based on income, education, and occupation, affecting access to resources and opportunities that can influence cognitive development and educational outcomes.

Theory of Mind. The ability, key for social interactions, to attribute mental states to oneself and others, understanding that others have beliefs, desires, and perspectives different from one's own.

3

A game-based approach to promote Media and Information Literacy through executive functions: Elli's World

Clara Bombonato, Andrea Frascari, Antea Scrocco and Silvia Della Rocca

The purposes of this chapter are to

- ✓ describe a game-based approach to reading and writing;
- ✓ introduce teachers to some strategies which can be integrated with the game in order to promote students' reading and writing skills.

3.1. Introduction

In this chapter, we continue along the theoretical line outlined by previous authors regarding the involvement of executive functions (EF) in supporting the development of self-regulated reading and media literacy (ML). Our aim is to describe an example of a gamified approach using a serious game integrated with curricular teaching in order to promote skills related to critical comprehension of multiple texts and intertextual integration.

Starting by presenting the context in which teachers currently find themselves, we highlight the importance of critical text reading and source reliability assessment as two of the most emergent challenges in teaching today. In addition, students must also learn to evaluate which information is relevant and which is not in order to construct ideas and opinions on a specific topic. Evidence-based educational research comes to the aid of teachers' practice and allows us to give an overview of the main features of the educational interventions that can be implemented to teach critical reading and comprehension of multiple texts, particularly by performing integrative tasks (e.g., written essays).

In our exploration of the integrative reading and writing didactic process, we want to highlight the advantages of a gamified approach, in both traditional settings and digital learning environments such as educational apps. Indeed, such an approach can increase students' motivation and engagement: gamification allows interventions to be designed from an inclusive perspective, with adapted content and methodologies, and personalized objectives.

After presenting some examples of educational interventions to reinforce reading or writing designed according to gamification principles, the chapter provides a detailed discussion of the EMILE project experience with the "Il mondo degli Elli" ("Elli's World") video game app created by the Anastasis cooperative. The aim of the serious game (a game designed with educational or training purpose) created for this planned educational intervention model is to boost the EFs (interference control, working memory, response inhibition, cognitive flexibility) through the exploration of an urban scenario in which each zone is dedicated to training a particular cognitive skill. The purpose of training these EFs is to support the media literacy skill, the focus of the last game zone, in which students work on the integrative task of writing an article from multiple texts referring to the same topic.

The next section describes the serious game-based intervention conducted in two Tuscan schools within the EMILE (Empowering Schools in Self-regulation of Media and Information Literacy Processes) European project funded by the Calouste Gulbenkian Foundation. The project, which aims to expand the scope of media and information literacy, has a dual target: to provide interdisciplinary professional development for teachers, supporting their perceived competence in media literacy tasks; and to empower students' cognitive skills involved in competence-building processes through gamified solutions.

Finally, some future directions are proposed, highlighting the possibilities of integrating the app and gamified approach with curricular teaching and teacher intervention in the classroom. In particular, the research highlights how teaching and learning critical understanding and integration of information from multiple texts can be supported by interventions that stimulate metacognitive reflection. The personalization and adaptation to different educational needs fostered by a gamified approach means that the educational model outlined in this chapter can be applied from an inclusive perspective in pathways aimed at the whole class or only at pupils with special educational needs.

3.2. Strategies for integrating reading and writing in the digital age: educational approaches

The profusion of information that can currently be found on any topic makes critical evaluation of sources one of the main educational challenges facing teachers at all levels (Braten et al., 2018). What are the main risks for our students in the process of constructing personal knowledge through the use of digital tools? By surfing the web, every day students encounter and learn news from different sources, which often describe a certain topic from different perspectives and with different opinions (Goldman et al., 2013; Tabak, 2015). Consequently, it is crucial that they can read and understand a given topic critically, accommodate the various points of view, and be able to build a mental model (Multiple Text "Document model", Rouet & Britt, 2011) that integrates information from all of the texts and synthesizes the main ideas. In this complex process, which calls upon students' disciplinary and metacognitive skills, it is also necessary to be able to assess the reliability of the sources from which the information comes, because the fact that many websites are open source makes it increasingly difficult to check the content expressed and, above all, to verify the data regarding the author (Flanagin & Metzger, 2008). This is why students are continuously required to activate decision-making processes to choose and critically evaluate which information can be considered reliable and which cannot (Bråten et al., 2018; List & Alexander, 2017).

The international and national normative levels reiterate the educational need to train students to make them active citizens capable of meaningfully understanding information received from different sources, using different media channels, and making informed decisions about which resources are reliable, so as to increase their personal knowledge (OECD, 2016; MIUR, 2018). In the information age, in which all individuals have access to enormous amounts of resources and tools, including digital ones, it is crucial to educate students to use them: they must be able to understand and develop their own opinion on important issues regarding various topics relevant to society, which they very often learn about by reading information online (Chinn et al., 2014; Barzilai et al., 2018). For teachers, it thus becomes crucial to use appropriate didactic strategies aimed at comprehension of multiple texts. Multiple text comprehension is a macro process that can be broken down into subprocesses toward which teachers should direct educational actions. Students principally need to be taught: how to understand what the reading objective is; how to research, evaluate, and select the information most relevant to the objective; and finally, how to communicate or present the results of the reading and integration, for example, through discussion with peers or writing an essay (Goldman et al., 2013; Rouet & Britt, 2011).

What teaching strategies can be implemented in the classroom to achieve these goals? Which of these are most effective, in given educational contexts? Educational research rushes in support, highlighting which educational approaches are used to teach integration between multiple texts and showing how reading and writing are closely connected (Mateos et al., 2018; Lopera, 2023). Reading and writing are in fact interdependent social practices, characterized by specific cognitive processes and a multiplicity of implementation contexts in everyday life, whether in print or digital format (Lopera, 2023). In particular, the dynamic act of reading is associated with writing, which is considered an activity that involves reflection and analysis, because while writing a text we increase our knowledge of both the topics covered by the readings and ourselves (Henao et al., 2006). By writing, an order is given to ideas in order to communicate a message. By doing so, prior knowledge is activated, reinforced, and even transformed. Consequently, reading and writing are fundamental to knowledge creation (Lopera, 2023).

3.2.1. How intertextual integration is taught (print and digital approaches)

The skill of intertextual integration is extremely complex, and in order to facilitate access to the variety of disciplinary contexts, text types, and integration tasks that can be implemented in classrooms, the following paragraph will describe the ways in which this skill can be taught. It is also important to consider the assessment measures that can be taken and the different purposes for which technologies can be used in a cross-curricular and multidisciplinary skill teaching-learning context (Barzilai et al., 2018).

The table below schematically summarizes the content of the following section, highlighting the variety of writing tasks, educational practices, and integration measures that empirical studies present as most effective for teaching cross-curricular integration.

Table 3.1. Summary of the main features of educational interventions on intertextual integration (adapted from Barzilai et al., 2018)

Level of education	Elementary school Lower secondary school Upper secondary school (High school) University
Disciplines	History Social Sciences Science Languages Other (e.g., Mathematics)
Textual types	Primary texts Secondary texts Literary texts
Types of supplementary tasks	Summary tasks Argumentation tasks Synthesis tasks Inquiry tasks Narrative tasks Comparison and contrast tasks
Typologies of educational practices	Explicit teaching of integration Integration modeling Suggestions on the integration process Annotation or summary of individual texts Graphic organizers and representations Discussion and collaborative practice Individual practice Feedback
Typologies of integration measures	Written essays based on multiple texts Answers to open-ended questions Answers to multiple-choice questions Intertextual verification Thinking aloud protocol Observation of students' ways of working Analysis of students' oral discourse

Levels of education and disciplines

The educational interventions reported in the studies analyze the process of intertextual integration applied to different curricular disciplines. Beginning with elementary school and the first grades of lower secondary school, multiple text integration is mainly taught in language subjects, while as far as high school is concerned, educational interventions using an integrative intertext approach are in the disciplinary context of history. Finally, university students are more likely to be involved in intertextual integration processes in subjects related to the social sciences.

Text types

Actions to enhance intertextual integration mainly involve three types of multiple texts for integration: primary texts, identified as handwritten texts, including official documents, letters, memos, diary pages, speeches, conceptual maps, historical accounts; secondary texts, the most frequent, which include written essays on past historical events, such as excerpts from manuals, websites, historical news, expert essays; literary texts, such as novels, poems, stories. The latter are the least used for intertextual integration tasks (Barzilai et al., 2018). In addition to written texts, some studies also use static visual and graphical representations, such as photographs, tables, and maps, and dynamic visual representations, such as films and documentaries, as sources to draw on to derive information for integration.

Types of supplementary tasks

The integrative writing tasks also vary according to disciplinary context and educational level. Integration is foundational to the comprehension of multiple texts and first and foremost requires students to bring their reading skills into play: the demands to work on intertextual integration that teachers can place on students vary precisely according to the level of development of these skills. Pupils' writing skills must also be considered in order to choose an intertextual integration activity appropriate for their disciplinary pre-knowledge and cognitive abilities. Most studies highlight the use of writing tasks as practical examples to train and develop multiple text integration skills: intertextual integration is supported by activities in which students are asked to actively participate by identifying different ideas, perspectives, and arguments across texts and creating comparisons, syntheses, and reworking them (Stadtler et al., 2014). Summary tasks require students to summarize the main topic or most important concepts in the texts, prompting reflection on the concept of relevance to determine what information is most pertinent to address a certain issue; in argumentative tasks, on the other hand, students have to describe the arguments in the texts and add the reasons behind the positions taken by the authors.

To carry out a synthesis from multiple texts, students must follow precise instructions provided by teachers to synthesize and integrate the texts according to the outlines provided, while inquiry tasks start with open-ended inquiry questions on a certain topic explored by making use of the information provided by the multiple texts. Finally, as integration tasks teachers can use narrative writing activities whose aim is to describe a particular phenomenon explored in depth from multiple perspectives, or comparing and contrasting tasks, which involve describing similarities and differences between texts.

Types of educational practices

The main educational practices to teach intertextual integration highlighted in an evidence-based pedagogical framework describing the most effective teaching strategies in specific educational contexts (Mitchell, 2018) include: strategies aimed at teaching how to integrate multiple texts, focusing on performance of the practical activity and subsequent metacognitive reflection on the task in order to highlight "good and bad" examples of integrative synthesis texts (Boscolo et al., 2007); strategies aimed at teaching students about the various types of text structures that can emerge from integration tasks, leading to reflection on what structural components a specific integrative text should have (De La Paz et al., 2017); teaching practices aimed at incentivizing the value and importance of the integration process by explicitly asking students to reflect on the motivation behind an integrative task (Barzilai & Ka'adan, 2017); and strategies focused on teaching the criteria for evaluating the final product of an intertextual integration process, in which what is described as a good integrative text is a textual exposition that includes coherent content, with the information integrated from different sources organized according to a logic (Boscolo et al., 2007). Therefore, it is evident that explicitly teaching the strategies that students must implement when faced with a request for an integrative task is one of the main didactic practices shown to be most effective in teaching the integration process. The modes of delivery can be through oral explanations, written instructions, video tutorials, or discussions guided and directed by the teacher, whose initial intervention should be to provide the scaffolding of the task and then gradually leave students to work independently, in pairs, or in groups.

Group discussions can be fostered, in particular to initiate integration activities between multiple texts. The goal is to get students to work together to gather ideas about the relevant information in the texts and the reliability of the sources and to read and note the content that will go into the integrative text (De La Paz, 2017).

Whether in a cooperative learning context or individual practice, teachers can provide useful tools for the intertextual integration process, such as graphic organizers, tables, or concept maps, or verbal prompts that can guide students throughout or at specific stages of the task, using, for example, guiding questions, cues to reflect on the information provided by the texts, or memos. A practical example of an intertextual integration task involved an activity proposed to a fifth-grade elementary school class, embedded within the History curriculum (VanSledright, 2002). Students were asked to read some historical documents and think about the authors' positions reported in the written texts, with guidance and suggestions from the teacher. Targeting secondary school students, on the other hand, the intervention described by Gonzales-Lamas et al. (2016) showed how written guides can be provided, either for work in the classroom or in a digital environment, as well as diagrams summarizing the steps to be followed in a process of intertextual integration. Explicit teaching of how to use these written guides can also be accompanied by demonstrating how certain tools can be useful in practice, describing actions, and showing appropriate behaviors, providing a model of the integration process to be followed. Guiding questions and metacognitive prompts, such as "Have I thought about how I should organize the text?" can also be included in the diagrams. Graphic organizers that can be provided also include concept maps or structured diagrams that guide students in analyzing the texts and organizing the information. They can include spaces where they are asked to enter the titles and type of texts, the authors' names, the authors' perspectives emerging from the texts, the purpose of the documents, and the main idea emerging from each text. In addition, supplementary maps may ask for authors' statements and their arguments in favor of the topic, supported by evidence and information on the reliability of the sources (De La Paz, 2017; Barzilai & Ka'adan, 2017).

Feedback is one of the most effective didactic strategies for teaching and learning, whether in a classroom setting or in an online environment. Feedback allows teachers to provide students with information on the progress and quality of their performance, directing their work toward producing an effective intertextual integration product (Barzilai et al., 2018). Positive feedback can raise students' expectations about the task and make them more likely to employ metacognitive strategies while performing the task (Maier & Richter, 2014).

Types of integration measures

Intertextual integration activities can be evaluated by teachers with a focus on the final products, the integration tasks fulfilled, or the processes enacted by students while engaged in integrative reading and writing. In most of the studies describing school-led interventions for enhancing intertextual integration skills, the main assessment measures involve teachers' analysis of student-written essays: texts can be coded and evaluated by putting together coding rubrics and grids based on variables of interest that help determine the quality of the integrative text.

In the study by Martinez et al. (2015), essays written by students in a first-grade secondary school class were evaluated according to five variables, each defined at four levels of complexity. First, the level of selection of relevant information was analyzed, that is, how many relevant and irrelevant arguments contained in the reading texts were then included in the supplementary essays. Next, the elaboration of the arguments was taken into account to analyze how many sentences were rewritten in exactly the same form as the original texts and how many were reworked through paraphrasing processes. Another variable taken into account in the assessment was the degree of intratextual integration, that is, how much information and which ideas were rewritten from each original text with the insertion of logical and cohesion connectors. As for comparing the texts, the level of intertextual integration was also assessed based on the strategies used to integrate positions from the different texts (Tarchi & Villalon, 2021). Finally, the score for the quality of the textual product also included the title assigned to the essay, which could have been copied from the titles of the original texts, or could be the result of integrative reworking. Additional tasks to check for the presence of integration among multiple texts could involve directly highlighting integrative and conflicting information in the texts; alternatively, students could be required to answer open-ended or multiple-choice questions, to reveal information integrated at different levels in the texts (Barzilai & Ka'adan, 2017). For a more comprehensive view of the intertextual integration process that is enacted, observational grids could be made to measure the thinking aloud processes employed by students during performance of the task, or to assess their oral contributions during the integration of multiple texts. This can be done by including some items in the grids that consider cognitive and metacognitive aspects of the task, such as "read and underline the sources of the text" or "write the final text from a draft" (Martinez et al., 2015).

3.2.2. Use of digital technologies for intertextual integration tasks

Frequently, didactic practices for teaching intertextual integration take place in traditional education settings, with texts provided on paper and writing activities carried out in pen. Moreover, because intertextual integration can support the learning of disciplinary content, particularly in the contexts of disciplines such as History and Science, the sources of the texts to be integrated are often to be found in the textbooks that students use in school. The enormous impact that technological development has had in introducing new digital tools into the school environment, including in support of reading and writing tasks, cannot be ignored, however. Many of the interventions that have been described in the preceding paragraphs, in fact, use digital technologies to directly access written texts online as well as document archives with links to written texts. Moreover, using digital technologies for integration tasks allows teachers to provide graphic supports such as concept maps or diagrams of text structures made with software that directly processes the digital text. This also allows teachers to easily return to the graphic organizer content and update or modify it according to the information to be integrated (Cerdan & Vidal-Abarca, 2008). Digital tools can also be effective in collaborative learning contexts in which students are given problem-solving activities to approach by sharing information and ideas. In these activities students compare and evaluate the most appropriate modes of resolution for the context, with the instructions and feedback from teachers, in combination with suggestions provided by the digital software used to integrate the multiple texts, playing a regulative role in the learning and augmenting the students' learning of content and task awareness in digital environments (Raes et al., 2012).

3.2.3. Game-based approaches for reading and writing

The use of digital technologies in education cannot translate exclusively into the introduction of new teaching tools to perform traditional learning tasks, such as learning to read and write. Nevertheless, for teaching and learning processes to be effective, methodologies also need to adapt to the digital context, starting with the design of activities (Lourillard, 2012; Gaggioli, 2018). The framework of digital game-based learning fits into the context of educational technologies, combining game characteristics, such as a fantasy scenario, rules, objectives, sensory stimuli, challenges, mysteries, and self-regulation, and rewards with educational content to increase learning motivation (Garris et al., 2002). In general, the application of game elements and dynamics in nongame contexts is referred to as *gamification* (Deterding et al., 2011) and is directed at increasing users' involvement and motivation in order to encourage certain behaviors. Gamification is a disciplinary field that encompasses psychology, instructional design, and the fields of technology and marketing; moreover, interventions in education designed according to a gamified approach have grown in recent years, also through the use of digital applications and platforms. Indeed, gamification in education brings certain advantages to instructional design, such as adaptability of content and methodologies, stimulation of user interest, and ease of application in numerous contexts (Gaggioli, 2018).

Shifting the focus to the use of a gamified approach to enhance cross-curricular skills such as reading and writing, Cheung and Slavin's (2013) meta-analysis highlights how interventions implemented through educational technology applications can effectively stimulate the enhancement of reading skills in elementary school students with learning disabilities. What is certain is that the use of serious games allows didactic content to be tailored to students' educational needs and is easily adaptable to skill levels, allowing for a gradual increase in the executive difficulty of tasks and challenges. The game objectives, which are aligned with the didactic goals set forth in the instructional design, thus gradually become more and more challenging for students, who find themselves performing the proposed tasks at a level that is slightly higher than their actual skills but still simple enough to be understood and carried out. As such, the game-based approach stimulates student engagement and allows activities to be repeated in order to consolidate knowledge and skills in a playful and motivating setting.

The literature review offers several examples of educational interventions developed to enhance reading skills for elementary school children, such as the study by Rominus and colleagues (2019), which shows the use of the "GraphoGame" serious game to enhance grapheme discrimination and phonological awareness and grapheme-phoneme correspondence in early elementary school children. The application's simple interface makes it usable even for students who are learning to read, as all of the instructions in the game are repeated orally. The difficulty of the proposed exercises adapts to the children's performance and allows them to return to the same task if their scores are not high enough to indicate a sufficient level of achievement. In addition, the design of the game allows for continuous feedback from the application with a view to personalizing learning, thus making users aware of their paths and engaging them personally, behaviorally, emotionally, and cognitively (Fredricks, 2004). Indeed, strong student engagement supports the effectiveness of game-based approaches in education: engagement from a behavioral perspective translates into paying attention and persisting so as to complete assigned tasks through observable behaviors, while cognitive engagement refers to the internal resources that students invest in the game performance, such as self-regulation skills and cognitive strategies put in place to try to understand and master the tasks. Finally, emotional or affective engagement refers to the positive and negative emotions that students may experience while performing the activities, which can be considered a source of motivation for their involvement in the activities.

In the Italian context, Anderle and colleagues (2022) and Pasqualotto et al. (2022) have shown how it is possible to train reading and writing skills through intensive gamified training aimed at children in the final grades of elementary school, including pupils with autism spectrum disorder. The training described by Anderle and colleagues involved conducting 6 gamified sessions during school hours, for a total of 12 hours, using the "Evolving Dyslexia" (Savelli & Pulga, 2016) and "Recovery in Spelling" (Ferraboschi & Merini, 2016) reading and writing skills improvement applications produced by the Centro Studi Erickson S.p.A. Tablets were the preferred device upon which to implement the intervention. For both applications, it was possible to customize the profile by creating an avatar, whose function was to explain the different activities to be performed to the children and provide continuous feedback through the audiovisual channel. In line with the characteristics of gamification, the applications also included a reward system based on the correctness of responses and execution time. The results of this study reported an improvement in reading and writing skills both for the class group and for students with specific learning disorder who had been given reinforcement activities using the same applications in an individual mode tailored to their specific difficulties. In addition, from a qualitative point of view, a high level of perceived enjoyment among the children was also measured. This could be useful to consolidate the information and skill trained as they are motivated to repeat the activities, hence achieving improvements in the final learning (Anderle et al., 2022; Lister, 2015).

The interventions described so far refer to the use of gamified applications to boost the learning of cross-curricular skills such as reading and writing in elementary school children. One of the greatest educational challenges of the digital age, however, concerns the active engagement of students in tasks that require high cognitive effort and critical thinking, such as comprehending multiple texts belonging to various textual genres and taking contrasting perspectives. As pointed out by Barzilai and colleagues (2018), by accessing online social platforms and various online search engines, students come into contact with numerous multimedia documents, in which information is conveyed through a combination of verbal, audio, and visual channels. Accessing this content calls into play certain cognitive control functions, EFs, which allow knowledge, thoughts, and actions to be controlled, monitored, and adjusted according to the context in which the student is acting. The EMILE project adopts a gamified approach to enhance media literacy and train future citizens to access information with critical thinking, while understanding and consciously and actively interacting with the available digital resources. The next section will describe the Elli's World application, developed by the Anastasis social cooperative to enhance EFs. Designed for implementation in school settings, the app fosters the transfer of skills trained in disciplinary learning. For the EMILE project, the video game was updated with the introduction of a specific media literacy zone where students engage in reading multiple texts with the end goal of producing an integrative text.

3.3. Elli's World: the game structure

Elli's World is an EF educational intervention model designed on the basis of the previous POR-FESR EMILIA ROMAGNA 2018 regional project COMPRENDO (COMponenti tecnologiche PeR l'inclusionE Nella Didattica e nella fOrmazione). The model integrates the use of a serious game with practical and metacognitive activities aimed at EF empowerment and awareness both at group level (e.g., in contexts of inclusion of students with difficulties in behavioral and emotional self-regulation) and at individual level (e.g., to improve students' learning skills).

It is an open and shared model run by a large group of authors who grow and improve the video game and complementary activities thanks to public and private funding. All authors are at the same time free to use the model for empowerment and research activities without restriction. The Anastasis cooperative is responsible for the project, also providing technological support, and ensuring its adaptation to the security and data protection (GDPR) standards, its ordinary and extraordinary maintenance, and the distribution of a commercial version for schools.[1]

For the EMILE project, the Elli's World intervention model was adapted for secondary schools, with the aim of enhancing students' ability to comprehend and integrate multiple texts by supporting the cognitive processes involved in the task. Indeed, EFs have been found to play a primary role in the task of comprehension and integration of multiple texts. Specifically, the inhibition EF is involved in the suppression of textual information irrelevant to the task, while working memory supports the selection of sources relevant to the task and the integration of information across texts and between text content and prior knowledge, facilitating inference generation and information evaluation and integration. Finally, cognitive flexibility supports readers' ability to make connections between texts, make sense of conflicting information, and construct valid intra- and intertext inferences. Training through the platform is intended to provide students with the necessary tools to develop skills to critically analyze messages offered by the web as well as an opportunity to experience digital tools properly. The goal, therefore, is to stimulate critical thinking and reasoning about the information read in order to identify which is the most relevant and reliable.

3.3.1. How it is structured

Elli's World is thus a kit composed of several important elements for the implementation of an EF empowerment pathway:

- video game;
- metacognitive videos;
- complementary activities, divided into:
  - reinforcement activities;
  - group play activities;
  - bridging activities with teaching;
- monitoring system for teachers and educators (console).

The reinforcement program takes place entirely at school: the session structure and duration can be adapted according to the chosen pathway (standard or intensive) and school grade level. Along the way, students travel through "EF zones": interference control, response inhibition, working memory, and cognitive flexibility. Students stay in each zone for a specific time and a series of sessions conducted in

[1] www.mondoelli.it

the classroom. The first session in each zone lasts about an hour: it is a group session and includes all the elements in the kit; individual sessions, on the other hand, last about 20 minutes and only focus on certain elements, mainly the video game. In the video game, the children impersonate *Little Ello*, the protagonist: a young brain with budding EFs, ready to experience new challenges and hone its skills in Elli's World. This all takes place under the watchful eye of mentor *Big Ello*, a mature and experienced brain who guides the younger Ello in the adventure. The players' task is to lead Ello in exploring an urban, city-like scenario where some *coding exercises* allow them to find the path to the *treasure rooms*, that is, the places hosting the EF-enhancing activities. These coding activities promote planning and problem-solving skills: in order for the children to move and reach the goal, they have to plan the movements to be made, figuring out how many squares to move and which arrows to use. Only when the planning is complete can they press the *go* button and move and verify that they have planned correctly. Coding is a methodology for training computational thinking: it is a logical process useful in all subject areas for tackling complex problems and hypothesizing solutions (see Figure 3.1).

Figure 3.1. Example of a coding activity in the game. The arrows in the left box must be placed in the correct order in the central grid.

The treasure rooms contain two channels – visual and auditory verbal – of EF reinforcement exercises. In each room there are self-adaptive mini games with six levels of difficulty: if the children's response is more than 65% accurate, the difficulty increases; if it is less than 30%, it decreases. Between 30 and 65% it stays the same. There is also a "level 0" that can be configured for players assumed to have a-priori difficulties (see Figure 3.2).

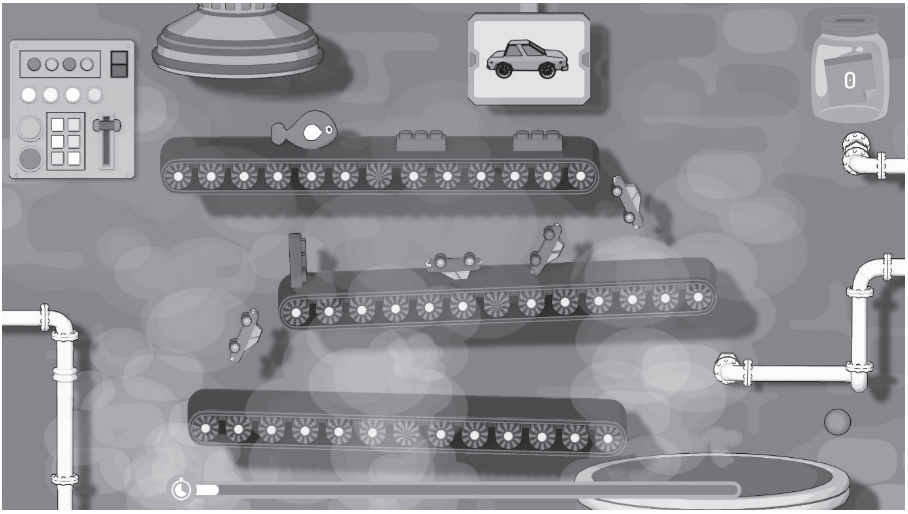


Figure 3.2. Example of an interference control activity. Students should select the same object shown in the monitor, without letting sounds and visual stimuli distract them

At the entrance to each new EF zone, the children are shown a metacognitive video in which Big Ello illustrates the EF they are about to train through examples and references to its usefulness in school and daily life. At the end of the video, the teachers encourage a moment of metacognitive reflection among students.

Upon completion of the coding and treasure room exercises, the player wins a *gadget* that can be used to answer a quiz on the use of the EF zone in daily life.

3.3.2. The media literacy zone

To facilitate the transition from EF-specific training to the final media literacy (ML) task involving the comprehension and integration of multiple digital texts, a number of "bridge exercises" are proposed in which the specific EFs become tools and strategies for the comprehension task. Therefore, students can gradually apply the skills learned from the EF training within the complex ML task at the end of the course. Furthermore, they clarify to students the function of cognitive control processes within the process of comprehension, selection, and integration of multiple digital texts.

Specifically, at the end of each EF zone, players are provided with a three-level bridge exercise between the EFs and ML. The first level, the interference and inhibition control to ML bridge exercises, require students to 1) control interference from pop-ups or different types of alerts while selecting text titles relevant to their research topic, 2) select the information that makes a specific text irrelevant to their research topic, and 3) select relevant text fragments and ignore irrelevant ones under time pressure. Passing to the second level, at the end of the working memory zone, students are trained to (1) select titles relevant to their research, discarding the ones that are repetitions by continuously updating the input information, (2) put sentences summarizing paragraphs of a newly read passage in the correct order, and (3) simultaneously judge the relevance of certain titles for an increasing number of texts. Finally, the third level – cognitive flexibility to ML bridge exercises – involves the students flexibly adapting and evaluating their decisions, in relation to an increasing amount of information, as to (1) relevance of the title, (2) text fragments relevant to the research topic, and (3) time required to read a passage.

Once the EF training is over and the bridge games between EF and ML are completed, the players reach the final media literacy zone. The ML zone has been designed to simulate an online research task; this type of deliverable is often required of students as early as the end of elementary school. However, teachers and educators must take into account the complexity inherent in digital information tools. In today's media-saturated world, the abundance of easily accessible information threatens to overwhelm readers. The problem for students is making sense of all this information, accessing it and having a critical understanding of it, interacting with it, integrating the pieces of information, verifying facts and sources, and knowing how to navigate different and contradictory points of view (Tarchi & Villalón, 2021). The structure of the ML zone supports students in proceeding in stages, devoting sufficient time to each of the distinct phases into which the online research process and text construction are articulated. Accordingly, at the end of each stage, the video game gives or takes away one or more stars based on the students' progress.

The ML zone, contrary to the previous zones, does not offer the possibility of a simplified level 0 with shorter or simpler texts. However, in order to facilitate and support students in difficulty or with a learning disorder, it allows students to autonomously activate a voice support to listen to the headlines, previews, or texts that will be presented in the video game. Upon entering the ML zone, Big Ello describes the new task the students have to tackle, that is, writing an article for the school newspaper on one of the four different themes provided given a set of pre-selected texts. The themes, which are tackled by the students one at a time and in a random order, have been selected as they are emblematic of common different and contrasting viewpoints: bottled or tap water; animal or lab-grown meat; electric or gasoline-powered cars; the use of robots in medicine. The session begins with a coding session that anticipates the presentation of the theme to be explored, which is followed by questions designed to test the students' knowledge of the given theme. Then, to support the reasoning and provide a guideline to refer to, students are asked to put the ten steps of an article outline in the right order:

1. understand what the theme and objective of the task is;
2. carefully read the titles and previews of the different texts available;
3. select the texts relevant to the topic;
4. establish an order for the relevant texts;
5. read the texts in their entirety;
6. select the parts of the text that are important;
7. reflect whether different parts of the text add new information or are repetitions;
8. merge information between different texts;

9. reread your own work and check that you have achieved the goal of the task;
10. submit the task.

At this point the student views the titles, previews, and author's name of eight different texts prepared ad hoc. The task is to select the most fair and relevant previews for the proposed topic, assigning a score of 2 to the previews that appear very relevant, 1 to those that appear fairly relevant, or 0 to those that appear not relevant. For the four previews selected as not relevant, students have to justify their choice by indicating whether it was because the title was not relevant, the preview was not relevant, or the text seemed too difficult or required too much effort (see Figure 3.3). At the end, the solution appears, comparing the given answers with the correct scores. This will enable students to understand which preview is actually relevant and which characteristics should be considered relevant.

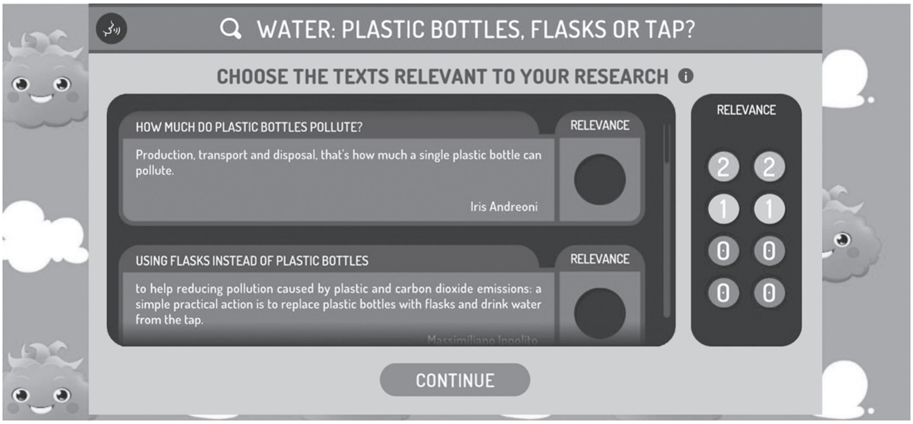


Figure 3.3. Example of a relevance determination task in the ML zone

The next stages will be carried out only using the texts in the four correct previews; the decision to have students work on the correct texts, and not on the ones incorrectly selected as correct, is the result of the educational angle taken throughout the video game. Once this phase is completed, the student is asked to estimate the time in minutes needed to perform the following tasks:

1. reading through the texts and choosing the portions of digital text (snippets) that appear relevant;
2. rearranging and merging the different snippets to produce an article;
3. assigning a title and keywords inherent to the article produced.

The ability to make correct time estimates is essential in everyday life and helps students self-regulate while performing tasks or other daily activities. At the end of this phase, a countdown with the time set by the student is placed at the top of the screen in order to monitor the minutes actually needed to perform the next steps of the task. If the time runs out, it does not mean that the session ends; students can in fact finish their work but will lose the correct time estimate star. Before proceeding to display the texts in full, Big Ello asks the student to make a prediction of how many snippets – based on the total number of snippets in each text – to take from each one (out of a total of 20 snippets), while displaying the relevant previews only. This expectation can then be confirmed or modified when the students access the full document. The objective behind this specific phase of the task is to stimulate students' expectation when they are about to approach different sources of information and they know only some of the features but not the entire content. After this the complete texts are displayed, with an indication of the relevance score. Students should select the most relevant and informative snippets from each text, creating a pool in their virtual notebooks. The texts on which students work have been purpose-built so that each one contains two snippets that are particularly relevant to the topic. If selected, these snippets give maximum points. In addition, there are two non-relevant snippets, worth a score of 0, and other moderately relevant ones, assigned a score of 1. In the article composition phase, students rearrange the selected snippets present in their virtual notebooks. Text snippets can be connected to each other using cards with various types of conjunctions (coordinating, adversative, correlative, causal, temporal, conditional, consecutive, concluding...). In addition, at the revision stage, students can use the *superpowers* gained while playing Elli's World to obtain useful suggestions for drafting the document. In particular, the interference control and response inhibition button suggests eliminating parts that are repeated or irrelevant; the working memory button helps not to forget any important information; finally, the cognitive flexibility button advises students to check the order of the snippets in order to create an article that is coherent. Next, from the proposed keywords, students have to choose the three that best represent the theme addressed in the article and the title that fits best. In the last stage, students are asked some questions from a metacognitive angle that aim to investigate the personal perception of difficulty of the task before being asked to choose one or more pieces of advice to leave to future Little Ellos who will face the same challenge, to help them with the article writing activity.

3.4. The experimentation of Elli's World in two schools in Tuscany

An experimental intervention was set up in two schools in Tuscany in order to validate the positive effects obtained by the Elli's World video game. The students identified as the target of the intervention were in the last year of elementary school and the three years of lower secondary school. The choice fell on this specific age group as it was felt that these children, starting to approach digital tools for the first time, needed more support in order to use them in a conscious and fruitful way. Specifically, 8 fifth-grade elementary school classes, 5 first-year, and 13 second-year lower secondary school classes took part in the trial, totaling 528 students. About half of the students

(266), equally distributed among the different school grades, participated as experimental subjects and were actively involved in using the video game. The other half, on the other hand, acted as control subjects, carrying out the regular teaching activities required by the ministerial regulations.

The proposed training had a total duration of eight weeks, divided as follows: the first and last weeks, which involved both groups (experimental and control), were devoted to the assessment of several skills, such as EFs, through: a computerized test to measure inhibition, flexibility, and working memory skills; a test requiring reading a text and answering multiple-choice questions to measure text comprehension skills; and a multiple-choice test with various options integrating the information from three short texts read previously to measure text integration skills. This test was also administered mid-intervention in both groups. In addition, a questionnaire assessing the children's executive behavior at school and at home was filled out by both teachers and parents. The next six weeks, exclusively for students in the experimental group, were dedicated to the training course. The project always took place within school hours, with support from qualified personnel, and was constructed in such a way as to be extremely inclusive, as all of the pupils in the classes were able to participate (with the informed consent of their parents), including those with neurodevelopmental disorders or disabilities. Specifically, in the first four weeks, the areas of the video game dedicated to EF training were addressed in a two-weekly, 30-minute slot. In contrast, the last two weeks of training in the ML zone required two longer 1-hour sessions per week.

The tests and questionnaires conducted the week before and after the training course are currently undergoing comparison analysis in order to ascertain any improvements in the children in the experimental group compared with those in the control group. At the end of the project, a questionnaire on the enjoyment of the training course, with scores from 1 to 5, was proposed to both the students and teachers in the experimental group. The results, shown in the following graphs (see Figures 3.4 and 3.5), indicated that the teachers were generally happy that they had participated in the training course (mean=3.64 out of 5), would take part in it again if they had the chance (mean=3.21), and would recommend it to other colleagues (mean=3.43). They also reported a perception of improvement in the pupils' school performance (mean=3.07). The students, on the other hand, found the course fun (mean=3.57) and enjoyable (mean=3.55). Hence, they would also recommend friends to take part in it (mean=3.37). They also reported that they were determined to do it well (mean=4.08) and felt they had improved (mean=3.17) as a result of the course.

3.5. Future directions

The educational intervention model described in the previous section offers the possibility of integrating the use of a video game with more reflective and metacognitive practices in the class group. In addition to a gamified approach using the Elli's World application, support for teaching and learning media literacy can be provided through the intervention of class teachers and their role in stimulating metacognitive

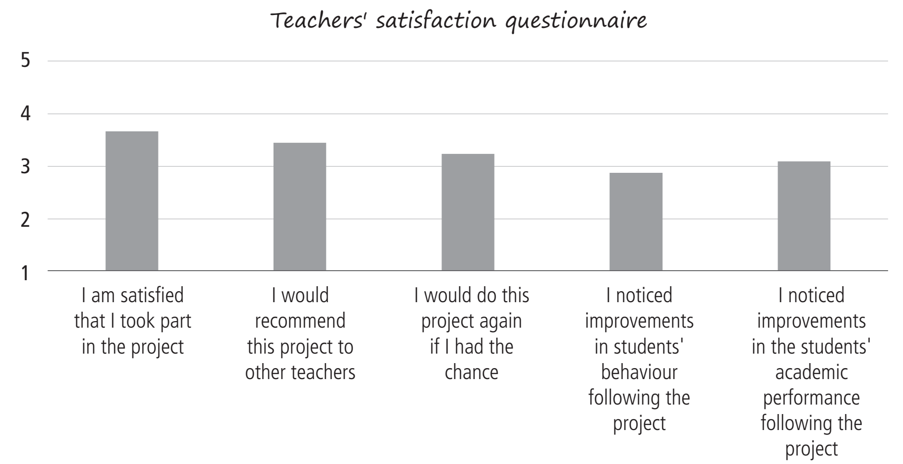


Figure 3.4. Graph of responses to the teachers' satisfaction questionnaire

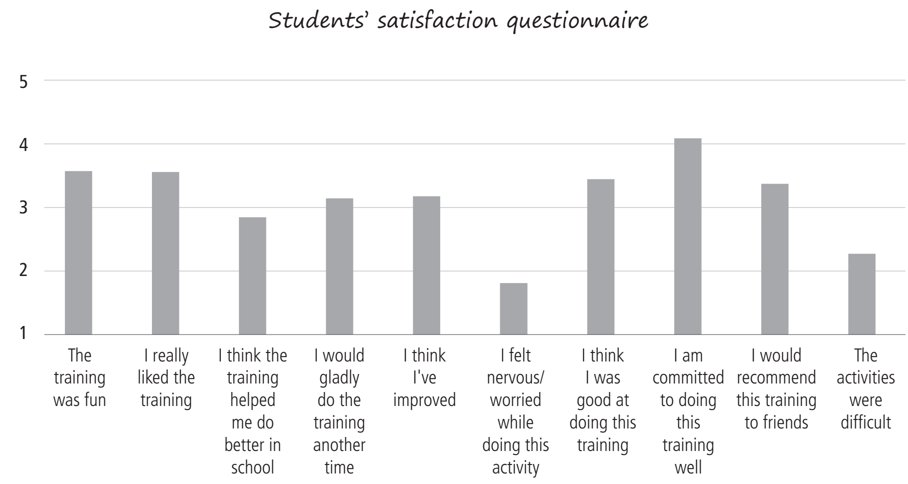


Figure 3.5. Graph of responses to students' satisfaction questionnaire

reflections on the integration task. In accordance with educational research (Rouet & Britt, 2011; Barzilai et al., 2018), a metacognitive approach can support the interpretation of contexts, task understanding, and decision-making, processes that are part of intertextual integration. The support of metacognitive tools that pay attention to the value of the integration process and the importance it can have in the construction of personal knowledge and development of personal skills can be crucial in achieving greater student engagement and promoting higher levels of learning. Moreover, by integrating shared reflection practices, the intervention also intercepts the social dimension of learning, within which knowledge and competences are built in interaction with peers and in group work, working together for a common goal, while critically comparing opinions and visions. It can encourage a generalization of learning, with the adoption of the same behaviors and attitudes outside the activities proposed in the classroom context, in order to seek improvement in everyday life situations. The analysis of the ML zone and the skills it aims to foster shows that their generalization in the everyday context would mean that students, as well as future adults who have to interact with a variety of information easily accessible through different open-source digital platforms, would be able to make sense of all this information, access it critically, interact with it, and verify the veracity and reliability of the sources and contents. Hence, guided group discussion is a crucial pedagogical strategy at teachers' disposal to stimulate a critical approach to information and media, because in class it is possible to reflect together on the relevance or irrelevance of a certain type of information in relation to a topic; select ideas from several sources describing a certain phenomenon in order to describe it from several perspectives, even constraining ones; and relate them to each other by taking a position.

Within the Elli's World pathway, short introductory videos describing situations in which learners experience the role of a specific cognitive function in real-life activities, tasks, or situations are already present in the areas of the game dedicated to EF enhancement. Hence, one can grasp the importance of training a given function so that it can adapt to different challenging contexts. Based on this model, one can envisage the creation of metacognitive videos, supplementary to the game sessions, presenting examples of situations taken from everyday life in which the components of digital literacy of source evaluation and intertextual integration knowledge and skills need to be put into practice: by proposing these videos at the beginning of the individual game sessions, teachers have the opportunity to activate the students' pre-knowledge of both the content of the texts that will be the subject of the task in the zone, and the working methods, in order to consolidate a methodological approach to online research tasks and intertextual integration that the students will be able to internalize and then apply to other disciplinary contexts. Within the metacognitive videos, for example, Ello could be shown working with classmates on a research project on a particular topic (e.g., discipline: History; topic: the arrival of Europeans in the American continent and the relationship with the natives), with whom an agreement has to be reached on the contents of the final product, namely, an integrative essay. Ello and classmates then have to use the search engines available at the school to identify information, assess the reliability of sources, and recognize the most authoritative ones that can be considered for research. In this first task, the video could show the difficulty of evaluating sources, given the enormous amount of information that can be found online by simply typing the name of the discipline and a few keywords of the topic of interest. In addition, Ello may end up in the situation of having to agree with some classmates on the choice of the most relevant information to be included in the final supplementary essay, describing the difficulties in judging the relevance and author's intention when writing a specific text. This first video, with a greater focus on the structural aspects of the task required in the classroom context, could then be supplemented with subsequent metacognitive videos that instead describe everyday life situations in which a person has to bring media literacy skills into play, such as consulting a newspaper or online magazine to find out about news and current events, or reading information and data provided by companies selling electric or gasoline-powered cars, accompanied by customer reviews, to guide the choice of a personal purchase.

Metacognitive videos can thus become supplementary tools for both individual video game sessions and complementary activities that the teacher can design at the beginning, during, or at the end of the gamified intervention, to consolidate knowledge and skills and encourage a generalization of learning. Indeed, teachers can stimulate metacognitive reflections to bring students closer to the media literacy task, starting from some comprehension questions. Here are a few examples:

– “In your opinion, what is the point of evaluating sources?”
– “Why is it important to be able to assess how reliable an author is?”
– “What is the use of not being distracted by the various stimuli that appear when you open a web page to read a text?”
– “In your opinion, is it important to know the author’s purpose or intentions when reading a text?”
– “How can we decide when information in the text is relevant or not?”
– “In your opinion, what is the point of assessing the relevance of information when reading?”
– “When you read different opinions on the same topic, how do you manage to put them together in a text? Can you usually take a position? If you can, on the basis of what do you give more relevance to one argument over another?”

Subsequently, teachers could also stimulate competence assessment questions, such as:

– “How often do you find yourself taking these attitudes?”
– “How difficult is it for you to assess the reliability of a source or write supplementary texts?”
– “What risks do you run if you do not take a critical attitude in online reading contexts?”
– “When you read information from different sources on the same topic, can you usually understand what they mean and what the different perspectives are?”
– “Why is it more important to form an opinion based on multiple sources than to consider only one text and the information it contains?”

Particularly after the gamified training sessions, students could be asked the following questions to reflect on the task:

– “How could you improve?”
– “If you were to help a classmate or friend who has to practice the same online search skills, what would you tell them?”
– “What strategies should you use in the various stages of the text integration task?”

These could be accompanied by questions that instead stimulate thinking on how to generalize the competence:

- "In which contexts do you need to access information distributed by the media, analyze the messages, and assess the intentions of the authors behind the texts?"
- "When you find yourself in everyday situations, how do your attitudes and competences towards media change? Is information retrieved on media difficult to understand in your opinion?"

Digital literacy is a transversal field. This opens up numerous complementary activities to teachers. Alongside the game sessions, teachers can engage students in real tasks to put the structural components of media literacy into practice and stimulate their situated and active learning. For example, an interdisciplinary workshop-type teaching activity suitable to involve all the different subject teachers (in both elementary and secondary schools) could be a class newspaper. Every member of the class group could take on a role in the editorial team, in line with the different positions existing in a real newspaper editorial office. They would all be working towards a common goal: to write and publish a monthly issue of the newspaper, for the class group as well as the other classes in the school and families. The editorial line could be to inform about current events and topics, but it could also be to discuss the controversial issues that are addressed in the different subject areas, with working groups doing online research. The didactic strategy of *cooperative learning* proves to be effective in interventions aimed at teaching intertextual integration, because collaboration and peer discussion and the scaffolding provided by the teachers can help make the complex task of integration more meaningful for students (Barzilai et al., 2018).

In order to broaden the range of educational approaches that can be integrated into the use of the Elli's World video game, teachers could be given the possibility of using different research themes in the media literacy zone, depending on the areas of interest of their students and subject curricula. Game programmers and pre-service teachers could collaborate in a dialogue and add new themes and texts to work on in the game, in response to different teaching needs. As such, the gamified approach to enhancing intertextual integration can really take on a transversal character, across several disciplinary tasks and beyond. At this point, more training sessions would be needed with the video game and so the skills brought into play would be further improved.

The possibility of also using an English or other language version of the game makes the educational intervention a suitable and effective tool for teaching and learning a foreign language. Indeed, educational research describes game-based learning as an effective method for teaching and learning a second language (L2). It can arouse the interest and motivation of students, facilitating the learning of content whose skills could be transferred to everyday life situations (Ismaizam et al., 2022; Felszeghy, 2019). For the EMILE project, from the four proposals in the ML zone, the texts on the topic of the use of robots in medicine were chosen to be translated into English and Finnish, for use in interventions aimed at training teachers in media literacy skills. Teachers can use multimedia language and the gamified approach in the framework of

L2 teaching proposals in secondary school classrooms. Indeed, three theories essential in the development of game-based learning – learning centered on storytelling, problem-solving, and active involvement – can be applied to certain learning objectives related to foreign language competence: consolidating vocabulary, introducing specific grammatical and syntactic structures to be implemented later in role play situations, and improving reading and listening comprehension (Adipat et al., 2021).

Parallel to these proposals of integration with metacognitive reflection activities and the adaptation of gamified didactic tools for various disciplinary contexts and with various educational purposes, teachers can always accompany their interventions with more conventional paper-and-pen activities, specifically designed for students who might benefit most from support and reinforcement in teaching activities where the use of games might be impractical or insufficient. The aim of complementing the video game sessions with individual or small group reinforcement activities is to make the training more adaptable to all educational needs. In order to make the intervention even more inclusive, another possibility is to start from the facilitated level of the game. The facilitated challenges proposed in the various EF zones allow pupils with special educational needs (SEN), who might have particular difficulties in carrying out the challenges under standard conditions, to follow the pathway together with the entire class group and thus share the learning experience in a collective playful context. A proposal to update the ML zone of the video game envisages the insertion of a facilitated pathway (level 0) in the intertextual integration task too: a way to adapt and simplify the task could be to reduce the number of texts and words within them in order to reduce the verbal load. Furthermore, a task schedule could be made permanently available on the game screen, as a reminder and tool for students to keep track of the pathway already followed and the subsequent work phases. As for the exercise to evaluate the relevance of the sources, some metacognitive competence questions could students guide in choosing the scores. There could be a button next to each text, from which a guiding questions could pop up on the screen (e.g., "Considering that the topic for your newspaper article is the use of robots in medicine, do you think that a text describing a film with robot protagonists could be useful to you?"). Regarding the task to select relevant snippets within each of the texts, those of interest for the topic could already be highlighted when students finish reading the text, or audio or visual feedback could be inserted enabling the student to understand that the information contained in that part of the text is relevant or not for the chosen topic. While there are numerous possibilities for facilitating and simplifying the integration task, it must not be forgotten that the Elli's World app gamified educational intervention can be integrated with other educational approaches and parallel proposals in the classroom context, at individual and group level, to achieve full personalization of the path depending on individual educational needs.

Summary

Based on theories that emphasize the role of EFs in the development of self-regulated reading and ML, the EMILE project supports the innovative educational approach

of integrating serious games in the school curriculum. In this case, students are offered the opportunity to enhance their EFs and practice intertextual integration tasks through use of the Elli's World app. In an urban game scenario, each zone focuses on training a specific cognitive skill, ultimately contributing to the development of media literacy skills and enabling students to tackle integrative tasks, such as writing articles based on different sources.

In today's media and information-rich landscape, teachers face the challenge of promoting critical reading and source evaluation among students. Evidence-based educational research describes the key features of interventions aimed at teaching critical reading skills, especially through integrative writing tasks. Gamified approaches to integrative reading and writing, whether in traditional or digital learning contexts, can increase students' motivation and interest, as well as enabling the design of inclusive interventions with flexible content and individualized goals.

From the EMILE project experience, future directions emerge to use serious games in ML-enhancement teaching methodologies and extend their disciplinary application, while responding to the multiple needs of students.

Glossary

Decision-making. Cognitive process that leads to choosing a belief or course of action among several possible options, based on presuppositions of values, beliefs, and memories.

Digital game-based learning. Digital game-mediated learning (includes computer games, on special consoles and mobile devices), with the potential to increase learner motivation and engagement.

Evidence-based education. A cultural orientation aimed at eliminating the gap traditionally present between educational theory and practice, aimed at offering teachers advice regarding the most effective methods as supported by scientific evidence from educational research.

Metacognition. Awareness of knowing and control of cognitive activities.

Open source. Term that originally referred to open-source software (OSS). Open-source software is code designed to be publicly accessible: anyone can view, modify, and distribute it as they see fit.

Serious game. A category of games specifically designed with the main objective of teaching, training, raising awareness, or promoting specific behaviors, skills, or knowledge. They are applied in contexts such as school education, corporate training, health and medicine. They can simulate real or complex situations, as well as increase cognitive abilities.

Snippet. A small and often interesting part of a text of any kind, such as a news story, information bulletin, or dialogue.

4

Educational data mining for adaptive interventions

Andrei Luchici and Alexandru Tabusca

The purposes of this chapter are to

- ✓ introduce educational data mining (EDM) and explain how it has revolutionized the educational landscape by enhancing teaching and learning experiences;
- ✓ showcase the benefits of applying EDM and highlight the numerous benefits of applying data mining techniques in educational settings;
- ✓ discuss the impact of EDM on media literacy education;
- ✓ present the main challenges of applying EDM in general and in enhancing media literacy, in particular;
- ✓ introduce adaptive learning systems and speculate on future advancements.

4.1. Introduction

In the ever-evolving landscape of education, the integration of technology and data analytics has opened new horizons for enhancing teaching and learning experiences. Among the various technological advancements, educational data mining (EDM) is an efficient approach to understand and improve the educational process. EDM refers to the application of data mining techniques to educational contexts. The primary aim of EDM is to explore the data accumulated in educational environments to then better learning outcomes. This process involves analyzing large datasets to uncover previously hidden or unexplored patterns, trends, and relationships.

Applying data mining techniques within educational settings to parse through extensive datasets derived from various educational activities and platforms leads to many benefits, including personalized learning environments, early identification of at-risk students, curriculum improvement, and enhanced feedback mechanisms. For example, according to Romero and Ventura (2013), EDM allows for the customization of learning experiences by analyzing student performance and engagement data, thereby addressing individual learning needs. This personalization has been shown to significantly impact learning outcomes by catering to the specific requirements of each student. Moreover, Márquez-Vera et al. (2012) highlight EDM's capability to predict potential student dropouts and identify at-risk students early in the learning process. This predictive analysis enables timely interventions, providing crucial support to those who need it most. Besides greater personalization, EDM can also guide teachers and curriculum developers in refining and optimizing educational content. In an exploratory study, Baker and Yacef (2009) discuss how the insights gained from EDM research can lead to developing more effective teaching strategies and learning materials. Finally, EDM is also an excellent tool for providing timely and personalized feedback. In a recent study, Papamitsiou and Economides (2014) explored the use of EDM in automating feedback, demonstrating how data-driven insights can inform students about their learning progress, strengths, and areas for improvement, fostering a more engaged and self-directed learning experience.

These examples clearly show that the significance of EDM extends beyond simply bettering academic performance. The same tools and techniques used to enhance traditional educational contexts can also be applied to ameliorate media literacy (ML) education. Educators and policymakers can rapidly gain insights into how students interact with media, identify gaps in their understanding, and tailor learning experiences to meet individual needs. The implications of this data-driven approach are twofold. First, it enables educators to tailor their content and interventions to quickly react to the ever-changing media landscape and create a personalized educational context. Second, it offers a suite of tools for policymakers to better understand how students react to new media and develop policies and strategies that counteract the potentially harmful effects of the digital age.

The intersection of EDM and ML education is an emerging area of inquiry, hence as yet few completed studies attest to its efficacy. Nonetheless, this is not to say that EDM cannot benefit ML education. As with more traditional educational contexts, EDM can help educators and policymakers improve ML training by leveraging data analysis to create personalized learning experiences, identify learning gaps, and develop more effective ML curricula. ML education, which aims to equip learners with the skills to critically analyze, create, and engage with media, can benefit from EDM's capacity to analyze complex datasets and uncover insights into students' learning processes and outcomes.

Specifically, EDM can support educators in personalizing learning paths, monitoring engagement and understanding, identifying misconceptions and knowledge gaps, enhancing curriculum development, supporting continuous development, and encouraging reflective learning.

EDM can identify individual students' learning preferences and difficulties by analyzing data from their interactions with digital media and educational platforms. This information allows educators to tailor ML instruction to meet each student's needs, making learning more relevant and practical. For instance, if data analysis reveals that a student excels in understanding written media but struggles with visual media, educators can adjust the curriculum to provide more support and resources focused on visual literacy. Moreover, by tracking engagement metrics (such as time spent on tasks, interaction rates, and completion rates) and assessing comprehension through quizzes and activities, EDM can help educators understand how students interact with ML content. This can help identify particularly engaging or challenging content, guiding the refinement of instructional materials to better capture students' interest and address their learning needs. EDM techniques can also analyze students' responses to assessments and activities and thereby identify common misconceptions or gaps in understanding regarding media messages, bias, credibility, and other critical ML concepts. Educators can use these insights to design targeted interventions or revisited lessons that address these areas, ensuring all students develop a solid foundation in ML. In addition, data-driven insights from EDM can inform the development of ML curricula by highlighting the most effective teaching methods, content types, and assessment strategies. For example, suppose data analysis shows that students engage more deeply with ML concepts through project-based learning rather than traditional lessons. In that case, the curriculum can be adjusted to incorporate more hands-on projects. Finally, EDM facilitates continuous improvement in ML education by providing ongoing feedback on the effectiveness of teaching strategies and learning materials. This iterative process, informed by data analysis, allows educators to make evidence-based decisions that enhance the quality of ML instruction over time. EDM can also support reflective learning practices by giving students personalized feedback and insights into their learning progress and difficulties. This self-awareness motivates students to actively participate in their learning journey, fostering a deeper understanding of ML concepts and encouraging critical reflection on their media consumption and creation practices.

Another exciting area of inquiry stands out in addition to more traditional cases of EDM use: adaptive learning systems. Adaptive learning systems are advanced educational technologies that customize the learning experience to meet the unique needs of each student. These systems leverage various data sources and machine learning algorithms to dynamically adjust the content, difficulty level, feedback, and learning paths based on real-time interactions and learner performance. Adaptive learning systems aim to optimize educational outcomes by providing personalized support that aligns with individual learning preferences and pace. One example of these adaptive learning experiences is the ASSISTments online platform. The platform provides immediate feedback to students while they complete math problems and generates detailed reports for teachers on students' strengths and weaknesses. A case study by Heffernan and Heffernan (2014) showed that the math learning outcomes of students using the platform improved significantly. These results support the idea that adaptive learning systems help students and teachers alike. ALEKS (Assessment and LEarning in Knowledge Spaces) is another successful application of adaptive learning systems, assessing the state of students' knowledge in STEM subjects to then provide personalized instruction paths. Craig et al. (2013) evaluated the effectiveness of this platform in an after-school context and found that students' mathematical understanding greatly improved after using this system. These case studies demonstrate that EDM can be very beneficial in building active learning systems that enhance student performance more effectively than traditional methods.

In conclusion, integrating EDM within ML education constitutes a pioneering approach to enhancing the teaching and learning landscape. As illustrated through various examples and case studies, including the utilization of platforms like ASSISTments and ALEKS, the potential of EDM to revolutionize educational outcomes is clear. By harnessing the power of data analytics, educators and policymakers are equipped with the tools to create adaptive learning environments that respond to students' individual needs, thereby significantly improving learning processes and outcomes.

The application of EDM in ML education, while still an emerging field, holds the promise of transforming how students interact with and understand media. EDM empowers educators to deliver more effective ML instruction through personalized learning paths, engagement monitoring, gap identification, and curriculum enhancement. This personalized approach not only caters to students' diverse learning preferences but also addresses the challenges posed by the digital age, fostering a more media-savvy generation.

Furthermore, the success of adaptive learning systems underscores the efficacy of data-driven educational strategies. The significant improvements in student performance highlighted in studies of ASSISTments and ALEKS demonstrate how personalized, adaptive learning experiences can foster more profound understanding and engagement among students. These case studies serve as a testament to the potential of EDM to enhance not only ML education but also broader educational objectives.

As we progress through this chapter, we delve deeper into the intricacies of EDM and its pivotal role in enhancing educational methodologies, particularly within ML. The upcoming section, "Theoretical background and EDM techniques and tools," will lay down the foundational knowledge necessary to understand the mechanics and methodologies behind EDM. We will explore a range of techniques and tools that enable the collection, analysis, and application of educational data to tailor learning experiences. Following this, the chapter moves on to cover "Adaptive learning and media literacy," examining how adaptive learning systems powered by EDM can be applied explicitly to ML education, fostering critical thinking and analytical skills in navigating digital content. The discussion then shifts to "Challenges and ethical considerations," addressing the potential hurdles and moral dilemmas that arise with the application of data mining in education. This includes privacy concerns, data security, and ensuring equity among diverse learner populations. As we approach the chapter's conclusion, "Future directions" will speculate on the evolving landscape of EDM in education, highlighting emerging trends, potential innovations, and the ongoing research needed to fully harness its capabilities. The chapter culminates in the "Conclusion," synthesizing the insights gathered and reaffirming the transformative potential of EDM in crafting dynamic, responsive, and personalized educational experiences for ML and beyond.

4.2. Theoretical background and EDM techniques and tools

EDM is a research area that focuses on applying data mining, machine learning, and statistical methods to data generated in educational settings. Its primary aim is to better understand students and the settings in which they learn to improve educational outcomes. The definition and scope of EDM can be encapsulated by examining its objectives, methodologies, and areas of application, as outlined in the academic literature.

4.2.1. Definition, and areas of application

Baker and Yacef (2009) define EDM as "the area of scientific inquiry centred around the development of methods for making sense of educational data." This definition highlights EDM's focus on analyzing educational data to uncover patterns and insights that can inform educational practice and policy. Romero and Ventura (2013) further elaborate on the definition of EDM, describing it as extracting useful information from large datasets within educational contexts. They emphasize the role of EDM in understanding how students learn and in optimizing the learning process and environments to therefore enhance student performance. The scope of EDM is broad, encompassing various research areas and applications within educational settings. According to Romero et al. (2010), the scope of EDM includes but is not limited to:

- *Prediction:* Utilizing historical data to predict future outcomes, such as student performance, dropout rates, and the effectiveness of educational interventions.
- *Clustering:* Grouping students based on similar characteristics or behaviors to tailor educational approaches or interventions.
- *Relationship mining:* Identifying relationships between variables within educational datasets, such as the correlation between study habits and academic performance.
- *Discovery with models:* Building models to understand and improve learning and instructional processes, including cognitive models of student learning and decision-making models for educational strategies.
- *Text mining:* Analyzing textual data from educational contexts, such as open-ended responses and forum posts, to understand student sentiments, misconceptions, and learning strategies.
- *Visualization:* Creating visual representations of educational data to make complex data understandable and actionable for educators and policymakers.

EDM and ML education present a compelling intersection of data science and pedagogical strategy. As digital media become increasingly central to students' lives, understanding their interactions with them is crucial to developing effective ML curricula. EDM offers sophisticated tools to analyze educational data, including students' media consumption patterns and learning preferences. The insights gained by leveraging these tools can help educators create ML programs tailored to meet the diverse needs of learners.

ML education aims to equip students with critical thinking skills to navigate the complex landscape of digital media and discern between reliable and unreliable sources of information. To this end, EDM can analyze data from various digital platforms to uncover student media consumption patterns. For instance, Shaffer et al. (2009) discuss how data from educational games and simulations can be analyzed to understand how students interact with media content. These interactions can reveal students' preferences, the media types that engage them most, and potential misconceptions or bias in their understanding of media messages.

The insights gained from EDM can directly inform the development of ML curricula. By understanding the specific ways students engage with media, educators can design instructional materials and activities that address students' learning preferences and challenge their critical thinking about media. For example, Baker and Yacef (2009) highlight how the analysis of student data can lead to personalized learning experiences and tailoring the curriculum to include types of media that students frequently engage with to make learning more relevant and impactful.

Applying EDM in ML education can also enhance student engagement and learning outcomes. By identifying the characteristics of media content that most effectively engage students, educators can create more compelling and interactive learning experiences. Warschauer and Matuchniak (2010) discuss integrating digital media in education to promote engagement and develop critical literacy skills. EDM can provide the data-driven insights needed to integrate digital media effectively and ensure that ML education is engaging and educationally sound.

The methodologies employed in EDM research are diverse, including decision tree induction, neural networks, cluster analysis, and regression models, among others (Baker, 2010). These methodologies are applied to various types of educational data, such as log files from learning management systems, student demographic information, and academic performance records. The most common EDM techniques include clustering, classification, regression, association rule mining, and learning path analysis. These techniques have been applied in numerous educational contexts to improve understanding of learning processes, predict student outcomes, personalize learning experiences, and enhance educational decision-making.

4.2.2. Clustering

Clustering is a fundamental technique in the field of data analysis, particularly within the domain of machine learning and data mining. Clustering can be thought of as organizing an extensive, mixed collection of objects into smaller, manageable groups based on how similar those objects are. It is like sorting a mixed pile of coins into separate piles of pennies, nickels, dimes, and quarters. Each pile represents a cluster, and the sorting is based on the characteristic of value, even though initially, all the coins were mixed up in a single pile. In other words, clustering involves grouping a set of objects so that the objects in the same group (or cluster) are all similar to each other. Imagine a librarian wanting to organize books on a shelf so that similar topics are placed together, without a predefined categorization system. The librarian examines each book's content, author, genre, and other characteristics and begins to place the ones that are alike in certain aspects next to each other. Over time, distinct sections for fiction, non-fiction, science, and literature emerge, naturally based on the characteristics of the books. This process is akin to clustering in the data world, wherein each book represents a data point, and the sections on the shelf represent different clusters.

In the digital realm, "similarity" can be defined in various ways depending on the specific characteristics of the data being analyzed. For example, every observation can be imagined as a point in a multidimensional space (see figure below for a 2D representation) and similar observations defined as points that are close together in that space (using a distance measurement) or lying along the same direction. Depending on the measurement used, the points will be clustered in different groups. It is always

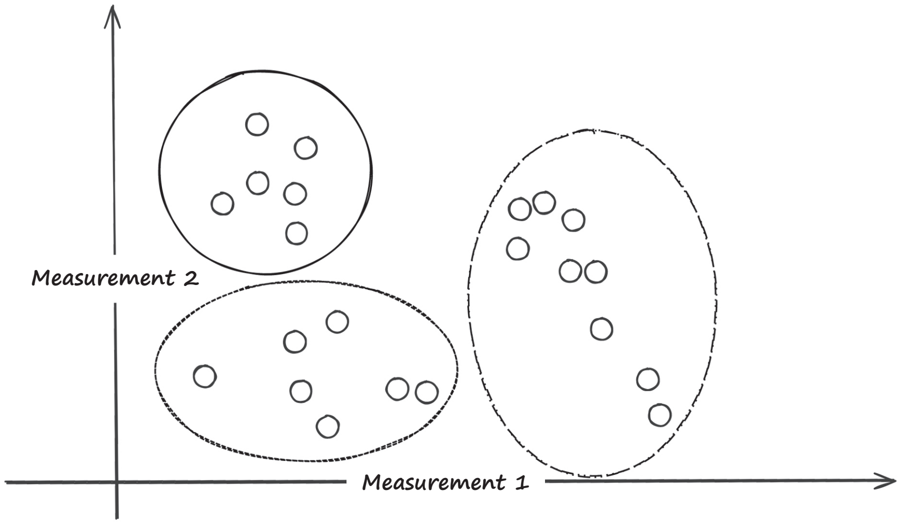


Figure 4.1. Clustering example. The figure shows a scatter plot with two axes, labeled "Measurement 1" on the horizontal axis and "Measurement 2" on the vertical axis. There are three clusters of data points, each encircled by an ellipse, showing that the data points within each ellipse are grouped based on similarity. Each cluster is distinguished by a different colored ellipse: one red, one orange, and one blue.

a significant challenge to validate and interpret the results of the clustering process. Indeed, a domain expert is needed to go through and validate the outcome.

There are several widely employed techniques for clustering data. They all share the same principles: start with an unlabeled dataset; define a similarity metric; find out which data points should be grouped. However, they differ in the implementation and the method used to determine the groups. The first clustering technique is hierarchical clustering. Hierarchical clustering creates a tree of clusters called a dendrogram, representing the arrangement of the clusters produced by the algorithm. There are two variants of this technique: agglomerative and divisive. The agglomerative approach is a "bottom-up" approach in which each object starts in its cluster, and pairs of clusters are merged on the way up the hierarchy. In contrast, a divisive approach goes in a "top-down" direction, with all objects starting in one cluster, with recursive splits performed on the way down the hierarchy. Hierarchical clustering is an excellent tool for situations where the number of groups is unknown in advance, and the desire is to explore all possible data groupings.

Another widely used technique is partitional clustering. Partitional clustering divides the data set into non-overlapping subsets (clusters) so that each data point lies within a single subset. The most common method for partitional clustering is K-means clustering. This method partitions the dataset into K clusters, wherein each data point belongs to the cluster with the nearest mean. It is known for its simplicity and efficiency.

Density-based clustering offers an alternative for grouping data, starting from the density of the points. Clusters are defined as areas of higher density than the remainder of the data set. Objects in the sparse areas—required to separate clusters—are usually considered noise and border points. DBSCAN (density-based spatial clustering of applications with noise) is a popular density-based clustering method that pinpoints core samples of high density and expands clusters from them. This method is suitable for data which contain clusters of similar density.

The methods described herein are some of the fundamental and most widely used techniques for clustering analysis, each with a unique approach to grouping unlabeled datasets based on a defined similarity metric. While hierarchical, partitional, and density-based clustering are prominent in the field, they do not constitute an exhaustive list of the available methods. The landscape of clustering techniques is broad and continuously evolving, with new methodologies and improvements being developed to address the diverse and complex nature of data across various domains. For readers interested in exploring the breadth of clustering techniques beyond those mentioned, some comprehensive resources delve deeper into the subject. One such reference is the book *Data Clustering: Algorithms and Applications* by Charu C. Aggarwal and Chandan K. Reddy, which thoroughly explores clustering methods, including advanced topics and the latest developments in the field.

Clustering has a wide range of applications across various fields. Specifically, in educational data mining, clustering is used to identify groups of students with similar learning behaviors or performance levels, enabling educators to customize teaching strategies and interventions. By clustering students, educators can identify different learning patterns and create interventions to address potential issues or enhance the learning experience. For example, Romero and Ventura (2013) discuss the application of clustering to identify groups of students based on their online learning activities, facilitating the development of customized instructional strategies.

Clustering methods present both pros and cons. Used appropriately, they can be an excellent tool for discovering new and unseen patterns in large datasets. Moreover, clustering can simplify the data, making data analysis and visualization more accessible. At the same time, clustering can serve as a method to compress data (that is, large datasets can be summarized by grouping them into distinct clusters), or can help spot essential features that distinguish different groups. Sometimes, clustering can also detect outliers and anomalies, as data points that do not fit well into any cluster can be considered outliers. Finally, clustering can be used as a pre-processing step for other algorithms, such as dimensionality reduction, or to enhance the performance of supervised learning models (classification or regression).

Unfortunately, clustering also presents some challenges that one has to be aware of before applying these methods. The biggest challenge is presented by the subjectivity involved in defining the cluster. The "correct" number of clusters is not always apparent and can also be subjective. Different algorithms may yield different clusters, and the results can be sensitive to the method used. Moreover, the algorithms used for grouping the data are susceptible. Clustering algorithms can be sensitive to the initial conditions and may converge to local optima. For instance, K-means clustering requires the number of clusters to be specified in advance, and it can be sensitive to the initial choice of centroids. Another aspect that needs to be considered is the clustering algorithm's performance regarding large data sets (i.e., large numbers of samples or high-dimensional issues). Increased data size can require some clustering algorithms to scale better, leading to a significant increase in computational complexity and resource consumption. Also, clustering in high-dimensional spaces can be challenging due to the curse of dimensionality, which can make clusters less meaningful. Finally, some clustering algorithms are sensitive to noise and outliers, which can distort the cluster shapes.

Moreover, without predefined classes, the evaluation of a clustering algorithm's effectiveness can be subjective. Metrics like the silhouette coefficient can provide guidance, but they may only sometimes align with domain-specific needs. What is more, interpreting the clustering results can be challenging, especially when the clusters are not easy to define or interpret in a meaningful way.

In conclusion, clustering provides a powerful tool for extracting meaningful patterns and structures from complex datasets. By uncovering natural groupings, clustering helps simplify data analysis, supports decision-making processes, and reveals insights across a broad spectrum of applications.

4.2.3. Classification

Classification is a data mining technique that assigns items in a collection to target categories or classes. Classification is the process of sorting things based on their feature values into different boxes or categories that are already labeled. This contrasts with clustering, where it is not necessary to learn the labels in advance and try to find patterns in the data. In other words, a classification exercise can be imagined as similar to a child who learns to differentiate between toys and books by understanding what makes a toy a toy and a book a book. Classification algorithms learn from examples to understand what characteristics define each category. Once the algorithm has "learned" this, it can automatically sort new items into the correct boxes without human intervention.

Classification is a pivotal technique in data analysis and machine learning, designed to categorize objects (or data points) into predefined groups or classes based on their attributes. This process involves learning from a dataset that has known categories and applying this learned knowledge to classify new, unseen data points into these categories. It is essential to note this latter aspect of classification, namely that the process is not just about making sense of the data but also about making predictions (Figure 4.2). For instance, after learning from past weather data, a classification model could predict whether a new day will be sunny, rainy, or snowy based on input features such as temperature, humidity, and pressure.

Imagine you are a teacher with a box full of mixed flashcards, some depicting animals and others fruit. Your task is to sort these cards into two piles: one of animals and one of fruit. You start by creating rules in your mind based on the characteristics of the images you see; for example, if it has fur, wings, or fins, it goes into the animal pile, while if it has seeds, is edible, and grows on trees or plants, it goes into the fruit pile. Once you have sorted all the cards, you have effectively "classified" them based on their features. Having obtained this understanding of the connections between features and

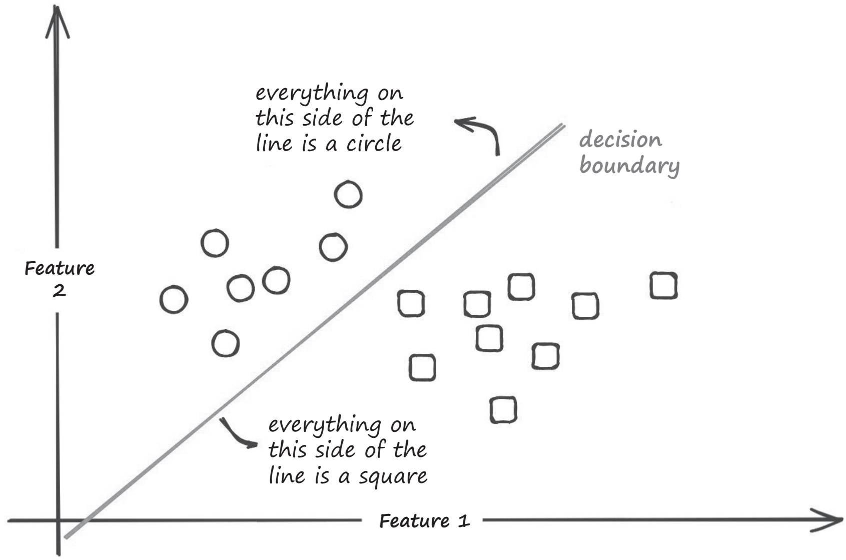


Figure 4.2. A two-dimensional scatter plot illustrating a binary classification problem, with the data points represented by two distinct shapes: circles and squares. The horizontal axis is labeled "Feature 1," and the vertical axis is labeled "Feature 2," characterizing the points. The green line, diagonally bisecting the plot, is labeled as the "decision boundary," which is a concept from machine learning used to separate different classes within a dataset. In this case, the decision boundary demarcates the two classes represented by circles and squares. A classification algorithm's job is to find the decision boundary between the classes. This line can then be used to predict new, unseen data points.

labels, it can be exploited to make predictions about new cards. In educational settings, classification algorithms can predict student performance, classify students into different learning needs, or identify students at risk of failing or dropping out. For example, Márquez-Vera et al. (2012) employed classification techniques to predict student dropouts in high school, providing valuable insights for early intervention strategies.

As presented above, classification belongs to the supervised learning order of algorithms for categorizing data into classes. The main goal of classification is to accurately predict the target class for each data point in the dataset. Classification algorithms are distinguished based on the number of classes or the types of labels they need to predict. One widely encountered situation is the need to classify data into two classes. Algorithms for achieving this task are generically called binary classification algorithms. This is one of the simplest forms of classification with two possible outcomes: spam or not spam, pass or fail, and true or false. The world is not always binary, however. Therefore, some algorithms split data into multiple classes, a process known as multiclass or multinomial classification.

Moreover, there are situations where an observation has multiple labels. In these cases, when each data point can belong to multiple classes simultaneously, multilabel classification algorithms can be used. This is common in scenarios such as tagging systems where an item might have several categories assigned to it. Finally, there are situations when one or multiple classes are underrepresented in the data set. These situations are generically dealt with by imbalanced classification.

There are different data classification learning options available. One of the most straightforward and intuitive approaches to classification is instance-based learning methods. Methods such as k-nearest neighbors (k-NN) classify points by comparing new observations with instances seen in training which have been stored in the memory and decided based on the class of the most significant number of examples like the new observation. One of the most used approaches is decision trees. These flowchart-like structures use a branching method to illustrate every possible decision outcome. The algorithms include classification and regression trees (CART) and C4.5. Support vector machines (SVMs) are another alternative for classification. SVMs are supervised learning methods that effectively classify high-dimensional spaces and cases where the number of dimensions exceeds the number of samples. Alternatively, probabilistic and statistical algorithms can be employed. These include algorithms like naive Bayes and logistic regression, which are based on statistical approaches and provide outcome probabilities.

Sometimes, more than one algorithm is required to classify the data. In these instances, ensemble methods are used. These methods use multiple learning algorithms to obtain better predictive performance than could be obtained from any of the constituent learning algorithms alone. Examples include random forests and gradient boosting machines. With the improved computing power and wide availability of data, a new class of algorithms has emerged as the winner for many classification problems: neural networks. Neural networks, including deep learning networks, are a set of algorithms modeled loosely after the human brain that are designed to recognize patterns. They interpret sensory data through machine perception, labeling, or clustering raw input.

Each type of classification has its specific applications and is chosen based on the problem at hand, the nature of the data, and the required outcome. It is not uncommon for practitioners to experiment with multiple algorithms to determine which one performs best for their dataset and classification task.

Classification has several advantages and disadvantages that make it suitable for certain types of problems but less so for others. In the remainder of this section, we will briefly discuss the pros and cons of classification algorithms. Classification models are powerful tools for predicting categorical outcomes and therefore help in decision-making processes across different domains. Many classification algorithms are scalable and can handle large datasets efficiently, making them suitable for big data applications. Moreover, these algorithms can be applied to various problems, from email filtering to medical diagnosis to credit scoring. They can provide insights into the relationships and correlations between different data features and how they relate to the outcome of interest.

One should also be aware that classification algorithms are not without fault. For all their benefits, some pitfalls always need to be considered. One of the most significant issues with classification is overfitting, meaning they perform well on the training data but poorly on unseen data. Stemming from this, one also needs to consider the dependency of all classification algorithms on data quality. The performance of classification algorithms relies heavily on data quality; noisy or incomplete data can lead to poor model performance.

Moreover, if the training data are biased, the classification model may inherit this bias, leading to unfair or discriminatory outcomes. Depending on the algorithm employed, extensive feature engineering is sometimes required, making classification a costly exercise. Additionally, if complex models are used, such as (deep) neural networks, there might be issues with interpreting the decision. Results are hard to interpret as these models are very complex. Another factor to be considered is class representation. Although in most situations, practitioners aim to represent all classes in the dataset equally, there are situations when that is impossible. Therefore, the classification algorithms may have difficulties in accurately predicting minority classes. Finally, classification models are static. This means they will only learn a representation of the world as provided by the training dataset. If there are any changes in the world, that is, if the input data change over time, they cannot make accurate predictions, and retraining is required. This could lead to further issues because new labeled data are required, which can be costly and time-consuming.

In conclusion, classification is a powerful tool in the arsenal of data science and EDM, enabling the automated categorization of data into predefined classes. This capability is fundamental in transforming raw data into actionable insights across many domains, from healthcare to finance to customer relationship management. Understanding the basic concept of classification facilitates decisions and strategies for future interventions.

4.2.4. Regression

Regression is a statistical method used in data analysis and machine learning to understand the relationship between a dependent variable (often called the outcome or target) and one or more independent variables (often called predictors or features). Regression aims to model how the dependent variable changes as the independent variables vary. This model can then be used to predict the value of the dependent variable based on new values of the independent variables (Figure 4.3). Imagine you are planning a road trip and want to estimate the total fuel cost. The total cost (the dependent variable) depends on several factors: the distance you will travel, your car's fuel efficiency, and the fuel price (the independent variable). By analyzing past trips (where you know the distance, fuel efficiency, price of fuel, and actual cost), you can develop a formula that relates these factors to the cost. Once you have this formula, you can use it to estimate the fuel cost for any new trip by inputting the expected distance, your car's fuel efficiency, and the current fuel price. In educational research, regression models can predict various outcomes, such as student grades or the effectiveness of educational interventions, based on factors such as study habits, attendance records, and prior academic performance. For example, Baker and Yacef (2009) highlight using regression analysis in EDM to predict student success in online learning environments, offering opportunities for proactive support.

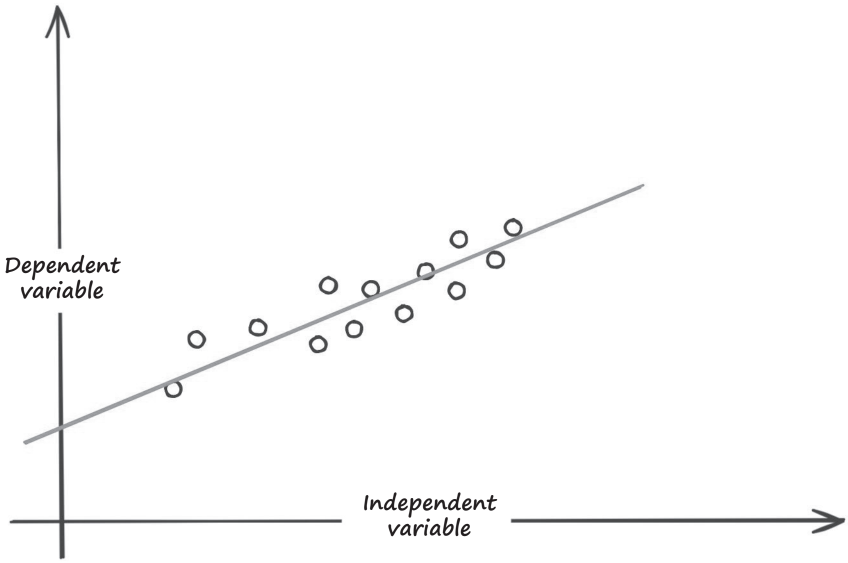


Figure 4.3. A linear regression line fitted to a scatter plot of data points depicting the positive linear relationship between an independent variable (on the horizontal axis) and a dependent variable (on the vertical axis). The line represents the best fit, showing the general trend that as the independent variable increases, the dependent variable also tends to increase.

There are several types of regression analysis, each suited to different kinds of data and research questions:

- *Linear regression:* This is the simplest form of regression, which assumes a straight-line relationship between the independent and dependent variables. It is used when the target variable is expected to have a linear relationship with the predictor variables.
- *Multiple regression:* Multiple regression is used when there are two or more predictor variables. This method can identify the relative influence of each predictor on the outcome variable.
- *Logistic regression:* Used for binary classification problems with categorical outcomes, such as spam detection (spam or not spam) or disease diagnosis (sick or healthy).
- *Polynomial regression:* When the relationship between the independent and dependent variables is curvilinear, polynomial regression can model this nonlinear relationship with higher-degree polynomials.
- *Ridge and lasso regression:* These variations of multiple regression incorporate penalty terms against significant coefficients in the model to prevent overfitting.

Regression has several well-known advantages:

1. Regression models can predict outcomes for new observations based on historical data, as in forecasting student performance.
2. It can help understand the impact of changes in predictor variables on the outcome variable, which is crucial for policymaking and strategy development in educational settings.
3. Educators can use regression analysis to identify the most significant factors affecting students' key performance indicators and optimize them for better results.

However, regression analysis also has its drawbacks. The accuracy of predictions depends on the quality of the data. Erroneous or biased data can lead to incorrect conclusions.

Moreover, each regression technique has assumptions (such as linearity). If these are violated, the model's results may be unreliable. Finally, models that are too complex may fit the noise rather than the signal in the data (overfitting), while less complex models may fail to capture the actual relationship (underfitting).

To sum up, regression is a powerful tool for understanding relationships within data and making predictions. It operates on the principle that the independent variables can explain the dependent variable's behavior. Regression analysis provides a foundation for informed decision-making and forecasting across various domains by creating a model that accurately describes these relationships.

4.2.5. Association rule mining

Association rule mining identifies interesting associations and relationships among large data items. In our case, it can be thought of as observing the habits of a large group of students to find common behaviors. For example, you might notice, "Whenever Alice comes up with the answer, Bob also agrees." If you see this pattern often enough, you can predict Bob's behavior based on Alice's actions. In other words, similar to this, association rule mining analyzes data to find "Whenever X happens, Y also happens" patterns, which can then inform educators' and policymakers' decisions about new strategies or interventions. An example of association rule mining could be a store sifting through data to find patterns such as "Customers who buy peanut butter also tend to buy jelly." These patterns are called "association rules" and can be used by the store to make decisions on marketing, store layout, and inventory management to increase sales.

An association rule has two parts: an antecedent (if) and a consequent (then). In the peanut butter and jelly example, the antecedent is buying peanut butter, and the consequent is buying jelly. The strength of the rule can be measured using metrics such as support (how often the items appear together), confidence (how often the rule is found to be confirmed), and lift (how much more often the antecedent and consequent occur together than would be expected had they been statistically associated with each other).

This technique is used in EDM to uncover patterns in student learning behavior or to identify associations between different learning resources and academic performance. For instance, Merceron and Yacef (2005) applied association rule mining to discover patterns in students' usage of an online learning system, revealing insights into how different types of interactions were related to learning outcomes.

Association rule mining has several advantages and can be used to provide critical insights from raw data:

1. This technique can reveal unexpected patterns in data that may not be immediately obvious, providing valuable insights for decision-making.
2. The rules generated are typically easy to understand, which can be particularly useful for strategy development and decision support.
3. Association rule mining is not limited to a particular data type and can be applied across various domains.

In contrast to regression and classification algorithms, association rule mining is not built for predictive modeling. However, association rules can help predict the occurrence of an item based on the presence of other items.

As with any other data analytics technique, association rules mining does not come without its drawbacks. One of the biggest is it generates many rules, which may be trivial or irrelevant. This requires additional processes to filter and prioritize the most significant ones. Moreover, while the rules can be easily understood, interpreting their significance and applying them requires domain expertise. The process can be computationally intensive, especially for large datasets, requiring efficient algorithms and sometimes significant computational resources.

Moreover, the output quality depends greatly on the quality of the input data. Noisy, incomplete, or incorrect data can lead to misleading rules. Finally, association rule mining is generally static and does not account for changes over time. This can be limiting when analyzing trends or patterns that evolve. Also, discovering association rules involves setting several thresholds for the analysis. The values for these thresholds need to be appropriately set to achieve confident results. This can be challenging and several iterations may be required to get it right. Improperly set thresholds can either miss important rules or generate too many insignificant ones.

To sum up, association rule mining is a crucial technique in data analysis for uncovering exciting and often unexpected relationships between variables in large datasets. It helps organizations make informed decisions by revealing patterns and associations that are not immediately obvious. By understanding these associations, educators can tailor their strategies to meet students' needs better, improve operations, and enhance decision-making processes.

4.2.6. Learning path analysis

Learning path analysis (LPA) is a method used in educational data mining and learning analytics to understand and optimize the student learning process. It involves analyzing the sequence of educational activities or resources that learners engage with over time. The goal is to identify the most effective paths that lead to successful learning outcomes, such as mastering a topic or achieving high grades, and to uncover any potential obstacles or inefficient steps in learners' educational journeys.

LPA can be thought of as a way to plan the best educational "journey" for students. In the same way a travel guide might help you find the best path through a city based on your interests and the time you have, LPA helps educators guide students through the learning material in the most effective way. It is about ensuring that every step in the learning process builds on the previous one and leads smoothly to the next, ensuring that students stay aware of the situation. Moreover, imagine planning a road trip to visit several cities. You have a map and mark all the cities you want to visit. LPA is like plotting the best route on this map so you can visit all the cities in the most efficient way, considering factors like distance, traffic, and attractions. In education, the "cities" are the learning objectives or goals, and the "roads" are the different learning activities, such as lessons, assignments, readings, and discussions. LPA helps educators and learners find the most effective "route" through these activities to achieve their learning goals.

The main applications of LPA are in personalized learning, curriculum design, new intervention strategy development, and learning analytics dashboards. LPA is an excellent tool for identifying the most effective learning paths for different types of learners. This, in turn, helps educators customize the learning experience to fit individual student needs and preferences, leading to a more personalized and effective learning journey. Moreover, by looking at the gaps and stumbling blocks in the learners' progress, LPA can underpin the design and organization of course content, helping educators sequence learning activities or develop targeted interventions in a way that optimally supports student learning. Finally, institutions can use LPA to provide students and educators with dashboards that offer insights into learning progress, suggesting the best next steps and resources.

This method uses data from past students' learning experiences—in the same way as GPS uses data from many travelers to suggest the best routes—to highlight which learning activities are most beneficial and which might need adjustment.

As mentioned, LPA aims to identify the most effective pathways that lead to successful learning outcomes and detect potential obstacles in educational trajectories. While LPA is not a specific algorithm but rather an application of various analytical techniques, several key algorithms and methods are commonly used within this framework. The main goal of LPA is to extract actionable insights from sequence or process data. For example, sequence mining algorithms can be employed to discover frequent subsequences within a dataset. This is equivalent to discovering the different trajectories that learners take as they engage with the learning content.

Moreover, the same analysis can reveal differences between learners, that is, successful students follow different trajectories to less successful students. Generalized sequential pattern and prefix-projected sequential pattern mining are commonly used algorithms within this domain. Process mining is another valuable approach in situations when educators only have access to logs recorded by educational institutions. The alpha algorithm or heuristic mining can be employed to discover how the educational process works. These two approaches provide educators with a more objective view of how learners engage with the content and the actual educational process as a whole.

As well as with specific sequence or process mining algorithms, LPA can be carried out using the methods introduced in the previous sections. For example, clustering algorithms are utilized to group students based on their learning paths and can identify patterns in how different student cohorts navigate learning materials. Moreover, classification algorithms can predict the next step in a learning path or classify the learning paths into successful or unsuccessful outcomes. Association rule mining can also be applied to discover interesting associations between different parts of the learning path. Finally, more advanced algorithms can also be developed to parse through the data generated during the educational process. In recent years, neural networks and deep learning models have been used to model sequences and predict future steps in the learning path. If the volumes of data are not large, probabilistic Markov models can also be employed.

Each of these algorithms and methods has its strengths and weaknesses and is chosen based on the specific requirements of the learning path analysis task, the nature of the data, and the desired outcome of the analysis. Researchers and practitioners often combine these methods to gain a comprehensive understanding of learning paths.

Before deciding on a specific algorithm or set of algorithms, it is necessary to carefully study the pros and cons of using LPA in an educational setting. In the remainder of this section, we will discuss some of the advantages and challenges of employing LPA.

The most apparent advantage of LPA is that it facilitates the creation of personalized learning paths that cater to students' individual needs and preferences, thereby improving learning outcomes. Moreover, it can be used to identify the most effective teaching materials, methodologies, and sequences, enabling the replication of successful strategies across different contexts. It can help identify points where learners struggle, allowing for timely intervention and support to address learning gaps and obstacles.

However, these advantages come at a cost. LPA is highly dependent on the available data, and data collection comes with significant costs and responsibilities. Most importantly, one must ensure the data are handled securely and ethically because collecting and analyzing detailed data on learners' behaviors raises significant privacy and ethical concerns. Moreover, what computational resources are available also needs to be considered. Learning paths can be complex, with numerous variables and potential sequences. Analyzing this data to extract meaningful insights requires sophisticated algorithms and considerable computational resources. No analysis is meaningful if no one can interpret and translate it into actionable insights correctly. This is especially true for LPA, as educators and administrators may have a skills gap in interpreting and applying the insights gained from LPA, necessitating training and professional development. Integrating LPA tools and methodologies with existing educational technologies and systems can also be complicated, requiring significant technical and organizational effort. Finally, for an LPA to be effective, the practitioners and researchers have to acknowledge that learners come from diverse backgrounds and different learning contexts, which can affect their learning paths. Therefore, they need to ensure that the models are inclusive and adaptable to various contexts and to continually monitor and update them so that they remain relevant and practical.

In conclusion, LPA is a powerful educational tool, offering insights that can significantly enhance the learning experience. Educators can create more personalized, effective, and enjoyable learning journeys by understanding and optimizing students' learning paths. This helps students achieve their learning goals more efficiently and supports educators in designing and refining their courses.

4.2.7. Successful applications of data mining in education

In the previous sections, we saw how EDM combines data mining, machine learning, and statistics with traditional educational research in order to analyze educational data and enhance the learning experience and outcomes. This field has evolved significantly over the years, along a path marked by several milestones and critical studies. Before looking at some concrete examples, it is essential to understand how the field got to its present form. The roots of EDM can be traced back to the late 1990s and early 2000s when the Internet and digital learning platforms were coming onto market. During those early days, most of the effort was focused on setting the foundations of the field, with many practitioners and researchers trying to make more objective sense of educational data. Early examples of this work were the result of efforts to analyze data from online learning systems and intelligent tutoring systems (ITS). Beck and Woolf's (2000) work on student modeling for an ITS named "Wayang Outpost" was a prime case in point, showing how data mining techniques can predict student performance and provide personalized feedback.

These original successes opened an era of rapid expansion and formalization within the field. The mid-2000s saw the establishment of the International Educational Data Mining Society and the launch of the *Journal of Educational Data Mining*. These were pivotal moments because these platforms provided a specialist space for researchers, educators, and policymakers to share findings and discuss specific methodologies (Romero & Ventura, 2013).

The formalization period was followed by a rapid expansion and diversification of EDM. Researchers explored a more comprehensive range of data sources, including massive open online courses (MOOCs), social media, and game-based learning environments. The rapid advancements during this period also resulted from the broader availability of accessible computing power and educational data. One notable example is the work by Pardos and Heffernan (2010), who used data from the ASSISTments platform to tailor educational content to individual students' needs. The same authors extended their original analysis to promote statistical and computational methods, namely, hidden Markov models and bagged decision trees to analyze data from the platform. The study aimed to personalize learning by adapting to individual students' needs. The analysis leveraged the rich features of user interaction and skill mastery, resulting in the system's ability to predict student performance more accurately and provide personalized feedback and recommendations. This implementation of EDM demonstrated a significant improvement in student learning outcomes, showcasing the potential of data-driven approaches in creating personalized learning environments.

Another issue that started to be tackled during the mid-2000s was the identification of students at risk. This is a critical concern in educational research and practice because it goes beyond academic achievement and affects students' long-term well-being, career prospects, and socioeconomic status. Identifying students at risk early on allows educators to intervene before issues escalate, potentially preventing academic failure or dropping out. Early interventions can be tailored to address specific challenges faced by students, whether they are academic difficulties, behavioral issues, or socioeconomic challenges (Mac et al., 2009; Eccles & Roeser, 2011; Oreopoulos & Salvanes, 2011; Tinto, 1993; Balfanz et al., 2014). EDM offers an alternative for dealing with identifying at-risk students. For example, Márquez-Vera et al. (2012) focused on using EDM to identify students at risk of failing in high school early in their academic journey. By applying genetic programming and various data mining techniques to educational data, the researchers could accurately predict student failure. This early identification allowed for timely interventions, such as personalized support and remedial programs, significantly reducing failure rates. This case study's success highlighted the capacity of EDM to support at-risk students and prevent academic failure through early detection and intervention.

Student engagement and participation also benefit from using EDM. Engagement refers to the degree of attention, curiosity, interest, optimism, and passion students show when learning or being taught. Participation involves the active involvement of students in learning activities, including classroom discussions, collaborative projects, and extracurricular activities. Both concepts are essential for effective learning and teaching processes. Engagement and participation are critical for a successful education because they affect not only academic outcomes and student satisfaction but also overall school success (Carini et al., 2006; Astin, 1993; Fredricks et al., 2004; Rumberger & Rotermund, 2012). These issues can be alleviated by employing data mining, statistics, and machine learning. For example, Romero et al. (2013) investigated using EDM to enhance student engagement and participation in online discussion forums. By analyzing the patterns of participation and contributions in the forums, the researchers developed models to predict students' final performance in the course. Insights gained from the data helped instructors identify students who were less engaged or at risk of underperforming, enabling them to encourage more active participation. This case study demonstrated how EDM can enhance online learning environments by fostering student engagement and improving academic performance.

The exploration of EDM presented in this chapter underscores the transformative potential of this interdisciplinary field at the intersection of data science and education. Since its nascent stages in the late 1990s and early 2000s, EDM has consistently pushed the boundaries of how educational data can be harnessed to enhance learning outcomes.

As EDM continues to evolve, its contributions to personalizing learning experiences, identifying and supporting at-risk students, and fostering engaging and participatory learning environments are increasingly being recognized. These developments highlight the field's growth and highlight the ongoing need for innovative approaches to analyzing educational data. The journey of EDM is far from complete, with future advancements poised to revolutionize educational practices further, making learning more responsive to individual needs and societal challenges. The foundations laid by early researchers and the continued efforts of the global EDM community ensure that the field remains at the forefront of educational innovation, promising to unlock new insights and opportunities for learners worldwide.

4.3. Adaptive learning and media literacy

Adaptive learning environments are sophisticated educational systems designed to tailor the learning experience to each student's individual needs, skills, and preferences. These systems leverage advanced algorithms and data analysis techniques to dynamically adjust the content, pace, and complexity of learning materials based on real-time feedback from student interactions. The core objective is to enhance learning efficiency, engagement, and outcomes by providing every learner with a unique learning path.

The introduction of adaptive learning environments has brought many improvements to the educational process. First, these systems personalize the educational content based on the single learner's performance, preferences, and interaction patterns. This personalization can range from adjusting the difficulty level of questions to suggesting resources that match the learner's interests (Xie & Reider, 2014). Moreover, providing real-time feedback to students, which is crucial for adaptive learning systems, helps learners understand their strengths and weaknesses and adjust their learning strategies accordingly (Timms, 2016). However, despite their potential, adaptive learning environments face challenges such as data privacy, algorithmic bias, and the digital divide. These challenges must be addressed to ensure equitable access and outcomes for all learners (Selwyn, 2019).

Adaptive learning environments rely on data-driven decision-making to inform the adaptation process. This involves collecting and analyzing vast amounts of student behavior, engagement, and performance data. Therefore, adaptive learning environment systems offer a very fertile ground for EDM applications. By allowing sophisticated algorithms to mine student data, tailor educational content, and provide real-time delivery, adaptive learning environments can enhance personalized learning experiences. This adaptation is based on student data points, including engagement metrics, learning pace, and comprehension levels. The ultimate goal is to optimize learning efficiency and outcomes by dynamically adjusting the educational process to fit the individual needs of each student (Baker & Siemens, 2014; Mikropoulos & Natsis, 2011).

Adaptive interventions have the potential to significantly enhance ML education by providing personalized, interactive, and engaging learning experiences tailored to the unique needs and learning paces of individual students. Educators can use adaptive learning systems to tailor ML content based on students' existing knowledge, skills or lack of skills, and learning preferences. For instance, a student with a strong understanding of evaluating online sources but less experience in content creation could receive more activities focused on creating digital content. This personalization ensures that learners receive both challenging and achievable instruction, promoting better engagement and understanding. The same intervention can also provide a safe, controlled environment for students to explore these topics, guiding them through complex issues with appropriate context and support.

All adaptive systems involve multimedia and interactive elements. These contents can be incorporated into the educational program as simulations that allow learners to practice identifying bias in news articles or create their own media messages, thereby providing hands-on experience. This interactivity helps solidify understanding and encourages active learning. As they are digital, adaptive systems facilitate immediate feedback, which allows learners to understand their mistakes and educators to develop a continuous learning program in a less time-consuming way. In ML, this could mean offering explanations and tips after the failure to correctly identify misleading information in a piece of writing, helping to gradually build the students' analytical and critical thinking skills (Buckingham, 2003; Greenhow et al., 2009).

Implementing EDM-driven adaptive learning environments presents several challenges that must be carefully managed to ensure the effectiveness and equity of these systems. Key among these challenges is ensuring the accuracy and representativeness of data, dealing with the digital divide, and maintaining student engagement in digital learning spaces. The efficacy of an EDM-driven adaptive learning environment depends greatly on the quality and representativeness of the data used to train the adaptive algorithms. Inaccurate, incomplete, and biased data can lead to misinformed decisions, potentially exacerbating educational inequalities. The collected data need to accurately represent the diversity of student populations and learning contexts, not to mention that their need for continuous validation. Moreover, models must be continuously refined to ensure they remain representative and effective over time (Linan & Juan Perez, 2015).

Another significant challenge for adaptive learning systems refers to the gap between individuals who have access to modern information and communication technology and those who do not (the so-called digital divide). This divide can significantly impact the accessibility and effectiveness of EDM-driven adaptive learning environments as differences in access to technology and digital literacy skills limit the ability of some students to effectively use these systems (Warschauer, 2004).

Finally, it is significantly more challenging to engage students in digital learning environments than in traditional learning milieus. Educators need to design interactive and personalized learning experiences to address this issue. EDM can be leveraged for this purpose as it can provide an alternative to teachers having to create dynamic, interactive content that responds to student needs and preferences (Henrie et al., 2015).

The implementation of EDM-driven adaptive learning environments encompasses a range of challenges that must be addressed to ensure these systems are effective, equitable, and engaging. Ensuring the accuracy and representativeness of data, addressing the digital divide, and maintaining student engagement are critical components of successful implementation. Addressing these challenges requires ongoing research, investment in technology infrastructure, and a commitment to inclusivity and equity in educational technology initiatives. By acknowledging and addressing these challenges, educators and technologists can use the full potential of EDM to enhance learning outcomes for all students.

4.4. Challenges and ethical considerations

Throughout this chapter, we have explored different ways in which EDM can enhance education. Until now, the discussion has primarily been focused on the algorithms powering EDM, the cases in which they are used, and the benefits of introducing a data-driven approach into education. However, implementing EDM also stirs up critical challenges related to data privacy, security, ethical implications, and mitigating bias to ensure equity and inclusivity. These issues are paramount, as student data encompass sensitive information that could impact students' lives and educational trajectories.

The foundation of any EDM application is data. There is no EDM if there is no data. However, the collection, analysis, and storage of educational data pose significant privacy and security risks; as educational institutions collect vast amounts of sensitive information, including academic performance, behavior data, and personal identifiers, the risk of data breaches and unauthorized access increases. Albeit a significant issue, data privacy should not deter practitioners. All it means is that they need to ensure robust encryption, secure data storage, and strict access controls, which are essential. Furthermore, the data collection, storage, and processing systems must comply with laws and regulations such as the Family Educational Rights and Privacy Act (FERPA) in the United States and the General Data Protection Regulation (GDPR) in the European Union. All these concerns can be successfully allayed by developing policies and practices that prioritize student privacy and data security and emphasize the importance of consent and informed participation (Slade & Prinsloo, 2013).

Besides privacy issues, EDM also has to ensure transparency and consent. The ethical use of student data hinges on informed consent and transparency. Students and their guardians should be fully informed about which data are collected, how they are analyzed, and for what purposes. This requires clear communication and the opportunity for students to opt in or opt out of data collection initiatives. Transparency about the algorithms and models used is also crucial to avoid "black box" scenarios where decisions are made based on opaque criteria. Educators and institutions must strive to explain these processes in accessible language, ensuring stakeholders understand the implications of data use. As with data privacy, ethical usage of data and algorithms can be guaranteed by creating and following a clear framework agreed upon by educators, institutions, students, and guardians (Drachsler & Greller, 2016).

Bias is a primary plague for any data science or machine learning solution, and EDM is not immune from this issue. Bias in EDM can manifest in various forms, from the data collection process to algorithmic bias in the analysis tools and can inadvertently reinforce existing disparities in educational outcomes, particularly for marginalized or underrepresented student groups. To address this, EDM practitioners must critically reflect on the design of their studies and the potential bias in their data sources and analytical methods. Implementing diverse and inclusive data collection strategies, along with regular audits of algorithms for bias, is vital. Equity-focused EDM approaches should aim to identify and lessen disparities, ensuring that interventions support all students, especially those at risk of being disadvantaged by systemic inequalities (Eubanks, 2018).

Moreover, creating fair and inclusive EDM systems requires a commitment to equity from the outset of any data mining project. This involves actively seeking to understand the diverse needs and contexts of all students, including those with disabilities, those from different cultural backgrounds, and those whom educational systems may have historically underserved. Inclusive design practices can help ensure that

EDM tools and interventions are accessible and beneficial to many learners. Engaging with students, educators, and communities in developing and implementing EDM initiatives can help align these efforts with the values and needs of those they aim to serve (Holstein et al., 2018).

As we move forward, the path to harnessing EDM's full potential in education is ever more complex and multidimensional. It requires technical solutions, ethical frameworks, policy guidelines, and a commitment to continuous improvement and inclusivity. Collaboration among educators, data scientists, policymakers, and the broader community will be pivotal in navigating these challenges. This collaboration can guarantee EDM as a powerful tool for enhancing learning experiences in an effective and equitable manner.

In essence, the journey of EDM in education is one of balance—balancing the opportunities afforded by advanced data analysis with the responsibilities of handling sensitive educational data. As we venture into this future, let us be guided by a commitment to enhancing educational outcomes while upholding the values of privacy, equity, and inclusivity. The promise of EDM in education is immense, and with careful stewardship, it can lead to transformative improvements in how we teach and learn.

4.5. Future directions

This chapter reviewed EDM and how it affects adaptive interventions. There is no questioning the fact that EDM has transformed education, offering many tools to better understand learners and the learning processes, and provide personalization. Now we will abandon the past and focus on the future. It is impossible to predict where EDM and adaptive interventions will go next, but one can speculate. We believe that EDM and adaptive interventions will lead to increasing personalization, more efficient and engaging learning experiences, and broader access and accessibility.

As technology advances and our understanding of learning processes deepens, we will begin to integrate more and more emerging technologies such as artificial intelligence (AI), augmented reality (AR), virtual reality (VR), and even blockchain. Combining these technologies will result in a transparent, digital-first learning experience that will be immersive and interactive and will not depend on the learners being physically present in a specific location at a specific time. In other words, students will be able to access personalized learning experiences, at their own pace, from anywhere, at any time. In parallel, the introduction of this digital-first approach will further enhance the capabilities of EDM, which, in turn, will continue to push the boundaries of these adaptive learning systems. Together, these technologies will be able to provide deeper insights into learning behaviors, enable real-time feedback and interventions, and ensure the security and privacy of educational data.

Another evolution that we will soon witness is a mindset shift facilitated by EDM. Although this chapter primarily focused on how EDM can improve student performance, personalize content, or offer educators and policymakers the tools to understand the educational process, in the future, it will also help tailor content that is not only adjusted to students' academic needs but also to their emotional states and learning preferences. Just imagine a system wherein not only the difficulty levels of the tasks are varied but also the mode of delivery, the types of activities, and the communication styles. This evolution will also lead to applications beyond traditional educational settings, encompassing lifelong learning, corporate training, and informal learning environments. This expansion will also focus on improving accessibility for learners with disabilities and those from diverse cultural and socioeconomic backgrounds. Moreover, coupling the exploratory and predictive tools built using EDM with digital adaptive interventions will enable educators to assess and develop students' soft skills, including critical thinking, creativity, collaboration, emotional intelligence, and academic knowledge. All this will be done using data-driven insights to guide personalized learning pathways that foster well-rounded individuals in a safe and engaging environment.

However, the future will not be without its (significant) challenges. As adaptive interventions become increasingly standard, we are poised to see a proliferation of digital systems designed to support them. This evolution will naturally result in a surge of options, potentially causing confusion among users. Consider, for instance, the plethora of online meeting platforms or accounting applications available today. Educators and policymakers will have to stay abreast of these developments. They need to keep pace because it is crucial to select the appropriate tools for the job. The right digital tools can enhance the effectiveness of educational strategies and policies, ensuring that the benefits of adaptive learning are fully realized. Therefore, staying informed and making judicious choices about technological tools becomes essential to successfully navigate the future of education.

Moreover, ethical and privacy considerations will take center stage as educational data become more integral to learning. Future developments must address data ownership, consent, transparency, and bias concerns. Educators, institutions, and policymakers will need to develop guidelines and frameworks for ensuring that EDM practices are ethical and that data are used responsibly, which will be crucial to maintaining trust and integrity in educational systems.

The ongoing advancements in educational technology will catalyze a shift towards a more decentralized educational landscape. As platform developers and technology corporations enter the educational arena, the diversity of learning opportunities for students is expected to expand significantly. This proliferation of choices will democratize access to education, allowing learners to tailor their educational journeys according to their unique needs and preferences. Concurrently, this diversification will necessitate the formulation of comprehensive policies to ensure that new participants in the education sector adhere to principles of responsibility and ethics.

Furthermore, the digitization of education compels us to reconsider the traditional roles of schools and educators. We foresee a transformation in the requirements for new entrants into the private and public sectors, moving from a focus on conventional academic credentials to a greater emphasis on specific skills and competences. Consequently, educators are likely to evolve into leaders and mentors, guiding students through personalized learning paths and fostering the development of essential skills. Amidst these systemic transformations, EDM stands as a formidable ally, offering sophisticated tools that enable educators to reach a broader audience in a more targeted and personalized manner, thereby enhancing the effectiveness and inclusivity of educational practices.

The evolution of EDM and adaptive learning is set to foster an unprecedented level of collaboration across a spectrum of stakeholders, including educators, researchers, technologists, policymakers, guardians, and, notably, the students themselves. The integration of open-source projects and the promotion of community-driven development are poised to catalyze innovation, facilitate the exchange of best practices, and establish standards that guarantee the interoperability and scalability of educational technologies. Such collaborative efforts are instrumental in harnessing collective expertise and insights to refine and advance the educational landscape.

This collaborative trend mirrors developments in the software and technology industry, where many companies are embracing open-source models, inviting global contributions to their digital platforms and tools. Education is anticipated to follow a similar trajectory, with institutions progressively open-sourcing their content, as evidenced by the growing availability of free online lectures and courses. Consequently, education is transforming into a community-driven endeavor empowered by technology, to which every participant can transparently contribute. This shift signifies a move towards a more inclusive and accessible educational environment, where learning is not just the transmission of knowledge but a shared journey of discovery and innovation. In this world, adaptive systems powered by EDM will be crucial in creating a compelling learning journey for students.

In conclusion, the future of EDM and adaptive learning heralds a collaborative era among all stakeholders in the educational ecosystem. Open-source projects and community-driven development will drive innovation and best practices, reflecting broader software and technology industry trends. Education, too, will embrace this open, collaborative approach, transforming into a community effort powered by technology, in which each and every participant contributes to a shared journey of learning and discovery. In this evolving landscape, EDM and adaptive systems will be instrumental to crafting effective and personalized educational experiences, marking a significant step forward in the quest to meet the diverse needs of learners worldwide.

Summary

In an evolving educational landscape, EDM and adaptive learning technologies are significantly shaping teaching and learning processes. In this chapter we described a path for the integration of technology in education, highlighting the pivotal role of EDM in enhancing ML education and adaptive learning systems.

Applying EDM facilitates a deeper understanding of learning behaviors, enabling the creation of personalized learning environments. Through the analysis of extensive datasets from various educational activities, EDM supports the early identification of at-risk students, curriculum improvement, and the development of more effective feedback mechanisms.

We also explored the potential of EDM in revolutionizing ML education. By leveraging data analysis, educators can tailor learning experiences to individual needs, identify learning gaps, and develop effective ML curricula. This personalized approach not only caters to diverse learning needs but also addresses the challenges of the digital age, fostering a more media-savvy generation.

Thereafter, we extended the discussion to adaptive learning systems, exemplified by platforms like ASSISTments and ALEKS. These systems illustrate how data-driven approaches can enhance learning experiences, demonstrating significant improvements in student performance. The adaptability of such systems to individual learning paths underscores the efficacy of EDM in creating personalized, engaging, and effective learning environments.

We concluded by envisioning the future of EDM and adaptive learning, emphasizing the potential for further personalization, enhanced learning experiences, and broader accessibility. The integration of emerging technologies, such as AI, AR, VR, and blockchain, is anticipated to offer immersive and interactive learning experiences, transcending traditional educational boundaries. However, challenges related to the digital divide, data privacy, and ethical considerations remain, calling for ongoing efforts to ensure the equitable and responsible use of educational data.

In summary, EDM and adaptive learning technologies present promising avenues for enhancing educational practices. By harnessing the power of data analytics, educators can create more personalized, engaging, and effective learning environments, ultimately contributing to the advancement of educational outcomes and ML in the digital age.

Glossary

Adaptive interventions. Educational strategies that make real-time adjustments tolearning content, difficulty, pace, and methods based on the individual learner's needs, preferences, and performance.

Adaptive learning environments. Educational systems designed to customize learning experiences to individual student needs, preferences, and performance through the use of advanced algorithms and data analysis.

Adaptive learning systems. Technology-based educational systems that use data and algorithms to dynamically adjust learning content, pace, and strategies to the individual learner's needs.

ALEKS (Assessment and LEarning in Knowledge Spaces). An adaptive learning system that assesses the state of students' knowledge in STEM subjects and provides personalized instruction paths.

Algorithmic bias. The potential for algorithms to reflect or amplify existing prejudices or bias in data, leading to unfair outcomes or decisions.

Algorithmic representativeness. The extent to which data used to train algorithms accurately reflects the diversity of student populations and learning contexts.

Alpha algorithm. A process mining technique used to discover process models from event logs.

ASSISTments. An online platform that provides immediate feedback to students on math problems and generates detailed reports for teachers on students' strengths and weaknesses.

Clustering. Grouping students based on similarities in characteristics or behaviors to tailor educational strategies.

Community-driven development. A development approach that empowers users, developers, and stakeholders to contribute to projects and share ideas, code, and solutions.

Curse of dimensionality. A phenomenon in which the more dimensions are added, the sparser the data in the feature space become, making classification difficult.

Data analytics. The process of examining data sets to draw conclusions about the information they contain, using specialized software and systems.

Data mining. The process of discovering patterns and knowledge from large amounts of data.

Data-driven decision-making. Using data analysis and insights to inform decisions and adaptations within educational systems, enhancing personalization and learning outcomes.

Decision tree. A model that uses a branching method to illustrate outcomes of decisions, useful for classification.

Deep learning. A subset of machine learning involving networks capable of unsupervised learning from data that are unstructured or unlabeled.

Digital divide. The gap between individuals who have access to modern information and communication technology and those who do not, which can affect the accessibility and effectiveness of digital learning environments.

Digital first approach. An approach that prioritizes the use of digital tools and platforms in designing and delivering educational content and experiences.

Discovery with models. Constructing models to understand and enhance learning and instructional processes.

Engagement metrics. Data points that measure how students interact with educational content, such as time spent on tasks, completion rates, and interaction patterns.

Ensemble methods. Techniques that use multiple learning algorithms to obtain better predictive performances.

Feature engineering. The process of using domain knowledge to extract features from raw data.

Feedback mechanisms. Tools or processes used to provide learners with information on their performance and progress, aimed at improving their learning outcomes.

FERPA (Family Educational Rights and Privacy Act). A United States federal law that protects the privacy of student education records.

GDPR (General Data Protection Regulation). A regulation in EU law on data protection and privacy in the European Union and European Economic Area.

Generalized sequential pattern (GSP). An algorithm for discovering sequential patterns in data.

Gradient boosting machines. An ensemble technique for classification and regression that builds models sequentially.

Heuristic mining. A process mining approach that uses heuristics to construct process models from incomplete data.

Imbalanced classification. Classification in the event that some classes are underrepresented.

Instance-based learning. Classification methods that compare new instances with instances seen in training.

Interactive learning experiences. Educational activities designed to be dynamic and engaging, requiring active participation from learners.

Interoperability. The ability of different systems, devices, applications, or products to connect and communicate in a coordinated way, within and across organizational boundaries.

Learning path analysis (LPA). Analyzing the sequence of educational activities to identify effective learning paths and potential obstacles.

Logistic regression. A statistical model that estimates probabilities using a logistic function commonly used for binary classification.

Machine learning. A subset of artificial intelligence involving the creation of algorithms that can learn from data and make predictions or decisions based on data.

Naive Bayes. A probabilistic classifier based on applying Bayes' theorem, while strongly assuming the attributes' independence.

Neural networks. A set of algorithms modeled loosely after the human brain, designed to recognize patterns.

Open-source projects. Software projects where the source code is made freely available for anyone to review, modify, and distribute.

Outliers. Data points that differ significantly from other observations, which can affect the results of clustering and other analyses.

Overfitting. A modeling error in which a function is too closely fit to a limited set of data points.

Personalization. The adaptation of educational content and experiences to meet the unique needs, preferences, and learning pace of each student.

Prediction. The use of historical data to forecast future outcomes, such as student performance or dropout rates.

Prefix-projected sequential pattern mining. An efficient method for finding frequent sequences in a dataset.

Process mining. Analyzing logs from educational systems to understand the educational process.

Random forests. An ensemble learning method that constructs a multitude of decision trees, used for classification.

Real-time feedback. Immediate responses provided by educational technologies to inform learners about their performance, understanding, and areas for improvement.

Relationship mining. The process of identifying relationships between variables within educational datasets.

Scalability. The capacity of a system to handle a growing amount of work or potential to be enlarged to accommodate that growth.

Sequence mining. Technique to discover frequent subsequences within a dataset, useful in LPA.

Support vector machines (SVMs). A set of supervised learning methods used for classification, effective in high-dimensional spaces.

Text mining. Process analyzing textual data from educational contexts to understand student sentiments and learning strategies.

5

Empowering teachers to educate critical online readers

Carita Kiili and Pirjo Kulju

The purposes of this chapter are to

- ✓ describe key features of critical online reading;
- ✓ define teacher self-efficacy and its sources;
- ✓ introduce design principles to support teachers' self-efficacy in educating critical online readers;
- ✓ illustrate how these design principles were implemented in two teacher education contexts;
- ✓ share teacher experiences of courses that implement these design principles.

5.1. Introduction

One widely pursued and highly regarded goal of education is to cultivate critical, digitally literate citizens (Grizzle et al., 2021). This includes educating online readers who can navigate online spaces purposefully, critically, and responsibly. Teachers play a key role in realizing this goal. However, constantly changing online spaces, the endless renewal of digital practices, and the broad proliferation of misinformation make educating critical online readers a challenging task. Undoubtedly, teacher education and professional development must support teachers in this arduous feat.

Teacher education and professional development courses can provide knowledge about skills, practices, and pedagogies related to critical online reading. However, teacher education should also address the motivational factors that play a pivotal role in teachers' willingness to develop as teachers. One well-established approach is to support teacher self-efficacy, which refers to a teacher's confidence in promoting their students' engagement and learning (Mok et al., 2023; Täschner et al., 2024). We adopted this approach in our efforts to empower teachers to educate critical online readers.

This chapter outlines the design principles that guided our decision making when we developed courses to support pre-service and in-service teachers' self-efficacy in educating critical online readers. To provide a context for our design, we will begin our chapter by describing the key features of critical online reading, followed by a characterization of students as critical online readers and an overview of some of our thoughts on teaching critical online reading. To lay further ground for our design principles, we will conceptualize self-efficacy as a theoretical construct. Then, we will introduce five design principles and show how we implemented them in the two contexts of formal teacher education and teacher professional development. Finally, we will share pre- and in-service teachers' experiences with the implementation of this project to reflect on each design principle in practice.

5.2. Critical online reading

Critical online reading refers to the various evaluative practices through which readers engage with online information. Evaluative practices can be employed when students search for information, process single or multiple online texts, and synthesize information across online texts (Hämäläinen, 2023; Kiili et al., 2021). Such practices can concern the relevance and credibility of online information (Kiili et al., 2008). In this chapter, we focus on *online credibility evaluation*, which refers to the process of evaluating the quality of online information.

When searching for information, readers can consider which sources (e.g., researchers, news sites, and organizations) are likely to publish credible information about a particular topic (Kiili et al., 2021). Readers can then use these potential sources in their search queries (e.g., organization + topic). They can also examine the search results (i.e., title, web address, and example text) to determine whether the identified content may include credible information (Gerjets et al., 2011). However, search results provide a limited amount of information, and readers can only make initial predictions regarding the credibility of the information behind the links. Therefore, readers need to evaluate potentially relevant and credible texts by scrutinizing the accuracy of the text's content and the trustworthiness of the source, such as the author or the publisher (Barzilai et al., 2020; Forzani et al., 2022; Stadtler & Bromme, 2014).

Readers can use several evaluation strategies to assess the content (i.e., ideas and arguments) presented in the text. First, if readers have solid prior knowledge of the topic, they can evaluate whether the ideas presented in the texts are aligned with what they already know (Stadtler & Bromme, 2014). However, if their prior knowledge is inaccurate or superficial, this evaluation strategy may not be fruitful. In the worst case, it may only strengthen a reader's misconceptions. Second, readers can evaluate the quality of the author's argumentation by examining how well the author's reasons and evidence support their claims (Barzilai et al., 2020; Forzani et al., 2022). Finally, readers can engage in corroboration by comparing information across texts to understand the prevailing consensus among experts on a given topic (Osborne & Pimentel, 2022).

Another influential evaluation strategy is sourcing, which refers to attending to, evaluating, and using information about individuals and organizations that have written or published a particular online text (Bråten et al., 2018). When readers evaluate an author's or publisher's trustworthiness, it is important to reflect on both their expertise and intentions (Hendriks et al., 2016). Determining an author's expertise can entail an investigation into their profession, education, and experiences (Bråten et al., 2018). Importantly, these indicators of expertise should always be evaluated in relation to the topic that the author is writing about.

When evaluating authors' *intentions*, readers should consider whether the source demonstrates goodwill and the intention to share accurate knowledge (Hendriks et al., 2016). The author's or publisher's intentions can sometimes be inferred from sponsors, advertisements, or the aims of affiliated organizations. Notably, the intentions of different types of organizations require prior knowledge of societal structures. Sometimes, intentions need to be inferred between the lines, which requires good reading comprehension skills.

In addition to the content and source, readers can take into account the context of the text in their evaluations (Forzani et al., 2022). Context refers to the sociopolitical setting in which the content and source appear. For example, readers may consider the historical setting of the text (Wineburg, 1991) or conventions associated with specific online genres (Corrigan & Slomp, 2021).

Theoretical considerations of credibility evaluation (Barzilai et al., 2020; Forzani et al., 2022) accentuate the fact that strategic evaluation processes are iterative. This means that such strategies are not used in isolation. For example, credibility judgments about the content affect judgments of the source. The relationship is bi-directional (Barzilai et al., 2020), so credibility judgments of the source also affect judgments of the content. In online contexts, credibility evaluation usually occurs across multiple texts. Thus, one's understanding of content and source credibility also evolves during reading. For example, readers may have initially considered the source very trustworthy, but after exposure to other texts, they may become more critical of the source (Svedholm-Häkkinen et al., under review).

Furthermore, evaluative practices are critical when readers synthesize information across multiple texts to build a coherent understanding of the topic they are examining online (Rouet, 2006). When synthesizing information, readers compare and contrast sources and their perspectives. Readers can consider, for example, the following: which sources share the same views, and which sources present conflicting views? Finally, readers can weigh different viewpoints by considering the strength of the argumentation and the trustworthiness of the sources when making their final conclusions regarding the topic (Vongkulluksn et al., 2023).

As depicted above, critical online reading is complex and requires flexibility in strategic processing. First, readers are expected to employ various evaluation strategies when navigating different types of texts. Second, readers need to regulate the depth of their evaluative processes. In some situations, readers can evaluate texts intuitively and quickly, whereas other situations demand slower, analytical, and reflective processing (Kahneman, 2003). Finally, readers face the challenge of remaining open to different views, especially when they encounter highly credible texts that contradict their prior beliefs (Svedholm-Häkkinen et al., under review).

The complexities inherent in critical reading challenge not only students but also their teachers. Teachers are best prepared when they are aware of the different strategies and their theoretical underpinnings, while also being able to explain how, when, and why to use them.

5.3. Students as critical online readers

Skilled critical online readers have a rich repertoire of evaluation strategies that they can employ when encountering different types of online texts. These students can differentiate more credible online texts from less credible ones. In addition, they can justify their evaluations from multiple perspectives. Our studies have observed skillful evaluation among students representing different grade levels (Kanniainen et al., 2022; Kiili et al., 2018, 2022). These students often have good comprehension skills that help them become skilled evaluators (Kanniainen et al., 2019). However, good reading comprehension skills do not automatically guarantee skillful, critical online reading.

Unfortunately, studies have also shown that many students struggle to judge the quality of online information (Coiro et al., 2015; Kiili et al., 2018, 2022; McGrew et al., 2018). For example, some students can hardly present any relevant justifications for why they trust or do not trust a specific online text. Furthermore, an International Computer and Information Literacy Study (ICILS) showed that 28% of Finnish eighth graders had limited skills in finding and using online information (Leino et al., 2019). Another important finding is that adolescent readers do better in confirming the credibility of more credible texts than in questioning the credibility of less credible texts (Kiili et al., 2023). However, even though students can confirm the credibility of the texts, they cannot necessarily justify why specific texts should be trusted (Kiili et al., 2022).

To conclude, evidence shows considerable interindividual differences among students that teachers may encounter in their classrooms. It is worth noting that students may be overconfident in their online credibility evaluation skills, when they need to question the credibility of online texts (Anttonen et al., 2023). This suggests that students are not necessarily aware of the complexities of online credibility evaluation. As questioning credibility is challenging for many students in comprehensive school, students need opportunities to critically analyze less credible and even misleading texts.

5.4. Teaching critical online reading

Although there is a clear need to teach critical online reading skills, not all students have equal opportunities to learn them. According to the ICILS, 63% of Finnish eighth-grade teachers participating in the study reported placing at least some emphasis on the credibility evaluation of information (Leino et al., 2021). Furthermore, a survey (Kulju et al., 2020) conducted among Finnish class teachers ($N = 593$) showed that only about a third of the class teachers reported that they had taught critical evaluation of texts (35% of the participating teachers) or reading online texts (31%) at least "quite a lot". Even though the amount of teaching increased among first- to sixth-grade teachers, 15% of the sixth-grade teachers reported teaching reading of online texts very little or not at all.

There are various instructional practices that teachers can employ to promote students' critical online reading skills, including modeling effective strategies, providing cognitive and metacognitive supports, facilitating discussions, and presenting contrasting cases (e.g., Bråten et al., 2019; Hämäläinen et al., 2020; 2022; Pérez et al., 2018). As specifying various teaching practices is beyond the scope of this chapter, we focus on sharing a few overarching ideas that we perceive as important when designing instructional activities for promoting critical online reading.

As ever-younger children engage with online information, critical online reading should be taught early on. However, teaching should be adjusted to the students' developmental level, keeping in mind that readers' strategic processing develops throughout their lifespan in conjunction with increases in their world and domain knowledge (Alexander, 2005). Thus, particularly for younger students, teachers should offer emotionally safe and manageable learning spaces. For example, when discussing online misinformation with younger students, it is crucial to maintain their sense of safety. In addition, the complexities related to online information quality should be gradually revealed. For example, when considering the quality of evidence, research evidence can be less refined (e.g., different types of research evidence) for younger students than for older students.

Even though there are some general developmental underpinnings, students' strategic reading development does not go hand in hand with their age, as evidenced by considerable individual differences in critical online reading skills at different grade levels (e.g., Hämäläinen et al., 2023; Kanniainen et al., 2022; Kiili et al., 2022). Therefore, teachers should seek to address students' individual needs by differentiating instruction. Such differentiation can be accomplished by regulating the amount and complexities of texts and the difficulty of the guiding prompts, for example.

To help teachers select appropriate tasks for their students' needs, we have classified credibility evaluation task types according to their difficulty (see the list below), ranging from the easiest to the most challenging (Kiili & Kulju, 2024). The restricted tasks (I) are most suitable for elementary grades, and the most demanding tasks (IV) are most appropriate for secondary and upper secondary school students. However, as stated earlier, teachers can also use this classification flexibly according to their students' needs.

i. Restricted tasks practicing the evaluation of one credibility aspect.
ii. Evaluating credibility with online texts designed for teaching purposes.
iii. Evaluating the credibility of authentic online texts selected by the teacher.
iv. Evaluating the credibility of self-selected online texts and composing a synthesis based on multiple texts.

Teachers can use the task types to gradually increase the complexity of online credibility evaluations. The first task type is the most restricted, as it focuses on one credibility aspect at a time (e.g., the author's expertise or the quality of the evidence). In the second task type, students practice credibility evaluation with online texts designed for teaching purposes. These texts can be manipulated regarding credibility aspects, topics, and length to suit a specific grade level.

After practicing credibility evaluation with restricted texts, students can then proceed to practicing credibility evaluation with authentic online texts. In the third task type, students evaluate texts selected by the teacher. Teachers can choose texts on specific topics that are relevant for teaching purposes (e.g., to focus on a specific credibility aspect or taught subject). The selected texts can vary in credibility; also, misleading texts can be analyzed critically through this task type. Finally, in the most demanding task type, students evaluate multiple online texts that they have selected to be part of a larger learning assignment. They may also synthesize information from these texts into written or multimodal products (i.e., composing an essay or video).

In the classification of these tasks, we used the credibility evaluation of online texts as an example. It should be noted that this classification can also be applied to other online reading practices, such as searching for information with search engines.

5.5. Teacher self-efficacy

Self-efficacy beliefs refer to one's confidence in accomplishing a specific task or goal (Bandura, 1997). Self-efficacy beliefs influence an individual's selection of activities, the effort they invest in the task, and their persistence in overcoming obstacles (Schunk, 2012). One area of self-efficacy that remains critical to the teaching profession is teacher self-efficacy, which concerns a teacher's beliefs in their ability to support their students' engagement and learning (Skaalvik & Skaalvik, 2010). It has been shown that high teacher self-efficacy is positively associated with the quality of classroom practices and students' motivation (Zee & Koomen, 2016). Furthermore, teachers who feel confident in their role as teachers are more open to new pedagogical ideas and may be more willing to try new methods than their counterparts with lower levels of confidence (Runhaar, 2010).

As with any other area of self-efficacy, teacher self-efficacy is situation specific (Bandura, 1997). Thus, even if a class teacher may be confident in teaching reading comprehension, the same individual may not necessarily be as confident in teaching new competencies, such as critical online reading. Therefore, even experienced teachers may need support to become self-efficacious in teaching critical online reading skills.

5.5.1. Sources of self-efficacy

Bandura (1997) differentiates four sources that can foster self-efficacy: 1) mastery experiences, 2) vicarious experiences, 3) social or verbal persuasion, and 4) physiological and emotional states. In teacher education, *mastery experiences* refer to previous successful teaching experiences that serve as indicators of one's capabilities. According to Bandura (1997), mastery experiences are regarded as the most influential source of self-efficacy because they provide direct feedback on one's capabilities. Teachers who view their past teaching efforts as successful will likely feel confident in similar future situations. On the contrary, if teachers have experienced failures, they are more likely to question their capabilities in similar circumstances. Mastery experiences in tasks that individuals perceive as challenging may be particularly impactful (Bandura, 1997).

In teacher education, opportunities for mastery experiences can be offered through teaching practicums or shorter teaching experiments (Täschner et al., 2024). To ensure positive teaching experiences, especially among pre-service teachers, such opportunities should be sufficiently supported. Notably, in-service teachers may benefit from experiences that are not part of their daily routines (Täschner et al., 2024).

Vicarious experiences, namely learning from observing others' performances or demonstrations, can also inform teachers of their capabilities (Bandura, 1997). In teacher education, vicarious experiences can be offered through modeling, observing peers, or using vignettes (Täschner et al., 2024). One effective way to facilitate vicarious experiences is to model planning or teaching practices, which could be accompanied by reasoning about the pedagogical ideas behind them (Mok et al., 2023). In addition, co-teaching can lead to mutual learning and confidence building (Hawkman et al., 2019). Specifically, offering vicarious experiences has been shown to be an effective means of promoting teacher self-efficacy, which may on some occasions even exceed the usefulness of mastery experiences (Täschner et al., 2024).

Verbal and social persuasion related to a specific activity are also essential sources of self-efficacy, which can be provided in several ways (Bandura, 1997). Teachers can discuss teaching experiences with colleagues and peers, receive feedback from different sources, and provide mutual support during teacher collaboration (Täschner et al., 2024). These interactions may encourage individuals to overcome self-doubt or personal deficiencies (Hawkman et al., 2019), and they can be especially powerful for pre-service teachers who still have little experience in the field (Morris et al., 2017). For instance, receiving feedback on lesson plans has been shown to have a high potential to increase teacher self-efficacy (Mok et al., 2023). However, if teachers receive mostly negative feedback, this may lead to decreased self-efficacy (Tschannen-Moran et al., 1998). Thus, teacher educators should pay attention to how critical feedback is given and ensure that it remains constructive, specific, and delivered in an emphatic manner.

Finally, individuals' *physiological and emotional states* (e.g., anxiety, mood, bodily arousal, and enjoyment) can also serve as sources of self-efficacy (Bandura, 1997). While positive emotions, such as teaching enjoyment, are likely to support instruction, emotional support to reduce the stress related to new experiences is essential, particularly at the beginning of teachers' careers (Hascher & Hagenauer, 2016). When designing professional development for pre- and in-service teachers, physiological and emotional states are seldom addressed compared to other sources of self-efficacy (Täschner et al., 2024).

In addition to the four sources mentioned above, some scholars consider *knowledge* to be an additional source of self-efficacy (see Morris et al., 2017). According to Palmer (2006), experiencing an increase in content knowledge (i.e., knowledge of the taught subject) or subject-specific pedagogical knowledge can also enhance teachers' confidence in teaching. This was confirmed in Palmer's study, in which pre-service teachers were prompted to consider sources of self-efficacy during a science methods course. Palmer called these knowledge-related experiences cognitive content mastery and cognitive pedagogical mastery. In addition, Lauermann and König (2016) found that the more pedagogical knowledge that in-service teachers had, the higher their teacher self-efficacy was.

It should be noted that the sources of self-efficacy do not operate in isolation, but are rather intertwined. Consequently, many interventions targeted at supporting pre-service teachers' self-efficacy combine different sources of self-efficacy (Täschner et al., 2024). Finally, Tschannen-Moran et al. (1998) have highlighted that sources of self-efficacy do not directly affect the evolution of teachers' self-efficacy beliefs. Instead, it is crucial for teachers to interpret the information they are exposed to and their own experiences. Therefore, teachers would benefit from opportunities to *reflect* on their experiences during their professional development (Täschner et al., 2024).

5.6. Design principles to support teachers' self-efficacy in educating critical online readers

Drawing on the literature on self-efficacy, we formulated five intertwined design principles to foster teachers' self-efficacy in educating critical online readers (see Figure 5.1). Teacher educators can employ these design principles in teacher education or professional development courses.

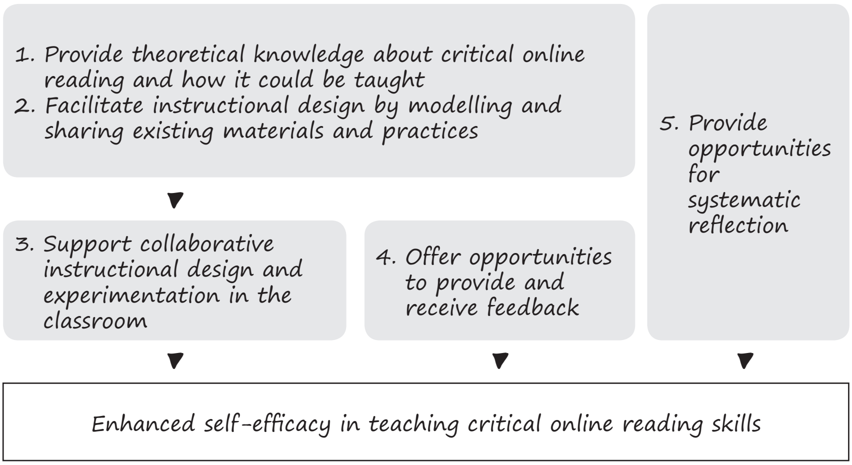


Figure 5.1. Design principles to support teachers' self-efficacy in educating critical online readers

Design Principle 1 encourages teacher educators to assist pre- and in-service teachers in building a solid knowledge base on critical online reading. Providing theoretical knowledge about critical online reading and teaching allows teachers to construct relevant knowledge and to experience cognitive and pedagogical mastery (Palmer, 2006).

Design Principle 2 motivates teacher educators to model and share existing learning materials and practices that teachers can use, apply, or modify when designing their instruction. The models demonstrate how theoretical knowledge of critical online reading can be applied in instructional design. Regarding learning materials, teacher educators can exemplify how theoretical knowledge is used to design materials that specifically support critical online reading skills. This kind of reasoning may provide vicarious experiences that support teacher self-efficacy (Bandura, 1997).

The first two design principles lay the groundwork for *Design Principle 3*, which advises that teacher educators support pre- and in-service teachers' collaborative instructional design and experimentation. When designing and implementing a teaching experiment, teachers can consider and utilize the knowledge, models, and materials shared with them. For example, utilizing materials designed by experts may encourage teachers to design similar tasks and materials for their own subjects or purposes. Alternatively, using existing materials or instructional design ideas allows teachers to focus more on interactions with their students. These opportunities may offer a solid foundation for a successful teaching experiment that can, in turn, support teacher self-efficacy. Finally, collaboration provides opportunities for vicarious experiences through encouragement, feedback, and mutual support.

Design Principle 4 highlights the importance of feedback as a source of self-efficacy. Thus, teacher educators should ensure that teachers have opportunities to provide and receive feedback on their instructional design ideas and on their implementation of teaching experiments.

Finally, *Design Principle 5* encourages teacher educators to provide opportunities for systematic reflection. Systematic reflection allows teachers to process and interpret their experiences, models, and verbal persuasion (e.g., feedback and discussions) so that they have the potential to promote self-efficacy beliefs.

5.7. Implementing design principles and teachers' experiences

We implemented these design principles in two contexts, which consisted of formal teacher education and professional development courses (see Table 5.1). In the teacher education, we designed a course of five ECTS (The European Credit Transfer and Accumulation System) for pre-service teachers who studied at the advanced level of their class-teacher program. The optional course was organized several times at two Finnish universities, and 58 pre-service teachers completed the course. The course included 13 hours of contact teaching, a short teaching experiment at schools, further refinement of the instructional design, and independent work. Both courses focused on online credibility evaluation, a key component of critical online reading.

We utilized the experiences of the pre-service teacher course to design a professional development course for in-service teachers. As in-service teachers' time for professional development is limited, this course was shorter than the one we organized for pre-service teachers, consisting of two four-hour face-to-face sessions. Between the sessions, the in-service teachers implemented a short teaching experiment in their classrooms. Altogether, 13 in-service teachers participated in the course.

We next describe how we implemented the design principles in the courses for the pre-service and in-service teachers. Table 1, at the end of this section, summarizes the implementation of the design principles in these two contexts. We will also share some of the teachers' insights about their experiences with the courses and relate them to the design principles. In this section, we will rely on guided reflections collected during the formal teacher education course and in-service teacher interviews conducted after the professional teacher course.

The pre-service teachers wrote three reflections at critical points in the course: at the beginning, after the teacher experiment, and at the end of the course. The extracts presented are drawn from the final reflections (*N* = 57), in which the pre-service teachers were asked to reflect on their own thoughts and feelings about critical online reading and teaching practices (Kulju & Mäkinen, 2022).

The extracts from the in-service teachers were drawn from semi-structured interviews (*N* = 6), which lasted approximately 25 minutes each. In these interviews, the in-service teachers were asked about which aspects they felt were meaningful in the course. They were also asked to share their thoughts about the different course elements, such as the role of collaboration.

5.7.1. Design principle 1: Provide theoretical knowledge about critical online reading and how it could be taught

Teacher knowledge is considered one of the key elements that guides everyday teaching activities (Shulman, 1987; Allas et al., 2020). Our course design was informed by Shulman's (1987) conceptualization of teacher knowledge. Shulman divides teacher knowledge into research-based content knowledge, pedagogical knowledge, and pedagogical content knowledge.

Content knowledge refers to the subject being taught. In our course designs, content knowledge concerned critical online reading, especially online credibility evaluation. *Pedagogical knowledge* concerns the general classroom management principles that transcend the subject matter (Shulman, 1987). Finally, *pedagogical content knowledge* combines the rich conceptual knowledge of the taught subject with the knowledge of teaching practices that best promote students' learning of the relevant content and skills (see also Loughran et al., 2012).

Pedagogical content knowledge highlights how particular topics are adapted to the diverse interests and abilities of learners and presented for instruction (Shulman, 1987). Similarly, teaching specific skills, such as critical online reading skills, has unique requirements and features that differentiate it from teaching basic reading skills. Knowledge about pedagogical approaches to support critical online reading skills facilitates teachers in developing their teaching practices in a pedagogically sound way.

To support teachers' knowledge of students, we provided empirical evidence of students' online credibility evaluation skills across different grade levels. We consider this important, as it provides an understanding of what students can and cannot do, especially for pre-service teachers. It also illustrates considerable individual differences among students. In addition, having a realistic view of students as critical readers may help teachers calibrate their learning supports to more effectively meet their students' needs.

In the course designed for the pre-service teachers, we used expert videos, readings, and interactive lectures to support their theoretical knowledge about critical online reading. The five educational experts created a total of seven 15-minute-long videos. The first four videos covered a) theoretical knowledge about online credibility evaluation, b) empirical evidence about students' online credibility evaluation skills, and c) pedagogical content knowledge about instructional methods that can support students' online credibility evaluation skills. The last three videos included knowledge about motivating learners, gamified instruction, and teaching critical online reading to diverse learners.

Aside from the expert videos, pedagogical content knowledge was supported by course readings, which included pedagogical conceptualizations about teaching online reading and materials for teaching critical online reading. In addition, interactive lectures outlined the current educational practices of online reading and related challenges.

Pre-service teachers considered the knowledge provided valuable in designing the teaching experiment and beyond. Extract 1 illustrates how the theoretical knowledge helped a pre-service teacher broaden her understanding of critical online reading and apply this knowledge in classrooms.

Extract 1

I particularly needed a theoretical background on the subject. The new knowledge gained during the course has enabled me to think broadly about the different aspects of critical online reading and the application of this theoretical basis in practice.

Pre-service teacher

For the in-service teachers' professional development, we scripted three videos that were professionally produced. The videos were five to twelve minutes long and covered the following topics: What is critical reading? How well can students evaluate the credibility of online texts? How can critical online reading be taught? The videos were watched and discussed in the first of the two sessions. In the discussions, the in-service teachers reflected on their knowledge and experiences of teaching online credibility evaluation in relation to the content of the videos.

Extract 2 illustrates how the pedagogical content knowledge helped a teacher understand how critical online reading instruction could be included as an integral part of yearly teaching, so that students' skills would accumulate during their secondary schooling. This is an important insight, as complex skills, such as critical online reading, require regular attention.

Extract 2

The course clarified what to do with seventh graders, starting from small pieces and gradually increasing the challenge. Somehow, it is now clearer how [teaching critical online reading] can be part of the yearly plan, and how teaching progresses through different grade levels.

In-service teacher

5.7.2. Design principle 2: Facilitate instructional design by modeling and sharing existing materials and practices

Learning through modeling, defined as the purposeful demonstration of the skills needed to perform tasks, is considered a valuable mean of supporting pre-service and in-service teachers' learning about teaching (e.g., Jansen et al., 2023; Lunenberg et al., 2007). However, comparatively few models may be available for teachers, especially in specific areas, such as critical online reading. Therefore, we found it essential to support teachers' pedagogical content knowledge through modeling.

There are various ways to use modeling in teacher education. For example, Montenegro (2020) has identified that teacher educators think of modeling as a means of 1) teaching pedagogical strategies, 2) recreating teacher-student relationships, 3) enacting a congruent teaching approach, and 4) developing teaching linked to the school classroom. Our design utilized the first and fourth of these means.

In our courses, we *modeled pedagogical strategies* to demonstrate specific instructional practices for teaching critical online reading skills. In the pre-service teachers' course, the teacher educator modeled, for example, how evaluation practices could occur during online reading. For in-service teachers, we demonstrated how they could model effective critical online reading practices by thinking aloud.

We also demonstrated how research-based learning materials could be used to teach online credibility evaluation strategies. We unpacked how theoretical knowledge has been utilized in designing learning materials to encourage teachers to adopt or develop theory-informed learning materials and tasks to serve their subjects. As shown in Extract 3, one pre-service teacher experienced that demonstrations gave her new insights into how teach critical online reading skills.

Extract 3

The lectures and learning materials have given me various aha experiences: I can actually teach this way, too.

Pre-service teacher

With the in-service teachers, we had less time for instructional design during the course. Thus, we presented a package of research-based materials to inspire their design. We also modeled task types for teaching credibility evaluation (see Table 1). In-service teachers used the materials as such or applied the task types in their own teaching experiments. One of the in-service teachers described how she gained the confidence to create materials by herself.

Extract 4

You [teacher educators] have designed texts for the assignments yourself. I haven't done that myself because I thought the texts should be authentic. It was a relief to find that I could create texts myself to teach critical reading in my subject.

In-service teacher

Modeling can also be seen as a means of *connecting teaching to the complexities of school classroom*s (Montenegro, 2020). Making these complexities explicit facilitates pre-service teachers' understanding of the challenges of teaching critical online reading skills. In our design, we discussed the potential challenges that might have been encountered before the teaching experiments. Sometimes, pre-service teachers verified facing these complexities in their own teaching experiments. For instance, they noticed that it would be wise to teach only one aspect of credibility at a time (Kulju & Mäkinen, 2020).

As professionals, the in-service teachers had a strong level of understanding of the classroom reality. However, they still shared their own experiences of the possible challenges or successes they encountered in applying the learning materials in their classrooms (e.g., the difficulty level of the teaching materials).

5.7.3. Design principle 3: Support collaborative instructional design and experimentation in the classroom

To provide authentic experiences for teaching critical online reading skills, the teachers designed a short teaching experiment. As sharing ideas, materials, and experiences may help teachers become aware of best practices in teaching challenging topics, we preferred collaboration in designing and implementing the experiment. Collaborative activities can range from teachers' spontaneous conversations about challenges in teaching to structured co-learning opportunities in formal teacher education (Avalos, 2011; Isac, 2022).

The pre-service teachers designed and implemented a 90-minute teaching experiment in pairs. Designing the teaching experiment proceeded in several phases. In the first phase, the pre-service teacher pairs wrote a concept paper that included initial design ideas for the teaching experiment. The creation of the concept paper was facilitated by expert videos and learning materials that the pre-service teachers could use or modify as they wished. The lesson plan template of the teacher training school served as a concrete tool for the concept paper. It included learning objectives, assessment practices, key concepts, facilities and materials, and a progress plan. In the second phase, the pairs presented their concepts to others in the class, and ideas were discussed by the peers and the teacher educator. In the third phase, the pairs submitted their completed teaching plans before implementing their experiments.

The pre-service teachers implemented their teaching experiments in the teacher training school. The advantage of teacher training schools lies in the experienced class teachers, who guide the pre-service teachers' teaching practices. In our case, however, the pre-service teachers co-taught the planned lessons independently, even though both the class teacher and the teacher educator were present. They supported the pairs only sporadically, if needed.

The co-design process continued as the pre-service teachers planned an improved and refined version of their instructional design. These improved versions were presented to others. Again, the designs were discussed. Extract 5 illustrates the benefits of sharing instructional designs and teaching experiences with others.

> **Extract 5**
> I found the presentations by other groups particularly useful. They have also given me further ideas that I am sure I will be able to use in the future.
>
> *Pre-service teacher*

The in-service teachers also designed and implemented short teaching experiments in their classrooms. They were encouraged to co-design the instruction with a colleague. The instructional design was supported by expert videos, related discussions, and existing learning materials. There was also an opportunity for joint brainstorming and planning at the first meeting.

After implementing the teaching experiment, the in-service teachers shared their experiences. These discussions served as a means of sharing good practices and providing feedback to colleagues. The teachers seemed to value these joint discussions, as illustrated in Extract 6.

Extract 6

It was particularly interesting to hear how the students responded to the given tasks in practice, what kinds of outputs they produced, and what kinds of challenges came up. I found it the most rewarding.

In-service teacher

5.7.4. Design principle 4: Offer opportunities to provide and receive feedback

In our design, we considered that feedback sessions could include both instructional and emotional support (Mok et al., 2023; Ellis et al., 2020). As feedback, especially on lesson plans, has been shown to be beneficial for pre-service teachers (Mok et al., 2023), we emphasized opportunities to provide and receive feedback during the instructional design process. Consequently, the pre-service teachers received oral feedback from their peers and the teacher educator at several key points. These opportunities were not explicitly framed as feedback, but rather as shared discussions.

First, feedback was provided on the concept papers for the teaching experiments. The pre-service teachers presented their concepts in class, where they were thoroughly discussed. As expert feedback may be more specific than that of pre-service teachers (Prilop et al., 2021), we also found it important for the teacher educator to offer personal guidance and feedback to pairs. In these discussions, the teacher educator's role as a pedagogical co-designer (cf. Bovill et al., 2015) was to pay attention to specific instructional aspects, such as the key idea of the instructional design, the suggested difficulty level of the text materials, and the use of classroom time. The purpose was to give room for pre-service teachers' ideas and gently guide them to identify potential challenges in applying the designed tasks and materials.

Second, the pre-service teachers received feedback when they presented their teaching experiences to others in the class. Both their peers and the teacher educator commented on the shared experiences and provided feedback. Third, feedback was provided in the final meeting, when pre-service teachers presented their ideas for further refinements of their instructional designs in the class.

Overall, the emphasis was on positive feedback, which has been recommended to assure teachers about their abilities, thereby resulting in higher goals and commitment (e.g., Prilop et al., 2021). Even though the teacher educator made suggestions on how to improve and develop the designed tasks and materials, an underlying aim was to encourage the pre-service teachers to teach critical online reading. In general, encouragement and emotional support are needed, especially after actual teaching experiments at school, as they can be rather revealing, for instance, in terms of task difficulty or task management.

Based on the teacher educators' experiences, most of the feedback pre-service teachers gave to each other was positive and encouraging. The pre-service teachers also found the peer feedback meaningful, as the following extract illustrates.

Extract 7

I think it was good that the lessons were discussed together afterwards so that everyone was able to share their experiences and get suggestions for improvement and positive comments from others.

Pre-service teacher

Since the pre-service teachers were at an advanced level of their teacher education, they had experience in providing and receiving feedback. That being said, it is important to provide opportunities to practice providing and receiving feedback during teacher education (Prilop et al., 2021).

For the in-service teachers in the professional context, we emphasized collegial feedback sessions, which have been shown to be fruitful at later stages of one's career (Täschner et al., 2024; von Suchodoletz et al., 2018). The in-service teachers shared their teaching experiences with others, including rich commentaries and feedback. The teacher educator's role was to facilitate the discussions, and again, substantial effort was put into providing positive feedback. It seems that the in-service teachers especially valued the collegial support and encouragement they received through this process (see Extract 8).

Extract 8

Having done different things, it is interesting to hear how they went for others. When you have colleagues working on the same topic, collegial communication is very important. I think it's important to be able to talk to people in the same field.

In-service teacher

5.7.5. Design Principle 5: Provide opportunities for systematic reflection

For teachers, reflection is pivotal in identifying, analyzing, and solving the complex problems that characterize their classroom work (Toom et al., 2015). However, as teaching is a multi-layered process, identifying underlying beliefs and knowledge may be challenging (Allas et al., 2020). Thus, our design was informed by two critical practices that support teachers' reflection. First, the reflection process was systematic and guided. We used specific prompts and questions to guide the reflections, as novice teachers in particular may need extra support to direct their attention to meaningful aspects, such as student learning (Husu et al., 2008; Allas et al., 2020). Second, we considered that reflection could be conducted individually and interactively with others. We believed that both the pre- and in-service teachers would benefit from reflective discussions that enabled them to share their experiences and learn from others (see Allas et al., 2020).

The pre-service teachers wrote individual reflections at three time points: at the beginning of the course, in the middle after the teaching experiment, and at the end of the course. The three reflections were guided in slightly different ways, but each time, the pre-service teachers were asked to reflect on their thoughts and feelings about critical online reading and how it could be taught (Kulju & Mäkinen, 2022).

The first reflection was supported by a short self-efficacy questionnaire, including questions related to the credibility evaluation of online texts and teaching this skill in classrooms. The first reflection was prompted by the initial discussion on teaching critical online reading skills.

The key input of the second reflection was the teaching experiment and the subsequent shared discussions and feedback on this phase. An example of a guided question was, "What did you learn about teaching critical online reading?"

The third reflection was prompted by a short self-efficacy questionnaire, like the first, which was filled out for the second time at the end of the course. In addition, the pre-service teachers were encouraged to consider the whole course and shared discussions in their reflections. In Extract 9, one of the pre-service teachers described the benefits of such reflection.

Extract 9

When reflecting on my own teaching, I became more aware of my areas for development, which I should consider when planning and delivering my next lessons on online reading.

Pre-service teacher

For the in-service teachers, the reflection process was not as systematic. However, a short self-efficacy questionnaire (the same as the pre-service teachers' questionnaire) was assigned at the beginning of the course to trigger the reflection process. The teacher educator collected the questionnaires and returned them at the end of the course. The teachers were encouraged to reflect on their answers and compare them with their current thoughts. Extract 10 illustrates how the short questionnaire supported reflection in this regard.

Extract 10

The self-efficacy questionnaire helped me reflect on what has changed. I gained the confidence to teach the subject [critical online reading].

In-service teacher

The main activity supporting the in-service teachers' reflections was the shared reflective discussions. In the first meeting, experiences of teaching critical online reading were shared. The most important shared discussion took place in the second meeting when the teachers shared their experiences of their teaching experiments. In Extract 11, one of the teachers describes the perceived benefits of reflective discussion with colleagues.

Extract 11

It is good to hear different kinds of experiences. They may confirm which parts work out and which may not, and how you could further develop. It is easier when you have another colleague with whom to engage in a dialogue.

In-service teacher

Table 5.1. Implementation of design principles for supporting teachers' self-efficacy in teaching critical online reading in teacher education and teacher professional development courses

Design principle	Teacher education (pre-service teachers)	Teacher professional development (in-service teachers)
1. Provide theoretical knowledge about critical online reading and how it could be taught	Building a theoretical foundation through expert videos, readings, and interactive lectures	Deepening theoretical foundation through watching expert videos and discussing them
2. Facilitate instructional design by modeling existing materials and practices	Modeling pedagogical strategies Sharing learning materials	Modeling pedagogical strategies Modeling task types Sharing learning materials
3. Support collaborative instructional design and experimentation in the classroom	Designing and implementing a short teaching experiment in pairs in a teacher training school's classroom Sharing the experiences of the teaching experiment with other pre-service teachers Planning a further version of a teaching experiment and sharing the ideas with others	Designing and implementing a short teaching experiment in the teachers' own class (in collaboration, if possible) Sharing the experiences of the teaching experiment with other in-service teachers
4. Offer opportunities to provide and receive feedback	Teacher educator's encouragement and feedback on instructional design, lessons taught, and further refinement of the instructional design Peer feedback on instructional design, lessons taught, and further refinement of the instructional design	Sharing and discussing experiences of the teaching experiment
5. Provide opportunities for systematic reflection	Guided, systematic written reflections at three key junctures of the course Shared discussions	Shared collegial discussions

5.8. Concluding remarks and future directions

Critical online reading skills are pivotal to survival in a society in which a substantial amount of information is communicated in digital spaces. Throughout their professional lives, teachers need to feel confident in their teaching practices and willing to develop new skills to support their students in becoming critical online readers in rapidly changing digital reading environments.

In this chapter, we proposed five design principles to support teachers' self-efficacy in teaching critical online reading. We also demonstrated how we applied these principles in two teacher education contexts. The pre-service teachers' written reflections and in-service teachers' interviews suggest that applying these design principles in a coordinated way is a promising practice to support teachers' self-efficacy.

Even short teaching experiments explicitly focusing on critical online reading may provide mastery experiences for teachers and nurture new pedagogical ideas. In this regard, the in-service teachers found learning materials designed for teaching critical online reading and collegial support especially meaningful. As these were initial observations, further systematic research is needed to determine the broader utility of the design principles.

Supporting teachers' self-efficacy should not be reliant solely on individual courses. Educational and school policies should encourage teachers to co-design meaningful learning experiences for their students, co-create new pedagogical knowledge, and co-teach to meet students' diverse needs (cf. Ellis et al., 2020). Furthermore, practices that enable collaboration between novice and experienced teachers would also provide an opportunity to enhance teacher's self-efficacy, especially at the beginning of their careers.

Summary

Educating critical online readers who can navigate purposefully, critically, and responsibly in online spaces is a fundamental goal of education. However, constantly changing online environments, evolving digital reading practices, and widespread misinformation pose significant challenges to achieving this goal. Therefore, teacher education should support teachers in this endeavor. This chapter presents five design principles to support teachers' confidence in promoting students' engagement in and learning of critical online reading. The principles include 1) providing theoretical knowledge about critical online reading and how it could be taught, 2) facilitating instructional design by modeling and sharing existing materials and practices, 3) supporting collaborative instructional design and experimentation in the classroom, 4) offering opportunities to provide and receive feedback, and 5) providing opportunities for systematic reflection. In addition, we illustrate how the design principles were implemented in formal teacher education and teacher professional development courses. The pre- and in-service teachers' experiences of the courses suggest that applying the design principles in coordinated way is a promising practice to support teachers' self-efficacy.

Glossary

Critical online reading. Evaluating credibility and relevance of information when searching for, processing, and synthesizing online information.

Mastery experience. Previous successful experiences that indicate one's capability to accomplish a specific task.

Online credibility evaluation. Evaluating the quality of online information by considering the accuracy of content and the trustworthiness of the source.

Pedagogical content knowledge. Teacher's knowledge of teaching specific content.

Reflection. Processing and interpreting experiences, beliefs, and emotions.

Self-efficacy. An individual's confidence in accomplishing a specific task or goal.

Sourcing. Attending, evaluating, and using information about individuals and organizations that have written or published online text.

Teacher self-efficacy. Teachers' confidence in supporting their students' engagement and learning.

Verbal and social persuasion. Comments, feedback, and encouragement that individuals receive on their performance.

Vicarious experience. Learning through observing others successfully perform a specific task.

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Conclusions

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This book has provided an innovative and evidence-based response to the question of how we can empower schools to promote the self-regulation of critical online reading processes while also leading us towards new research horizons in the field of education and learning psychology.

The EMILE model

Based on what has been presented throughout the volume, it is possible to outline some strengths and basic principles that characterize the EMILE project and which, overall, constitute a model for promoting media literacy processes.

Multi-level approach. In accordance with interactionist models of learning (Kaasila & Lauriala, 2010), media literacy requires the consideration, at once, of both the individual's characteristics and the environment to which they are exposed. EMILE fully adopts this view through direct actions at both the student and school levels. While traditional paper-based reading puts the individual directly in relation with a specific source of information, besides introducing a greater cognitive complexity, as emphasized in the book, the flashiness of the various pieces of information simultaneously available online risks drawing readers' attention to external information. Consequently, they lose sight of their own relevant perspectives, knowledge, and cognitive and emotional-motivational processes. In EMILE, students are asked to take on an active role; it provides them with greater awareness and strengthens the processes involved in media literacy tasks. At the same time, the project addresses the school institution, represented by teachers, with both informational actions, such as educational briefs through the dissemination campaign, and concrete development, such as the teacher professional development program, based on interactive experiences.

Early intervention. Generally, adults or young adults are the populations who are heavily involved in media literacy activities. This also happens because, as stated in the introduction to the book, digital learning systems are still not yet well integrated into the school system. However, from an evolutionary and neuroscientific perspective (Thelen & Smith, 1994), it is necessary to act preventively on cognitive processes, and consequently on the underlying brain circuits which will need to be used in later stages of development. In line with this perspective, EMILE targets the population from upper elementary school to lower secondary school, while aiming to strengthen strategies and germane cognitive processes from the early stages of media literacy.

Awareness and experience. In accordance with a view of learning as an active process based on the individual's action (Shapiro, 2019), through gamification EMILE fosters students' direct comprehension of their own cognitive processes and media literacy. In particular, in the "World of Elli" students become more aware of the cognitive processes necessary in complex tasks, such as the ones requiring media literacy, and are provided with training on this. Like any learning experience, enjoyment in performing the activity plays an essential role. In EMILE, this is targeted through a gamified approach and monitored with specific tools.
EMILE enables teachers to experience the different educational strategies that must be implemented to promote students' media literacy. In addition, it makes them aware of the role played by the confidence that they have in their own skills and knowledge when facing new educational challenges such as media literacy.

Structured activities. Media literacy is undoubtedly a very recent human function. Therefore, it is more than plausible that humans are not predisposed to it and that the human brain must make an effort to create new circuits and processes suitable for the characteristics that digital readings may have. Like any new function for which we are not predisposed (Dehaene, 2009), mere exposure to the environment (in this case the digital platforms on which reading takes place) is not a guarantee of learning. We need to provide systematic, explicit exposure to digital reading, including structured exercises. EMILE is a highly structured model with activities that are hierarchically organized in terms of difficulty, selection of information, populations involved, and completion times. This high level of structuring is necessary for all of the aforementioned reasons. At the same time, we must recognize that it is not sufficient to provide structured activities, and that they do not address all of the different media literacy experiences that individuals may have. EMILE can therefore be a model for a first step towards media literacy that must then be integrated and followed by opportunities for continuous learning and generalization through diverse and repeated experiences.

International scope. Compared to learning on paper with traditional methodologies, media literacy also transcends spatial boundaries and interlinguistic and cultural differences in learning, making it possible to select information from cultures and languages different from one's own even before materials are translated, revised, and adapted. Furthermore, it is evident that the spread of media literacy involves all populations, regardless of the level of literacy or educational system. These characteristics make media literacy a universal issue that must rely on shared approaches at the international level. EMILE integrates the methodologies and expertise of three European countries in terms of educational systems, languages, and needs to propose a shared model that can be transferred to different countries.

Personalization of learning. Teachers have been asked to implement personalized education for decades, but their response often highlights how difficult it is for an individual (the teacher) to apply appropriate adaptations to 20 or 25 different individuals (the students) at the same time. This response realistically reflects how our brain functions: it has specific limits as to the quantity and speed of information it can process. To overcome this difficulty, it is increasingly important to assign data processing to machine learning systems, which instead work best when elaborating large datasets, based on which they can model different patterns of responses. These must then be interpreted by the human brain through generative processes that machines fortunately cannot perform. This new alliance between humans, teachers, technology, and digitized data, as formed in the EMILE project, opens new frontiers in the personalization of media literacy learning for student responses (Hart, 2016).

Future perspectives

Looking towards new frontiers, two main questions will need to be addressed in the near future: Should we adopt a biliterate approach to reading? How will artificial intelligence influence the way we read?

A biliterate approach to reading. The diversity of paper-based and digital environments seems to suggest a "biliterate" approach to the reading brain (Wolf, 2019). Like bilingual children who need to go back and forth between languages and writing systems, contemporary developing readers should become expert code-switchers and go back and forth between the print and digital mediums. Learning to read should be initially separate for distinct domains, until each process (paper-based processing and digital processing of texts) can be intertwined. Importantly, paper-based reading has the potential to teach how to self-regulate processing and tolerate cognitive fatigue when elaborating complex written material. These characteristics can become fundamental aspects to transfer to digital reading.

Evidence from paper-vs.-digital comparative studies, synthesized by literature reviews and meta-analysis (e.g., Singer & Alexander, 2017; Delgado et al., 2018), suggest an advantage of paper over digital devices, especially in expository texts and under time pressure. It seems, overall, that digital devices create a higher (extraneous) cognitive load than paper does, which sometimes can be compensated by readers with a more strategic approach. However, as the task becomes more complex (increase in intrinsic cognitive load), readers may struggle more to self-regulate their reading processes.

The main problem is that our evidence is still based on reading brains that have mostly learned to read on paper and only started reading on digital devices later in their development. Todays' teenagers have certainly interacted with digital devices since early on in their lives but learned to read on paper in elementary school and, in all likelihood, have read paper books more often than e-books. Once in secondary school, they may have started to use digital devices to read for school projects, as well as for their own personal reasons and purposes. This balance may change in the future, and we may have a growing number of students who practiced reading on digital devices early in their development. We are still unaware of the consequences of this shift in reading routines. For instance, digital environments are connotated by a sense of immediacy and easiness: when navigating online we feel we have the answers to all possible questions at our fingertips. Every piece of knowledge we may need is just one click away. This may influence readers to favor standards of access over standards of accuracy: a text is more relevant the easier it is to retrieve, rather than the more accurate it is. If so, choosing the right keywords when navigating on search engines becomes crucial and a skill to support in learning environments. Moreover, digital natives are more used to shorter texts, such as those typically found on the web, thus they should be supported in self-regulating cognitive fatigue when engaged in long and complex texts.

What would the implications be for schools? Teachers may address reading instruction by explicitly scaffolding strategies for reading on paper separately from strategies for reading on digital devices. By adopting a goal-oriented reading framework, readers should be able to choose when it is appropriate to read on digital devices and when, conversely, it would be better to read on paper. This decision may depend on how long and complex the text is, or what kind of actions we want to do with the text. For example, if students need to makes note on a text, paper is ideal, but for a social approach to reading, digital texts may be a better solution.

Artificial intelligence and reading. The release of ChatGPT to the general public in 2022 raised attention to the role of AI in education, as a likely next-up revolution. According to Baker and Smith (2019), "Artificial Intelligence (AI) comprises computers that execute cognitive functions typically associated with human minds, particularly those involving learning and problem solving" (p. 10). These authors assert that AI does not represent a single technology but serves as an umbrella term that encompasses a variety of technologies and methodologies, including machine learning, natural language processing, data mining, neural networks, and algorithms.

The main problem with AI-produced information is that it is difficult to detect its origin. Unfortunately, the potential contribution of AI as an ally in the fight against disinformation is understudied. Efforts are mainly going in the direction of regulating the use of AI (European Parliament et al., 2019) and making users aware of AI-fabricated news (Jakkola, 2023). Concerns regarding the regulation of AI within the EU space are expressed by the same citizens who stated, in 51% of cases, the need for public policy intervention to ensure the ethical development of AI and, in 80% of cases, the importance of being informed when a digital service or mobile application is using this tool (Evas, 2020).

However, AI can also be an ally of educational practitioners. Some AI tools have long been implemented in educational systems, mainly in one of these three categories: personal tutors, intelligent support for collaborative learning, and intelligent virtual reality. AI can be used to adapt instruction to the needs of different types of learners (Verdú et al., 2017), to provide customized prompt feedback (Dever et al., 2020), and to develop assessment strategies (Baykasoğlu et al., 2018). In this scenario, critical reading becomes more … "critical". Readers may use AI tools when they struggle to comprehend texts, to translate them into their L1, or make them easier to read (e.g., by prompting a generative AI such as ChatGPT to "make the following text easier to read" or "sum up the main points of the following text"). Readers need to be aware that such tools are not necessarily reliable or accurate, thus they need to be provided with validation strategies to ensure that the assigned task has been successfully completed. Allen and Kendeou (2024) proposed ED-AI Lit, An interdisciplinary framework for AI literacy in education. ED-AI Lit includes six components (Knowledge, Evaluation, Collaboration, Contextualization, Autonomy, and Ethics) and is based on a perspective of human-AI collaboration. AI literacy should be promoted in students so that they can rely on AI tools in an effective way. Similarly, AI literacy should be promoted in pre-service and in-service teachers too, to foster a more evidence-based use of AI tools in teaching and learning practices.

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